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## System and Method for Frequency Up-Conversion

### *Background of the Invention*

#### *Field of the Invention*

5 The present invention is generally directed to frequency up-conversion of electromagnetic (EM) signals.

#### *Related Art*

10 Modern day communication systems employ components such as transmitters and receivers to transmit information from a source to a destination. To accomplish this transmission, information is imparted on a carrier signal and the carrier signal is then transmitted. Typically, the carrier signal is at a frequency higher than the baseband frequency of the information signal. Typical ways that the information is imparted on the carrier signal are called modulation.

15 Three widely used modulation schemes include: frequency modulation (FM), where the frequency of the carrier wave changes to reflect the information that has been modulated on the signal; phase modulation (PM), where the phase of the carrier signal changes to reflect the information imparted on it; and amplitude modulation (AM), where the amplitude of the carrier signal changes to reflect the information. Also, these modulation schemes are used in combination with each other (e.g., AM combined with FM and AM combined with PM).

#### *Summary of the Invention*

20 The present invention is directed to methods and systems to up-convert a signal from a lower frequency to a higher frequency, and applications thereof.

25 In one embodiment, the invention uses a stable, low frequency signal to generate a higher frequency signal with a frequency and phase that can be used as stable references.



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In another embodiment, the present invention is used as a transmitter. In this embodiment, the invention accepts an information signal at a baseband frequency and transmits a modulated signal at a frequency higher than the baseband frequency.

The methods and systems of transmitting vary slightly depending on the modulation scheme being used. For some embodiments using frequency modulation (FM) or phase modulation (PM), the information signal is used to modulate an oscillating signal to create a modulated intermediate signal. If needed, this modulated intermediate signal is "shaped" to provide a substantially optimum pulse-width-to-period ratio. This shaped signal is then used to control a switch which opens and closes as a function of the frequency and pulse width of the shaped signal. As a result of this opening and closing, a signal that is harmonically rich is produced with each harmonic of the harmonically rich signal being modulated substantially the same as the modulated intermediate signal. Through proper filtering, the desired harmonic (or harmonics) is selected and transmitted.

For some embodiments using amplitude modulation (AM), the switch is controlled by an unmodulated oscillating signal (which may, if needed, be shaped). As the switch opens and closes, it gates a reference signal which is the information signal. In an alternate implementation, the information signal is combined with a bias signal to create the reference signal, which is then gated. The result of the gating is a harmonically rich signal having a fundamental frequency substantially proportional to the oscillating signal and an amplitude substantially proportional to the amplitude of the reference signal. Each of the harmonics of the harmonically rich signal also have amplitudes proportional to the reference signal, and are thus considered to be amplitude modulated. Just as with the FM/PM embodiments described above, through proper filtering, the desired harmonic (or harmonics) is selected and transmitted.

Further features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying figures. The left-most digit(s) of a reference number typically identifies the figure in which the reference number first appears.

### *Brief Description of the Figures*

FIG. 1 illustrates a circuit for a frequency modulation (FM) transmitter;

FIGs. 2A, 2B, and 2C illustrate typical waveforms associated with the FIG. 1 FM circuit for a digital information signal;

FIG. 3 illustrates a circuit for a phase modulation (PM) transmitter;

FIGs. 4A, 4B, and 4C illustrate typical waveforms associated with the FIG. 3 PM circuit for a digital information signal;

FIG. 5 illustrates a circuit for an amplitude modulation (AM) transmitter;

FIGs. 6A, 6B, and 6C illustrate typical waveforms associated with the FIG. 5 AM circuit for a digital information signal;

FIG. 7 illustrates a circuit for an in-phase/quadrature-phase modulation ("I/Q") transmitter;

FIGs. 8A, 8B, 8C, 8D, and 8E illustrate typical waveforms associated with the FIG. 7 "I/Q" circuit for digital information signal;

FIG. 9 illustrates the high level operational flowchart of a transmitter according to an embodiment of the present invention;

FIG. 10 illustrates the high level structural block diagram of the transmitter of an embodiment of the present invention;

FIG. 11 illustrates the operational flowchart of a first embodiment (i.e., FM mode) of the present invention;

FIG. 12 illustrates an exemplary structural block diagram of the first embodiment (i.e., FM mode) of the present invention;

FIG. 13 illustrates the operational flowchart of a second embodiment (i.e., PM mode) of the present invention;

FIG. 14 illustrates an exemplary structural block diagram of the second embodiment (i.e., PM mode) of the present invention;

FIG. 15 illustrates the operational flowchart of a third embodiment (i.e., AM mode) of the present invention;

FIG. 16 illustrates an exemplary structural block diagram of the third embodiment (i.e., AM mode) of the present invention;

FIG. 17 illustrates the operational flowchart of a fourth embodiment (i.e., "I/Q" mode) of the present invention;

FIG. 18 illustrates an exemplary structural block diagram of the fourth embodiment (i.e., "I/Q" mode) of the present invention;

FIGs. 19A-19I illustrate exemplary waveforms (for a frequency modulation mode operating in a frequency shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram;

FIGs. 20A, 20B, 20C illustrate typical waveforms associated with the FIG. 1 FM circuit for an analog information signal;

FIGs. 21A, 21B, 21C illustrate typical waveforms associated with the FIG. 3 PM circuit for an analog information signal;

FIGs. 22A, 22B, 22C illustrate typical waveforms associated with the FIG. 5 AM circuit for an analog information signal;

FIG. 23 illustrates an implementation example of a voltage controlled oscillator (VCO);

FIG. 24 illustrates an implementation example of a local oscillator (LO);

FIG. 25 illustrates an implementation example of a phase shifter;

FIG. 26 illustrates an implementation example of a phase modulator;

FIG. 27 illustrates an implementation example of a summing amplifier;

FIGs. 28A-28C illustrate an implementation example of a switch module for the FM and PM modes;

FIG. 29A-29C illustrate an example of the switch module of FIGs. 28A-28C wherein the switch is a GaAs FET;

FIGs. 30A-30C illustrate an example of a design to ensure symmetry for a GaAs FET implementation in the FM and PM modes;

FIGs. 31A-31C illustrate an implementation example of a switch module for the AM mode;

FIGs. 32A-32C illustrate the switch module of FIGs. 31A-31C wherein the switch is a GaAs FET;

FIGs. 33A-33C illustrates an example of a design to ensure symmetry for a GaAs FET implementation in the AM mode;

FIG. 34 illustrates an implementation example of a summer;

FIG. 35 illustrates an implementation example of a filter;

FIG. 36 is a representative spectrum demonstrating the calculation of "Q;"

FIGs. 37A and 37B are representative examples of filter circuits;

FIG. 38 illustrates an implementation example of a transmission module;

FIG. 39A shows a first exemplary pulse shaping circuit using digital logic devices for a squarewave input from an oscillator;

FIGs. 39B, 39C, and 39D illustrate waveforms associated with the FIG. 39A circuit;

FIG. 40A shows a second exemplary pulse shaping circuit using digital logic devices for a squarewave input from an oscillator;

5 FIGs. 40B, 40C, and 40D illustrate waveforms associated with the FIG. 40A circuit;

FIG. 41 shows a third exemplary pulse shaping circuit for any input from an oscillator;

10 FIGs. 42A, 42B, 42C, 42D, and 42E illustrate representative waveforms associated with the FIG. 41 circuit;

FIG. 43 shows the internal circuitry for elements of FIG. 41 according to an embodiment of the invention;

15 FIGs. 44A-44G illustrate exemplary waveforms (for a pulse modulation mode operating in a pulse shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram, highlighting the characteristics of the first three harmonics;

FIGs. 45A-45F illustrate exemplary waveforms (for an amplitude modulation mode operating in an amplitude shift keying embodiment) at a plurality of points in an exemplary high level circuit diagram, highlighting the characteristics of the first three harmonics;

20 FIG. 46 illustrates an implementation example of a harmonic enhancement module;

FIG. 47 illustrates an implementation example of an amplifier module;

FIGs. 48A and 48B illustrate exemplary circuits for a linear amplifier;

FIG. 49 illustrates a typical superheterodyne receiver;

25 FIG. 50 illustrates a transmitter according to an embodiment of the present invention in a transceiver circuit with a typical superheterodyne receiver in a full-duplex mode;

30 FIGs. 51A, 51B, 51C, and 51D illustrate a transmitter according to an embodiment of the present invention in a transceiver circuit using a common oscillator with a typical superheterodyne receiver in a half-duplex mode;

FIG. 52 illustrates an exemplary receiver using universal frequency down conversion techniques according to an embodiment;

FIG. 53 illustrates an exemplary transmitter of the present invention;

FIGs. 54A, 54B, and 54C illustrate an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a half-duplex mode for the FM and PM modulation embodiment;

FIG. 55 illustrates an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a half-duplex mode for the AM modulation embodiment;

FIG. 56 illustrates an exemplary transmitter of the present invention in a transceiver circuit with a universal frequency down conversion receiver operating in a full-duplex mode;

FIGs. 57A-57C illustrate an exemplary transmitter of the present invention being used in frequency modulation, phase modulation, and amplitude modulation embodiments, including a pulse shaping circuit and an amplifier module;

FIG. 58 illustrates harmonic amplitudes for a pulse-width-to-period ratio of .01;

FIG. 59 illustrates harmonic amplitudes for a pulse-width-to-period ratio of .0556;

FIG. 60 is a table that illustrates the relative amplitudes of the first 50 harmonics for six exemplary pulse-width-to-period ratios;

FIG. 61 is a table that illustrates the relative amplitudes of the first 25 harmonics for six pulse-width-to-period ratios optimized for the 1<sup>st</sup> through 10<sup>th</sup> subharmonics;

FIG. 62 illustrates an exemplary structural block diagram for an alternative embodiment of the present invention (i.e., a mode wherein AM is combined with PM);

FIG. 63 illustrates an exemplary waveform for an information signal "A" for the embodiment of FIG. 62;

FIG. 64 illustrates an exemplary waveform for an oscillating signal for the embodiment of FIG. 62;

FIG. 65 illustrates an exemplary waveform for a phase modulated signal for the embodiment of FIG. 62;

FIG. 66 illustrates an exemplary waveform for a pulse-shaped PM signal for the embodiment of FIG. 62;

FIG. 67 illustrates an exemplary waveform for a reference signal for the embodiment of FIG. 62;

FIG. 68 illustrates an exemplary waveform for a harmonically rich signal for the embodiment of FIG. 62;

FIG. 69 illustrates an exemplary waveform for the fundamental harmonic of the signal of FIG. 68 for the embodiment of FIG. 62;

FIG. 70 illustrates an exemplary waveform for the second harmonic of the signal of FIG. 68 for the embodiment of FIG. 62;

5        FIGs. 71A and 71B illustrate exemplary implementations of aliasing modules;

FIGs. 71C-71G illustrate exemplary waveforms at a plurality of points in the FIGs. 71A and 71B circuits;

FIG. 72A is a block diagram of a splitter according to an embodiment of the invention;

10        FIG. 72B is a more detailed diagram of a splitter according to an embodiment of the invention;

FIGS. 72C and 72D are example waveforms related to the splitter of FIGS. 72A and 72B;

15        FIG. 72E is a block diagram of an I/Q circuit with a splitter according to an embodiment of the invention;

FIGS. 72F-72J are example waveforms related to the diagram of FIG. 72A;

FIG. 73 is a block diagram of a switch module according to an embodiment of the invention;

FIG. 74A is an implementation example of the block diagram of FIG. 73;

20        FIGS. 74B-74Q are example waveforms related to FIG. 74A;

FIG. 75A is another implementation example of the block diagram of FIG. 73;

FIGS. 75B-75Q are example waveforms related to FIG. 75A;

FIG. 76A is an example MOSFET embodiment of the invention;

FIG. 76B is an example MOSFET embodiment of the invention;

25        FIG. 76C is an example MOSFET embodiment of the invention;

FIG. 77A is another implementation example of the block diagram of FIG. 73;

FIGS. 77B-77Q are example waveforms related to FIG. 75A;

FIG. 78 illustrates an implementation of the present invention wherein multiple apertures are generated for each cycle of an oscillating signal;

30        FIG. 79 illustrates the multiple aperture generation module;

FIG. 80 illustrates exemplary waveforms for strings of pulses containing from one pulse through five pulses per cycle;

FIG. 81 illustrates the output spectra for one pulse per cycle;

FIG. 82 illustrates the output spectra for two pulses per cycle;

FIG. 83 illustrates the output spectra for three pulses per cycle;

FIG. 84 illustrates the output spectra for four pulses per cycle;

FIG. 85 illustrates the output spectra for five pulses per cycle;

FIG. 86 compares the amplitudes of the output spectra at the desired output  
5 frequency;

FIG. 87 illustrates a circuit diagram for the bi-polar pulses;

FIG. 88 illustrates the spectra resulting from the use of bi-polar pulses;

FIG. 89 illustrates the bi-polar pulse stream;

FIG. 90 illustrates the original pulse stream used to generate the bi-polar pulse  
10 stream;

FIGs. 91A-D illustrate exemplary implementations of a switch module  
according to embodiments of the invention;

FIGs. 92A-D illustrate exemplary aperture generators;

FIG. 92E illustrates an oscillator according to an embodiment of the present  
15 invention;

FIG. 93 illustrates an energy transfer system with an optional energy transfer  
signal module according to an embodiment of the invention;

FIG. 94 illustrates an aliasing module with input and output impedance match  
according to an embodiment of the invention;

FIG. 95A illustrates an exemplary pulse generator;

FIGs. 95B and C illustrate exemplary waveforms related to the pulse generator  
of FIG. 95A;

FIG. 96 illustrates an exemplary energy transfer module with a switch module  
and a reactive storage module according to an embodiment of the invention;

FIGs. 97A-B illustrate exemplary energy transfer systems according to  
25 embodiments of the invention;

FIG. 98A illustrates an exemplary energy transfer signal module according to  
an embodiment of the present invention;

FIG. 98B illustrates a flowchart of state machine operation according to an  
30 embodiment of the present invention;

FIG. 98C is an exemplary energy transfer signal module;

FIG. 99 is a schematic diagram of a circuit to down-convert a 915 MHz signal  
to a 5 MHz signal using a 101.1 MHz clock according to an embodiment of the  
present invention;

FIG. 100 shows simulation waveforms for the circuit of FIG. 99 according to embodiments of the present invention;

FIG. 101 is a schematic diagram of a circuit to down-convert a 915 MHz signal to a 5 MHz signal using a 101 MHz clock according to an embodiment of the present invention;

FIG. 102 shows simulation waveforms for the circuit of FIG. 101 according to embodiments of the present invention;

FIG. 103 is a schematic diagram of a circuit to down-convert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock according to an embodiment of the present invention;

FIG. 104 shows simulation waveforms for the circuit of FIG. 103 according to an embodiment of the present invention.

FIG. 105 shows a schematic of the circuit in FIG. 99 connected to an FSK source that alternates between 913 and 917 MHz at a baud rate of 500 Kbaud according to an embodiment of the present invention;

FIG. 106A illustrates an exemplary energy transfer system according to an embodiment of the invention;

FIGs. 106B-C illustrate exemplary timing diagrams for the exemplary system of FIG. 106A;

FIG. 107 illustrates an exemplary bypass network according to an embodiment of the invention;

FIG. 108 illustrates an exemplary bypass network according to an embodiment of the invention;

FIG. 109 illustrates an exemplary embodiment of the invention;

FIG. 110A illustrates an exemplary real time aperture control circuit according to an embodiment of the invention;

FIG. 110B illustrates a timing diagram of an exemplary clock signal for real time aperture control, according to an embodiment of the invention;

FIG. 110C illustrates a timing diagram of an exemplary optional enable signal for real time aperture control, according to an embodiment of the invention;

FIG. 110D illustrates a timing diagram of an inverted clock signal for real time aperture control, according to an embodiment of the invention;

FIG. 110E illustrates a timing diagram of an exemplary delayed clock signal for real time aperture control, according to an embodiment of the invention;

FIG. 110F illustrates a timing diagram of an exemplary energy transfer including pulses having apertures that are controlled in real time, according to an embodiment of the invention;

FIG.111 illustrates an exemplary embodiment of the invention;

5 FIG.112 illustrates an exemplary embodiment of the invention;

FIG.113 illustrates an exemplary embodiment of the invention;

FIG.114 illustrates an exemplary embodiment of the invention;

FIG.115A is a timing diagram for the exemplary embodiment of FIG. 111;

FIG.115B is a timing diagram for the exemplary embodiment of FIG. 112;

10 FIG.116A is a timing diagram for the exemplary embodiment of FIG. 113;

FIG.116B is a timing diagram for the exemplary embodiment of FIG. 114;

FIG.117A illustrates an exemplary embodiment of the invention;

FIG.117B illustrates equations for determining charge transfer, in accordance with the present invention;

15 FIG.117C illustrates relationships between capacitor charging and aperture, in accordance with the present invention;

FIG.117D illustrates relationships between capacitor charging and aperture, in accordance with the present invention;

20 FIG.117E illustrates power-charge relationship equations, in accordance with the present invention; and

FIG.117F illustrates insertion loss equations, in accordance with the present invention.

### *Detailed Description of the Preferred Embodiments*

#### *Table of contents*

- 25 1. Terminology.
2. Overview of the Invention.

2.1 Discussion of Modulation Techniques.

2.2 Explanation of Exemplary Circuits and Waveforms.

2.2.1 Frequency Modulation.

2.2.2 Phase Modulation.

2.2.3 Amplitude Modulation.

2.2.4 In-phase/Quadrature-phase Modulation.

2.3 Features of the Invention.

3. Frequency Up-conversion.

3.1 High Level Description.

3.1.1 Operational Description.

3.1.2 Structural Description.

3.2 Exemplary Embodiments.

3.2.1 First Embodiment: Frequency Modulation (FM) Mode.

3.2.1.1 Operational Description.

3.2.1.2 Structural Description.

3.2.2 Second Embodiment: Phase Modulation (PM) Mode.

3.2.2.1 Operational Description.

3.2.2.2 Structural Description.

3.2.3 Third Embodiment: Amplitude Modulation (AM) Mode.

3.2.3.1 Operational Description.

3.2.3.2 Structural Description.

3.2.4 Fourth Embodiment: In-phase/Quadrature-phase ("I/Q")  
Modulation Mode.

3.2.4.1 Operational Description.

3.2.4.2 Structural Description

3.2.5 Other Embodiments.

3.2.5.1 Combination of Modulation Techniques

3.3 Methods and Systems for Implementing the Embodiments.

- 3.3.1 The Voltage Controlled Oscillator (FM Mode).
  - 3.3.1.1 Operational Description.
  - 3.3.1.2 Structural Description.
- 5 3.3.2 The Local Oscillator (PM, AM, and "I/Q" Modes).
  - 3.3.2.1 Operational Description.
  - 3.3.2.2 Structural Description.
- 3.3.3 The Phase Shifter (PM Mode).
  - 3.3.3.1 Operational Description.
  - 3.3.3.2 Structural Description.
- 10 3.3.4 The Phase Modulator (PM and "I/Q" Modes).
  - 3.3.4.1 Operational Description.
  - 3.3.4.2 Structural Description.
- 3.3.5 The Summing Module (AM Mode).
  - 3.3.5.1 Operational Description.
  - 15 3.3.5.2 Structural Description.
- 3.3.6 The Switch Module (FM, PM, and "I/Q" Modes).
  - 3.3.6.1 Operational Description.
  - 3.3.6.2 Structural Description.
- 3.3.7 The Switch Module (AM Mode).
  - 20 3.3.7.1 Operational Description.
  - 3.3.7.2 Structural Description.
- 3.3.8 The Summer ("I/Q" Mode).
  - 3.3.8.1 Operational Description.
  - 3.3.8.2 Structural Description.
- 25 3.3.9 The Filter (FM, PM, AM, and "I/Q" Modes).
  - 3.3.9.1 Operational Description.
  - 3.3.9.2 Structural Description.
- 3.3.10 The Transmission Module (FM, PM, AM, and "I/Q" Modes).
  - 3.3.10.1 Operational Description.
  - 30 3.3.10.2 Structural Description.
- 3.3.11 Other Implementations.

#### 4. Harmonic Enhancement.

#### 4.1 High Level Description.

##### 4.1.1 Operational Description.

##### 4.1.2 Structural Description.

#### 4.2 Exemplary Embodiments.

##### 4.2.1 First Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create One Pulse per Cycle.

###### 4.2.1.1 Operational Description.

###### 4.2.1.2 Structural Description.

##### 4.2.2 Second Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create Two Pulses per Cycle.

###### 4.2.2.1 Operational Description.

###### 4.2.2.2 Structural Description.

##### 4.2.3 Third Embodiment: When Any Waveform Feeds the Harmonic Enhancement Module.

###### 4.2.3.1 Operational Description.

###### 4.2.3.2 Structural Description.

##### 4.2.4 Other Embodiments.

#### 4.3 Implementation Examples.

##### 4.3.1 First Digital Logic Circuit.

##### 4.3.2 Second Digital Logic Circuit.

##### 4.3.3 Analog Circuit.

##### 4.3.4 Other Implementations.

###### 4.3.4.1 Multiple apertures.

### 5. Amplifier Module.

#### 5.1 High Level Description.

##### 5.1.1 Operational Description.

##### 5.1.2 Structural Description.

#### 5.2 Exemplary Embodiment.

##### 5.2.1 Linear Amplifier.

5.2.1.1 Operational Description.

5.2.1.2 Structural Description.

5.2.2 Other Embodiments.

5.3 Implementation Examples.

5 5.3.1 Linear Amplifier.

5.3.1.1 Operational Description.

5.3.1.2 Structural Description.

5.3.2 Other Implementations.

6. Receiver/Transmitter System.

10 6.1 High Level Description.

6.2 Exemplary Embodiments and Implementation Examples.

6.2.1 First Embodiment: The Transmitter of the Present Invention  
Being Used in a Circuit with a Superheterodyne Receiver.

15 6.2.2 Second Embodiment: The Transmitter of the Present Invention  
Being Used with a Universal Frequency Down Converter in a  
Half-Duplex Mode

6.2.3 Third Embodiment: The Transmitter of the Present Invention  
Being Used with a Universal Frequency Down Converter in a  
Full-Duplex Mode.

20 6.2.4 Other Embodiments and Implementations.

6.3 Summary Description of Down-conversion Using a Universal  
Frequency Translation Module.

6.3.1 Optional Energy Transfer Signal Module

6.3.2 Smoothing the Down-Converted Signal

25 6.3.3 Impedance Matching

6.3.4 Tanks and Resonant Structures

6.3.5 Charge and Power Transfer Concepts

6.3.6 Optimizing and Adjusting the Non-Negligible Aperture  
Width/Duration

6.3.6.1 Varying the Input and Output Impedances

6.3.6.2 Real Time Aperture Control

6.3.7 Adding a Bypass Network

6.3.8 Modifying the Energy Transfer Signal Using Feedback

5 6.3.9 Other Implementations

6.3.10 Exemplary Energy Transfer Down-Converters

## 7. Designing a Transmitter According to an Embodiment of the Present Invention.

7.1 Frequency of the Transmission Signal.

7.2 Characteristics of the Transmission Signal.

10 7.3 Modulation Scheme.

7.4 Characteristics of the Information Signal.

7.5 Characteristic of the Oscillating Signal.

7.5.1 Frequency of the Oscillating Signal.

7.5.2 Pulse Width of the String of Pulses.

15 7.6 Design of the Pulse Shaping Circuit.

7.7 Selection of the Switch.

7.7.1 Optimized Switch Structures.

7.7.2 Phased D2D - Splitter in CMOS

7.8 Design of the Filter

20 7.9 Selection of an Amplifier.

7.10 Design of the Transmission Module.

### 1. Terminology.

25 Various terms used in this application are generally described in this section. Each description in this section is provided for illustrative and convenience purposes only, and is not limiting. The meaning of these terms will be apparent to persons skilled in the relevant art(s) based on the entirety of the teachings provided herein.

Amplitude Modulation (AM): A modulation technique wherein the amplitude of the carrier signal is shifted (i.e., varied) as a function of the information signal. The frequency of the carrier signal typically remains constant. A subset of AM is referred

WO 00/24116

- 16 -

PCT/US99/24127

to as "amplitude shift keying" which is used primarily for digital communications where the amplitude of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

5       Analog signal: A signal in which the information contained therein is continuous as contrasted to discrete, and represents a time varying physical event or quantity. The information content is conveyed by varying at least one characteristic of the signal, such as but not limited to amplitude, frequency, or phase, or any combinations thereof.

10       Baseband signal: Any generic information signal desired for transmission and/or reception. As used herein, it refers to both the information signal that is generated at a source prior to any transmission (also referred to as the modulating baseband signal), and to the signal that is to be used by the recipient after transmission (also referred to as the demodulated baseband signal).

15       Carrier signal: A signal capable of carrying information. Typically, it is an electromagnetic signal that can be varied through a process called modulation. The frequency of the carrier signal is referred to as the carrier frequency. A communications system may have multiple carrier signals at different carrier frequencies.

20       Control a switch: Causing a switch to open and close. The switch may be, without limitation, mechanical, electrical, electronic, optical, etc., or any combination thereof. Typically, it is controlled by an electrical or electronic input. If the switch is controlled by an electronic signal, it is typically a different signal than the signals connected to either terminal of the switch.

25       Demodulated baseband signal: The baseband signal that is to be used by the recipient after transmission. Typically it has been down converted from a carrier signal and has been demodulated. The demodulated baseband signal should closely approximate the information signal (i.e., the modulating baseband signal) in frequency, amplitude, and information

Demodulation: The process of removing information from a carrier or intermediate frequency signal.

Digital signal: A signal in which the information contained therein has discrete states as contrasted to a signal that has a property that may be continuously variable.

5 Direct down conversion: A down conversion technique wherein a received signal is directly down converted and demodulated, if applicable, from the original transmitted frequency (i.e., a carrier frequency) to baseband without having an intermediate frequency.

10 Down conversion: A process for performing frequency translation in which the final frequency is lower than the initial frequency.

Drive a switch: Same as control a switch.

15 Frequency Modulation (FM): A modulation technique wherein the frequency of the carrier signal is shifted (i.e., varied) as a function of the information signal. A subset of FM is referred to as "frequency shift keying" which is used primarily for digital communications where the frequency of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

20 Harmonic: A harmonic is a frequency or tone that, when compared to its fundamental or reference frequency or tone, is an integer multiple of it. In other words, if a periodic waveform has a fundamental frequency of "f" (also called the first harmonic), then its harmonics may be located at frequencies of " $n \cdot f$ ," where "n" is 2, 3, 4, etc. The harmonic corresponding to  $n=2$  is referred to as the second harmonic, the harmonic corresponding to  $n=3$  is referred to as the third harmonic, and so on.

25 In-phase ("I") signal: The signal typically generated by an oscillator. It has not had its phase shifted and is often represented as a sine wave to distinguish it from a "Q" signal. The "I" signal can, itself, be modulated by any means. When the "I" signal is combined with a "Q" signal, the resultant signal is referred to as an "I/Q" signal.

In-phase/Quadrature-phase ("I/Q") signal: The signal that results when an "I" signal is summed with a "Q" signal. Typically, both the "I" and "Q" signals have been phase modulated, although other modulation techniques may also be used, such as amplitude modulation. An "I/Q" signal is used to transmit separate streams of information simultaneously on a single transmitted carrier. Note that the modulated "I" signal and the modulated "Q" signal are both carrier signals having the same frequency. When combined, the resultant "I/Q" signal is also a carrier signal at the same frequency.

Information signal: The signal that contains the information that is to be transmitted. As used herein, it refers to the original baseband signal at the source. When it is intended that the information signal modulate a carrier signal, it is also referred to as the "modulating baseband signal". It may be voice or data, analog or digital, or any other signal or combination thereof.

Intermediate frequency (IF) signal: A signal that is at a frequency between the frequency of the baseband signal and the frequency of the transmitted signal.

Modulation: The process of varying one or more physical characteristics of a signal to represent the information to be transmitted. Three commonly used modulation techniques are frequency modulation, phase modulation, and amplitude modulation. There are also variations, subsets, and combinations of these three techniques.

Operate a switch: Same as control a switch.

Phase Modulation (PM): A modulation technique wherein the phase of the carrier signal is shifted (i.e., varied) as a function of the information signal. A subset of PM is referred to as "phase shift keying" which is used primarily for digital communications where the phase of the carrier signal shifts between discrete states rather than varying continuously as it does for analog information.

Quadrature-phase ("Q") signal: A signal that is out of phase with an in-phase ("I") signal. The amount of phase shift is predetermined for a particular application,

but in a typical implementation, the "Q" signal is 90° out of phase with the "I" signal. Thus, if the "I" signal were a sine wave, the "Q" signal would be a cosine wave. When discussed together, the "I" signal and the "Q" signal have the same frequencies.

Spectrum: Spectrum is used to signify a continuous range of frequencies, usually wide, within which electromagnetic (EM) waves have some specific common characteristic. Such waves may be propagated in any communication medium, both natural and manmade, including but not limited to air, space, wire, cable, liquid, waveguide, microstrip, stripline, optical fiber, etc. The EM spectrum includes all frequencies greater than zero hertz.

Subharmonic: A subharmonic is a frequency or tone that is an integer submultiple of a referenced fundamental frequency or tone. That is, a subharmonic frequency is the quotient obtained by dividing the fundamental frequency by an integer. For example, if a periodic waveform has a frequency of "f" (also called the "fundamental frequency" or first subharmonic), then its subharmonics have frequencies of "f/n," where n is 2, 3, 4, etc. The subharmonic corresponding to n=2 is referred to as the second subharmonic, the subharmonic corresponding to n=3 is referred to as the third subharmonic, and so on. A subharmonic itself has possible harmonics, and the i<sup>th</sup> harmonic of the i<sup>th</sup> subharmonic will be at the fundamental frequency of the original periodic waveform. For example, the third subharmonic (which has a frequency of "f/3") may have harmonics at integer multiples of itself (i.e., a second harmonic at "2•f/3," a third harmonic at "3•f/3," and so on). The third harmonic of the third subharmonic of the original signal (i.e., "3•f/3") is at the frequency of the original signal.

Trigger a switch: Same as control a switch.

Up conversion: A process for performing frequency translation in which the final frequency is higher than the initial frequency.

## 2. *Overview of the Invention.*

The present invention is directed to systems and methods for frequency up-conversion, and applications thereof.

In one embodiment, the frequency up-converter of the present invention is used as a stable reference frequency source in a phase comparator or in a frequency  
5 comparator. This embodiment of the present invention achieves this through the use of a stable, low frequency local oscillator, a switch, and a filter. Because it up-converts frequency, the present invention can take advantage of the relatively low cost of low frequency oscillators to generate stable, high frequency signals.

In a second embodiment, the frequency up-converter is used as a system and  
10 method for transmitting an electromagnetic (EM) signal.

Based on the discussion contained herein, one skilled in the relevant art(s) will recognize that there are other, alternative embodiments in which the frequency up-converter of the present invention could be used in other applications, and that these alternative embodiments fall within the scope of the present invention.

For illustrative purposes, various modulation examples are discussed below.  
15 However, it should be understood that the invention is not limited by these examples. Other modulation techniques that might be used with the present invention will be apparent to persons skilled in the relevant art(s) based on the teaching contained herein.

Also for illustrative purposes, frequency up-conversion according to the present  
20 invention is described below in the context of a transmitter. However, the invention is not limited to this embodiment. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

## 2.1 *Discussion of Modulation Techniques.*

Techniques by which information can be imparted onto EM signals to be  
transmitted are called modulation. These techniques are generally well known to one  
skilled in the relevant art(s), and include, but are not limited to, frequency modulation  
(FM), phase modulation (PM), amplitude modulation (AM), quadrature-phase shift  
keying (QPSK), frequency shift keying (FSK), phase shift keying (PSK), amplitude  
30 shift keying (ASK), etc., and combinations thereof. These last three modulation

techniques, FSK, PSK, and ASK, are subsets of FM, PM, and AM, respectively, and refer to circuits having discrete input signals (e.g., digital input signals).

For illustrative purposes only, the circuits and techniques described below all refer to the EM broadcast medium. However, the invention is not limited by this embodiment. Persons skilled in the relevant art(s) will recognize that these same circuits and techniques can be used in all transmission media (e.g., over-the-air broadcast, point-to-point cable, etc.).

## 2.2 *Explanation of Exemplary Circuits and Waveforms.*

### 2.2.1 *Frequency Modulation.*

FIG. 1 illustrates an example of a frequency modulation (FM) circuit 100 and FIGs. 2A, 2B, and 2C, and FIGs. 20A, 20B, and 20C illustrate examples of waveforms at several points in FM circuit 100. In an FM system, the frequency of a carrier signal, such as an oscillating signal 202 (FIG. 2B and FIG. 20B), is varied to represent the data to be communicated, such as information signals 102 of FIG. 2A and 2002 of FIG. 20A. In FIG. 20A, information signal 2002 is a continuous signal (i.e., an analog signal), and in FIG. 2A, information signal 102 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 102, the FM circuit 100 is referred to as a frequency shift keying (FSK) system, which is a subset of an FM system.

Frequency modulation circuit 100 receives an information signal 102, 2002 from a source (not shown). Information signal 102, 2002 can be amplified by an optional amplifier 104 and filtered by an optional filter 114 and is the voltage input that drives a voltage controlled oscillator (VCO) 106. Within VCO 106, an oscillating signal 202 (seen on FIG. 2B and FIG. 20B) is generated. The purpose of VCO 106 is to vary the frequency of oscillating signal 202 as a function of the input voltage, i.e., information signal 102, 2002. The output of VCO 106 is a modulated signal shown as modulated signal 108 (FIG. 2C) when the information signal is the digital information signal 102 and shown as modulated signal 2004 (FIG. 20C) when the information signal is the analog signal 2002. Modulated signal 108, 2004 is at a relatively low frequency (e.g., generally between 50 MHz and 100 MHz) and can have its frequency increased by an optional frequency multiplier 110 (e.g., to 900 MHz, 1.8 GHz) and

have its amplitude increased by an optional amplifier 116. The output of optional frequency multiplier 110 and/or optional amplifier 116 is then transmitted by an exemplary antenna 112.

### 2.2.2 Phase Modulation.

FIG. 3 illustrates an example of a phase modulation (PM) circuit 300 and FIGs. 4A, 4B, and 4C, and FIGs. 21A, 21B, and 21C illustrate examples of waveforms at several points in PM circuit 300. In a PM system, the phase of a carrier signal, such as a local oscillator (LO) output 308 (FIG. 4B and FIG. 21B), is varied to represent the data to be communicated, such as an information signals 302 of FIG. 4A and 2102 of FIG. 21A. In FIG. 21A, information signal 2102 is a continuous signal (i.e., an analog signal), and in FIG. 4A, information signal 302 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 302, the PM circuit is referred to as a phase shift keying (PSK) system. This is the typical implementation, and is a subset of a PM system.

Phase modulation circuit 300 receives information signal 302, 2102 from a source (not shown). Information signal 302, 2102 can be amplified by an optional amplifier 304 and filtered by an optional filter 318 and is routed to a phase modulator 306. Also feeding phase modulator 306 is LO output 308 of a local oscillator 310. LO output 308 is shown on FIG. 4B and FIG. 21B. Local oscillators, such as local oscillator 310, output an electromagnetic wave at a predetermined frequency and amplitude.

The output of phase modulator 306 is a modulated signal shown as a phase modulated signal 312 (FIG. 4C) when the information signal is the discrete information signal 302 and shown as a phase modulated signal 2104 (FIG. 21C) when the information signal is the analog information signal 2102. The purpose of phase modulator 306 is to change the phase of LO output 308 as a function of the value of information signal 302, 2102. That is, for example in a PSK mode, if LO output 308 were a sine wave, and the value of information signal 302 changed from a binary high to a binary low, the phase of LO output 308 would change from a sine wave with a zero phase to a sine wave with, for example, a phase of 180°. The result of this phase change would be phase modulated signal 312 of FIG. 4C which would have the same frequency as LO output 308, but would be out of phase by 180° in this example. For a

PSK system, the phase changes in phase modulated signal 312 that are representative of the information in information signal 302 can be seen by comparing waveforms 302, 308, and 312 on FIGs. 4A, 4B, and 4C. For the case of an analog information signal 2102 of FIG. 21A, the phase of LO output 308 of FIG. 21B changes continuously as a function of the amplitude of the information signal 2102. That is, for example, as information signal 2102 increases from a value of "X" to "X +  $\delta x$ ", the PM signal 2104 of FIG. 21C changes from a signal which may be represented by the equation  $\sin(\omega t)$  to a signal which can be represented by the equation  $\sin(\omega t + \phi)$ , where  $\phi$  is the phase change associated with a change of  $\delta x$  in information signal 2102. For an analog PM system, the phase changes in phase modulated signal 2104 that are representative of the information in information signal 2102 can be seen by comparing waveforms 2102, 308, and 2104 on FIGs. 21A, 21B, and 21C.

After information signal 302, 2102 and LO output 308 have been modulated by phase modulator 306, phase modulated signal 312, 2104 can be routed to an optional frequency multiplier 314 and optional amplifier 320. The purpose of optional frequency multiplier 314 is to increase the frequency of phase modulated signal 312 from a relatively low frequency (e.g., 50 MHz to 100 MHz) to a desired broadcast frequency (e.g., 900 MHz, 1.8 GHz). Optional amplifier 320 raises the signal strength of phase modulated signal 312, 2104 to a desired level to be transmitted by an exemplary antenna 316.

### 2.2.3 *Amplitude Modulation.*

FIG. 5 illustrates an example of an amplitude modulation (AM) circuit 500 and FIGs. 6A, 6B, and 6C, and FIGs. 22A, 22B, and 22C illustrate examples of waveforms at several points in AM circuit 500. In an AM system, the amplitude of a carrier signal, such as a local oscillator (LO) signal 508 (FIG. 6B and FIG. 22B), is varied to represent the data to be communicated, such as information signals 502 of FIG. 6A and 2202 of FIG. 22A. In FIG. 22A, information signal 2202 is a continuous signal (i.e., an analog signal), and in FIG. 6A, information signal 502 is a discrete signal (i.e., a digital signal). In the case of the discrete information signal 502, the AM circuit is referred to as an amplitude shift keying (ASK) system, which is a subset of an AM system.

Amplitude modulation circuit 500 receives information signal 502 from a source (not shown). Information signal 502, 2202 can be amplified by an optional

amplifier 504 and filtered by an optional filter 518. Amplitude modulation circuit 500 also includes a local oscillator (LO) 506 which has an LO output 508. Information signal 502, 2202 and LO output 508 are then multiplied by a multiplier 510. The purpose of multiplier 510 is to cause the amplitude of LO output 508 to vary as a function of the amplitude of information signal 502, 2202. The output of multiplier 510 is a modulated signal shown as amplitude modulated signal 512 (FIG. 6C) when the information signal is the digital information signal 502 and shown as modulated signal 2204 (FIG. 22C) when the information signal is the analog information signal 2202. AM signal 512, 2204 can then be routed to an optional frequency multiplier 514 where the frequency of AM signal 512, 2204 is increased from a relatively low level (e.g., 50 MHz to 100 MHz) to a higher level desired for broadcast (e.g., 900 MHz, 1.8 GHz) and an optional amplifier 520, which increases the signal strength of AM signal 512, 2204 to a desired level for broadcast by an exemplary antenna 516.

#### 2.2.4 In-phase/Quadrature-phase Modulation.

FIG. 7 illustrates an example of an in-phase/quadrature-phase ("I/Q") modulation circuit 700 and FIGs. 8A, 8B, 8C, 8D, and 8E illustrate examples of waveforms at several points in "I/Q" modulation circuit 700. In this technique, which increases bandwidth efficiency, separate information signals can be simultaneously transmitted on carrier signals that are out of phase with each other. That is, a first information signal 702 of FIG. 8A can be modulated onto the in-phase ("I") oscillator signal 710 of FIG. 8B and a second information signal 704 of FIG. 8C can be modulated onto the quadrature-phase ("Q") oscillator signal 712 of FIG. 8D. The "I" modulated signal is combined with the "Q" modulated signal and the resulting "I/Q" modulated signal is then transmitted. In a typical usage, both information signals are digital, and both are phase modulated onto the "I" and "Q" oscillating signals. One skilled in the relevant art(s) will recognize that the "I/Q" mode can also work with analog information signals, with combinations of analog and digital signals, with other modulation techniques, or any combinations thereof.

This "I/Q" modulation system uses two PM circuits together in order to increase the bandwidth efficiency. As stated above, in a PM circuit, the phase of an oscillating signal, such as 710 (or 712) (FIGs 8B or 8D), is varied to represent the data to be communicated, such as an information signal such as 702 (or 704). For ease of

understanding and display, the discussion herein will describe the more typical use of the "I/Q" mode, that is, with digital information signals and phase modulation on both oscillating signals. Thus, both signal streams are phase shift keying (PSK), which is a subset of PM.

5 "I/Q" modulation circuit 700 receives an information signal 702 from a first source (not shown) and an information signal 704 from a second source (not shown). Examples of information signals 702 and 704 are shown in FIG. 8A and 8C. Information signals 702 and 704 can be amplified by optional amplifiers 714 and 716 and filtered by optional filters 734 and 736. It is then routed to phase modulators 718 and 720. Also feeding phase modulators 718 and 720 are oscillating signals 710 and 712. Oscillating signal 710 was generated by a local oscillator 706, and is shown in FIG. 8B, and oscillating signal 712 is the phase shifted output of local oscillator 706. Local oscillators, such as local oscillator 706, output an electromagnetic wave at a predetermined frequency and amplitude

15 The output of phase modulator 718 is a phase modulated signal 722 which is shown using a dotted line as one of the waveforms in FIG. 8E. Similarly, the output of phase modulator 720, which operates in a manner similar to phase modulator 718, is a phase modulated signal 724 which is shown using a solid line as the other waveform in FIG. 8E. The effect of phase modulators 718 and 720 on oscillating signals 710 and 712 is to cause them to change phase. As stated above, the system shown here is a PSK system, and as such, the phase of oscillating signals 710 and 712 is shifted by phase modulators 718 and 720 by a discrete amount as a function of information signals 702 and 704.

25 For simplicity of discussion and ease of display, oscillating signal 710 is shown on FIG. 8B as a sine wave and is referred to as the "I" signal in the "I/Q" circuit 700. After the output of oscillator 706 has gone through a phase shifter 708, shown here as shifting the phase by  $-\pi/2$ , oscillating signal 712 is a cosine wave, shown on FIG. 8D, and is referred to as the "Q" signal in the "I/Q" circuit. Again, for ease of display, phase modulators 718 and 720 are shown as shifting the phase of the respective oscillating signals 710 and 712 by  $180^\circ$ . This is seen on FIG. 8E. Modulated signal 722 is summed with modulated signal 724 by a summer 726. The output of summer 726 is the arithmetic sum of modulated signal 722 and 724 and is an "I/Q" signal 728. (For clarity of the display on FIG. 8E, the combined signal 728 is not shown. However, one skilled in the relevant art(s) will recognize that the arithmetic sum of 2

sinusoidal waves having the same frequency is also a sinusoidal wave at that frequency.)

"I/Q" signal 728 can then be routed to an optional frequency multiplier 730, where the frequency of "I/Q" signal 718 is increased from a relatively low level (e.g., 50 MHz to 100 MHz) to a higher level desired for broadcast (e.g., 900 MHz, 1.8 GHz), and to an optional amplifier 738 which increases the signal strength of "I/Q" signal 728 to a desired level for broadcast by an exemplary antenna 732.

### 2.3 *Features of the Invention.*

As apparent from the above, several frequencies are involved in a communications system. The frequency of the information signal is relatively low. The frequency of the local oscillator (both the voltage controlled oscillator as well as the other oscillators) is higher than that of the information signal, but typically not high enough for efficient transmission. A third frequency, not specifically mentioned above, is the frequency of the transmitted signal which is greater than or equal to the frequency of the oscillating signal. This is the frequency that is routed from the optional frequency multipliers and optional amplifiers to the antennas in the previously described circuits.

Typically, in the transmitter subsystem of a communications system, upconverting the information signal to broadcast frequency requires, at least, filters, amplifiers, and frequency multipliers. Each of these components is costly, not only in terms of the purchase price of the component, but also because of the power required to operate them.

The present invention provides a more efficient means for producing a modulated carrier for transmission, uses less power, and requires fewer components. These and additional advantages of the present invention will be apparent from the following description.

### 3. *Frequency Up-conversion.*

The present invention is directed to systems and methods for frequency up-conversion and applications of the same. In one embodiment, the frequency up-converter of the present invention allows the use of a stable, low frequency oscillator to

generate a stable high frequency signal that, for example and without limitation, can be used as a reference signal in a phase comparator or a frequency comparator. In another embodiment, the up-converter of the present invention is used in a transmitter. The invention is also directed to a transmitter. Based on the discussion contained herein, one skilled in the relevant art(s) will recognize that there are other, alternative embodiments and applications in which the frequency up-converter of the present invention could be used, and that these alternative embodiments and applications fall within the scope of the present invention

For illustrative purposes, frequency up-conversion according to the present invention is described below in the context of a transmitter. However, as apparent from the preceding paragraph, the invention is not limited to this embodiment.

The following sections describe methods related to a transmitter and frequency up-converter. Structural exemplary embodiments for achieving these methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

### 3.1. *High Level Description.*

This section (including its subsections) provides a high-level description of up-converting and transmitting signals according to the present invention. In particular, an operational process of frequency up-conversion in the context of transmitting signals is described at a high-level. The operational process is often represented by flowcharts. The flowcharts are presented herein for illustrative purposes only, and are not limiting. In particular, the use of flowcharts should not be interpreted as limiting the invention to discrete or digital operation. In practice, those skilled in the relevant art(s) will appreciate, based on the teachings contained herein, that the invention can be achieved via discrete operation, continuous operation, or any combination thereof. Furthermore, the flow of control represented by the flowcharts is also provided for illustrative purposes only, and it will be appreciated by persons skilled in the relevant art(s) that other operational control flows are within the scope and spirit of the invention.

Also, a structural implementation for achieving this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

### 3.1.1 Operational Description.

The flow chart 900 of FIG. 9 demonstrates the operational method of frequency up-conversion in the context of transmitting a signal according to an embodiment of the present invention. The invention is directed to both frequency up-conversion and transmitting signals as represented in FIG. 9. Representative waveforms for signals generated in flow chart 900 are depicted in FIG. 19. For purposes of illustrating the high level operation of the invention, frequency modulation of a digital information signal is depicted. The invention is not limited to this exemplary embodiment. One skilled in the relevant art(s) will appreciate that other modulation modes could alternatively be used (as described in later sections).

In step 902, an information signal 1902 (FIG. 19A) is generated by a source. This information signal may be analog, digital, and any combination thereof, or anything else that is desired to be transmitted, and is at the baseband frequency. As described below, the information signal 1902 is used to modulate an intermediate signal 1904. Accordingly, the information signal 1902 is also herein called a modulating baseband information signal. In the example of FIG. 19A, the information signal 1902 is illustrated as a digital signal. However, the invention is not limited to this embodiment. As noted above, the information signal 1902 can be analog, digital, and/or any combination thereof.

An oscillating signal 1904 (FIG. 19B) is generated in step 904. In step 906, the oscillating signal 1904 is modulated, where the modulation is a result of, and a function of, the information signal 1902. Step 906 produces a modulated oscillating signal 1906 (FIG. 19C), also called a modulated intermediate signal. As noted above, the flowchart of FIG. 9 is being described in the context of an example where the information signal 1902 is a digital signal. However, alternatively, the information signal 1902 can be analog or any combination of analog and digital. Also, the example shown in FIG. 19

uses frequency shift keying (FSK) as the modulation technique. Alternatively, any modulation technique (e.g., FM, AM, PM, ASK, PSK, etc., or any combination thereof) can be used. The remaining steps 908-912 of the flowchart of FIG. 9 operate in the same way, whether the information signal 1902 is digital, analog, etc., or any combination thereof, and regardless of what modulation technique is used.

A harmonically rich signal 1908 (FIG. 19D) is generated from the modulated signal 1906 in step 908. Signal 1908 has a substantially continuous and periodically repeated waveform. In an embodiment, the waveform of signal 1908 is substantially rectangular, as is seen in the expanded waveform 1910 of FIG. 19E. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent or requirement of the present invention that a perfect rectangular waveform be generated or needed. However, for ease of discussion, the term "rectangular waveform" will be used herein and will refer to waveforms that are substantially rectangular, and will include but will not be limited to those waveforms that are generally referred to as square waves or pulses. It should be noted that if the situation arises wherein a perfect rectangular waveform is proven to be both technically and mathematically feasible, that situation will also fall within the scope and intent of this invention

A continuous periodic waveform (such as waveform 1908) is composed of a series of sinusoidal waves of specific amplitudes and phases, the frequencies of which are integer multiples of the repetition frequency of the waveform. (A waveform's repetition frequency is the number of times per second the periodic waveform repeats.) A portion of the waveform of signal 1908 is shown in an expanded view as waveform 1910 of FIG. 19E. The first three sinusoidal components of waveform 1910 (FIG. 19E) are depicted as waveforms 1912a, b, & c of FIG. 19F and waveforms 1914a, b, & c of FIG. 19G. (In the examples of FIGS 19F & G, the three sinusoidal components are shown separately. In actuality, these waveforms, along with all the other sinusoidal components which are not shown, occur simultaneously, as seen in FIG. 19H. Note that in FIG. 19H, the waveforms are shown simultaneously, but are not shown summed. If waveforms 1912 and 1914 were shown summed, they would, in the limit, i.e., with an infinite number of sinusoidal components, be identical to the periodic waveform 1910 of FIG. 19E. For ease of illustration, only the first three of the infinite number of sinusoidal components are shown.) These sinusoidal waves are called harmonics, and their existence can be demonstrated both graphically and

mathematically. Each harmonic (waveforms 1912a, b, & c and 1914a, b, & c) has the same information content as does waveform 1910 (which has the same information as the corresponding portion of waveform 1908). Accordingly, the information content of waveform 1908 can be obtained from any of its harmonics. As the harmonics have frequencies that are integer multiples of the repetition frequency of signal 1908, and since they have the same information content as signal 1908 (as just stated), the harmonics each represent an up-converted representation of signal 1908. Some of the harmonics are at desired frequencies (such as the frequencies desired to be transmitted). These harmonics are called "desired harmonics" or "wanted harmonics." According to the invention, desired harmonics have sufficient amplitude for accomplishing the desired processing (i.e., being transmitted). Other harmonics are not at the desired frequencies. These harmonics are called "undesired harmonics" or "unwanted harmonics."

In step 910, any unwanted harmonics of the continuous periodic waveform of signal 1908 are filtered out (for example, any harmonics that are not at frequencies desired to be transmitted). In the example of FIG. 19, the first and second harmonics (i.e., those depicted by waveforms 1912a & b of FIG. 19F and 1914a & b of FIG. 19G) are the unwanted harmonics. In step 912, the remaining harmonic, in the example of FIG. 19, the third harmonic (i.e., those depicted by waveforms 1912c of FIG. 19F and 1914c of FIG. 19G), is transmitted. This is depicted by waveform 1918 of FIG. 19I. In the example of FIG. 19, only three harmonics are shown, and the lowest two are filtered out to leave the third harmonic as the desired harmonic. In actual practice, there are an infinite number of harmonics, and the filtering can be made to remove unwanted harmonics that are both lower in frequency than the desired harmonic as well as those that are higher in frequency than the desired harmonic.

### 3.1.2 Structural Description.

FIG. 10 is a block diagram of an up-conversion system according to an embodiment of the invention. This embodiment of the up-conversion system is shown as a transmitter 1000. Transmitter 1000 includes an acceptance module 1004, a harmonic generation and extraction module 1006, and a transmission module 1008 that accepts an information signal 1002 and outputs a transmitted signal 1014.

Preferably, the acceptance module 1004, harmonic generation and extraction module 1006, and transmission module 1008 process the information signal in the manner shown in the operational flowchart 900. In other words, transmitter 1000 is the structural embodiment for performing the operational steps of flowchart 900. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 900. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1000 will now be described in detail with reference to the flowchart 900. In step 902, an information signal 1002 (for example, see FIG. 19A) from a source (not shown) is routed to acceptance module 1004. In step 904, an oscillating signal (for example, see FIG. 19B) is generated and in step 906, it is modulated, thereby producing a modulated signal 1010 (for an example of FM, see FIG. 19C). The oscillating signal can be modulated using any modulation technique, examples of which are described below. In step 908, the harmonic generation and extraction module (HGEM) generates a harmonically rich signal with a continuous and periodic waveform (an example of FM can be seen in FIG. 19D). This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform. A Fourier series analysis can be used to determine the amplitude of each harmonic (for example, see FIGs. 19F and 19G). In step 910, a filter (not shown) within HGEM 1006 filters out the undesired frequencies (harmonics), and outputs an electromagnetic (EM) signal 1012 at the desired frequency (for example, see FIG. 19I). In step 912, EM signal 1012 is routed to transmission module 1008 (optional), where it is prepared for transmission. The transmission module 1008 then outputs a transmitted signal 1014.

### 3.2 Exemplary Embodiments.

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to

these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

5                                    **3.2.1 First Embodiment: Frequency Modulation (FM) Mode.**

In this embodiment, an information signal is accepted and a modulated signal whose frequency varies as a function of the information signal results.

**3.2.1.1 Operational Description.**

10            The flow chart of FIG. 11 demonstrates the method of operation of a transmitter in the frequency modulation (FM) mode according to an embodiment of the present invention. As stated above, the representative waveforms shown in FIG. 19 depict the invention operating as a transmitter in the FM mode.

15            In step 1102, an information signal 1902 (FIG. 19A) is generated by a source by any means and/or process. (Information signal 1902 is a baseband signal, and, because it is used to modulate a signal, may also be referred to as a modulating baseband signal 1902.) Information signal 1902 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 19 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with an analog information signal wherein the information is represented by a continuously varying signal. In step 1104, information signal 1902 modulates an oscillating signal 1904 (FIG. 19B). The result of this modulation is the modulated signal 1906 (FIG. 19C) as indicated in block 1106. Modulated signal 1906 has a frequency that varies as a function of information signal 1902 and is referred to as an FM signal.

20            In step 1108, a harmonically rich signal with a continuous periodic waveform, shown in FIG. 19D as rectangular waveform 1908, is generated. Rectangular waveform 1908 is generated using the modulated signal 1906. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent of

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- 33 -

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the present invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed. A portion of rectangular waveform 1908 is shown in an expanded view as periodic waveform 1910 in FIG. 19E. The first part of waveform 1910 is designated "signal A" and represents information signal 1902 being "high," and the second part of waveform 1910 is designated "signal B" and information signal 1902 being "low." It should be noted that this convention is used for illustrative purposes only, and alternatively, other conventions could be used.

As stated before, a continuous and periodic waveform, such as a rectangular wave 1908 as indicated in block 1110 of flowchart 1100, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (i.e., at the Fourier component frequencies). Three harmonics of periodic waveform 1910 are shown separately, in expanded views, in FIGs. 19F and 19G. Since waveform 1910 (and also waveform 1908) is shown as a square wave in this exemplary embodiment, only the odd harmonics are present, i.e., the first, third, fifth, seventh, etc. As shown in FIG. 19, if rectangular waveform 1908 has a fundamental frequency of  $f_1$  (also known as the first harmonic), the third harmonic will have a frequency of  $3 \cdot f_1$ , the fifth harmonic will have a frequency of  $5 \cdot f_1$ , and so on. The first, third, and fifth harmonics of signal A are shown as waveforms 1912a, 1912b, and 1912c of FIG. 19F, and the first, third, and fifth harmonics of signal B are shown as waveforms 1914a, 1914b, and 1914c of FIG. 19G. In actuality, these harmonics (as well as all of the higher order harmonics) occur simultaneously, as shown by waveform 1916 of FIG. 19H. Note that if all of the harmonic components of FIG. 19H were shown summed together with all of the higher harmonics (i.e., the seventh, the ninth, etc.) the resulting waveform would, in the limit, be identical to waveform 1910.

In step 1112, the unwanted frequencies of waveform 1916 are removed. In the example of FIG. 19, the first and third harmonics are shown to be removed, and as indicated in block 1114, the remaining waveform 1918 (i.e., waveforms 1912c and 1914c) is at the desired EM frequency. Although not shown, the higher harmonics (e.g., the seventh, ninth, etc.) are also removed.

The EM signal, shown here as remaining waveform 1918, is prepared for transmission in step 1116, and in step 1118, the EM signal is transmitted.

### *3.2.1.2 Structural Description.*

FIG. 12 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an FM transmitter 1200. FM transmitter 1200 includes a voltage controlled oscillator (VCO) 1204, a switch module 1214, a filter 1218, and a transmission module 1222 that accepts an information signal 1202 and outputs a transmitted signal 1224. The operation and structure of exemplary components are described below: an exemplary VCO is described below at sections 3.3.1-3.3.1.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the voltage controlled oscillator 1204, switch module 1214, filter 1218, and transmission module 1222 process the information signal in the manner shown in the operational flowchart 1100. In other words, FM transmitter 1200 is the structural embodiment for performing the operational steps of flowchart 1100. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1100. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1200 will now be described in detail with reference to the flowchart 1100. In step 1102, an information signal 1202 (for example, see FIG. 19A) from a source (not shown) is routed to VCO 1204. In step 1104, an oscillating signal (for example, see FIG. 19B) is generated and modulated, thereby producing a frequency modulated signal 1210 (for example, see FIG. 19C). In step 1108, the switch module 1214 generates a harmonically rich signal 1216 with a continuous and periodic waveform (for example, see FIG. 19D). This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the

underlying waveform, and a Fourier analysis will determine the amplitude of each harmonic (for example, see FIGs. 19F and 19G). In step 1112, a filter 1218 filters out the undesired frequencies (harmonics), and outputs an electromagnetic (EM) signal 1220 at the desired harmonic frequency (for example, see FIG. 19I). In step 1116, EM  
5 signal 1220 is routed to transmission module 1222 (optional), where it is prepared for transmission. In step 1118, transmission module 1222 outputs a transmitted signal 1224.

### 3.2.2 *Second Embodiment: Phase Modulation (PM) Mode.*

In this embodiment, an information signal is accepted and a modulated signal  
10 whose phase varies as a function of the information signal is transmitted.

#### 3.2.2.1 *Operational Description.*

The flow chart of FIG. 13 demonstrates the method of operation of the transmitter in the phase modulation (PM) mode. The representative waveforms shown in FIG. 44 depict the invention operating as a transmitter in the PM mode.

15 In step 1302, an information signal 4402 (FIG. 44A) is generated by a source. Information signal 4402 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 44 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with  
20 an analog information signal wherein the information is represented by a continuously varying signal. In step 1304, an oscillating signal 4404 is generated and in step 1306, the oscillating signal 4404 (FIG. 44B) is modulated by the information signal 4402, resulting in the modulated signal 4406 (FIG. 44C) as indicated in block 1308. The phase of this modulated signal 4406 is varied as a function of the information signal  
25 4402.

A harmonically rich signal 4408 (FIG. 44D) with a continuous periodic waveform is generated at step 1310 using modulated signal 4406. Harmonically rich signal 4408 is a substantially rectangular waveform. One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving  
30 an exact or perfect rectangular waveform and it is not the intent of the present

invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed. As stated before, a continuous and periodic waveform, such as the harmonically rich signal 4408 as indicated in block 1312, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). The first three harmonic waveforms are shown in FIGs. 44E, 44F, and 44G. In actual fact, there are an infinite number of harmonics. In step 1314, the unwanted frequencies are removed, and as indicated in block 1316, the remaining frequency is at the desired EM output. As an example, the first (fundamental) harmonic 4410 and the second harmonic 4412 along with the fourth, fifth, etc., harmonics (not shown) might be filtered out, leaving the third harmonic 4414 as the desired EM signal as indicated in block 1316.

The EM signal is prepared for transmission in step 1318, and in step 1320, the EM signal is transmitted.

### 3.2.2.2 Structural Description.

FIG. 14 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as a PM transmitter 1400. PM transmitter 1400 includes a local oscillator 1406, a phase modulator 1404, a switch module 1410, a filter 1414, and a transmission module 1418 that accepts an information signal 1402 and outputs a transmitted signal 1420. The operation and structure of exemplary components are described below: an exemplary phase modulator is described below at sections 3.3.4-3.3.4.2; an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1406, phase modulator 1404, switch module 1410, filter 1414, and transmission module 1418 process the information signal in the manner shown in the operational flowchart 1300. In other words, PM transmitter 1400

is the structural embodiment for performing the operational steps of flowchart 1300. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1300. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1400 will now be described in detail with reference to the flowchart 1300. In step 1302, an information signal 1402 (for example, see FIG. 44A) from a source (not shown) is routed to phase modulator 1404. In step 1304, an oscillating signal from local oscillator 1406 (for example, see FIG. 44B) is generated and modulated, thereby producing a modulated signal 1408 (for example, see FIG. 44C). In step 1310, the switch module 1410 generates a harmonically rich signal 1412 with a continuous and periodic waveform (for example, see FIG. 44D). This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform, and a Fourier analysis will determine the amplitude of each harmonic (for an example of the first three harmonics, see FIGs. 44E, 44F, and 44G). In step 1314, a filter 1414 filters out the undesired harmonic frequencies (for example, the first harmonic 4410, the second harmonic 4412, and the fourth, fifth, etc., harmonics, not shown), and outputs an electromagnetic (EM) signal 1416 at the desired harmonic frequency (for example, the third harmonic, see FIG. 44G). In step 1318, EM signal 1416 is routed to transmission module 1418 (optional), where it is prepared for transmission. In step 1320, the transmission module 1418 outputs a transmitted signal 1420.

### ***3.2.3 Third Embodiment: Amplitude Modulation (AM) Mode.***

In this embodiment, an information signal is accepted and a modulated signal whose amplitude varies as a function of the information signal is transmitted.

#### ***3.2.3.1 Operational Description.***

The flow chart of FIG. 15 demonstrates the method of operation of the transmitter in the amplitude modulation (AM) mode. The representative waveforms shown in FIG. 45 depict the invention operating as a transmitter in the AM mode.

5 In step 1502, an information signal 4502 (FIG. 45A) is generated by a source. Information signal 4502 may be, for example, analog, digital, or any combination thereof. The signals shown in FIG. 45 depict a digital information signal wherein the information is represented by discrete states of the signal. It will be apparent to persons skilled in the relevant art(s) that the invention is also adapted to working with an analog information signal wherein the information is represented by a continuously  
10 varying signal. In step 1504, a "reference signal" is created, which, as indicated in block 1506, has an amplitude that is a function of the information signal 4502. In one embodiment of the invention, the reference signal is created by combining the information signal 4502 with a bias signal. In another embodiment of the invention, the reference signal is comprised of only the information signal 4502. One skilled in  
15 the relevant art(s) will recognize that any number of embodiments exist wherein the reference signal will vary as a function of the information signal.

An oscillating signal 4504 (FIG. 45B) is generated at step 1508, and at step 1510, the reference signal (information signal 4502) is gated at a frequency that is a function of the oscillating signal 4504. The gated referenced signal is a harmonically  
20 rich signal 4506 (FIG. 45C) with a continuous periodic waveform and is generated at step 1512. This harmonically rich signal 4506 as indicated in block 1514 is substantially a rectangular wave which has a fundamental frequency equal to the frequency at which the reference signal (information signal 4502) is gated. In addition, the rectangular wave has pulse amplitudes that are a function of the amplitude of the  
25 reference signal (information signal 4502). One skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving an exact or perfect rectangular waveform and it is not the intent of the present invention that a perfect rectangular waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to  
30 waveforms that are substantially rectangular. In a similar manner, the term "square wave" will refer to those waveforms that are substantially square and it is not the intent of the present invention that a perfect square wave be generated or needed.

As stated before, a harmonically rich signal 4506, such as the rectangular wave as indicated in block 1514, has sinusoidal components (harmonics) at frequencies that

are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). The first three harmonic waveforms are shown in FIGs. 45D, 45E, and 45F. In fact, there are an infinite number of harmonics. In step 1516, the unwanted frequencies are removed, and as indicated in block 1518, the remaining frequency is at the desired EM output. As an example, the first (fundamental) harmonic 4510 and the second harmonic 4512 along with the fourth, fifth, etc., harmonics (not shown) might be filtered out leaving the third harmonic 4514 as the desired EM signal as indicated in block 1518.

The EM signal is prepared for transmission in step 1520, and in step 1522, the EM signal is transmitted.

### 3.2.3.2 Structural Description.

FIG. 16 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an AM transmitter 1600. AM transmitter 1600 includes a local oscillator 1610, a summing module 1606, a switch module 1614, a filter 1618, and a transmission module 1622 that accepts an information signal 1602 and outputs a transmitted signal 1624. The operation and structure of exemplary components are described below: an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary a switch module is described below at sections 3.3.7-3.3.7.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1610, summing module 1606, switch module 1614, filter 1618, and transmission module 1622 process an information signal 1602 in the manner shown in the operational flowchart 1500. In other words, AM transmitter 1600 is the structural embodiment for performing the operational steps of flowchart 1500. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1500. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1600 will now be described in detail with reference to the flowchart 1500. In step 1502, information signal 1602 (for example, see FIG. 45A) from a source (not shown) is routed to summing module 1606 (if

required), thereby producing a reference signal 1608. In step 1508, an oscillating signal 1612 is generated by local oscillator 1610 (for example, see FIG. 45B) and in step 1510, switch module 1614 gates the reference voltage 1608 at a rate that is a function of the oscillating signal 1612. The result of the gating is a harmonically rich signal 1616 (for example, see FIG. 45C) with a continuous and periodic waveform. This waveform is preferably a rectangular wave, such as a square wave or a pulse (although, the invention is not limited to this embodiment), and is comprised of a plurality of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveform. These sinusoidal waves are referred to as the harmonics of the underlying waveform, and a Fourier analysis will determine the relative amplitude of each harmonic (for an example of the first three harmonics, see FIGs. 45D, 45E, and 45F). When amplitude modulation is applied, the amplitude of the pulses in rectangular waveform 1616 vary as a function of reference signal 1608. As a result, this change in amplitude of the pulses has a proportional effect on the absolute amplitude of all of the harmonics. In other words, the AM is embedded on top of each of the harmonics. In step 1516, a filter 1618 filters out the undesired harmonic frequencies (for example, the first harmonic 4510, the second harmonic 4512, and the fourth, fifth, etc., harmonics, not shown), and outputs an electromagnetic (EM) signal 1620 at the desired harmonic frequency (for example, the third harmonic, see FIG. 45F). In step 1520, EM signal 1620 is routed to transmission module 1622 (optional), where it is prepared for transmission. In step 1522, the transmission module 1622 outputs a transmitted signal 1624.

Note that the description of the AM embodiment given herein shows the information signal being gated, thus applying the amplitude modulation to the harmonically rich signal. However, it would be apparent based on the teachings contained herein, that the information signal can be modulated onto the harmonically rich signal or onto a filtered harmonic at any point in the circuit.

### ***3.2.4 Fourth Embodiment: In-phase/Quadrature-phase Modulation ("I/Q") Mode.***

In-phase/quadrature-phase modulation ("I/Q") is a specific subset of a phase modulation (PM) embodiment. Because "I/Q" is so pervasive, it is described herein as

a separate embodiment. However, it should be remembered that since it is a specific subset of PM, the characteristics of PM also apply to "I/Q."

In this embodiment, two information signals are accepted. An in-phase signal ("I") is modulated such that its phase varies as a function of one of the information signals, and a quadrature-phase signal ("Q") is modulated such that its phase varies as a function of the other information signal. The two modulated signals are combined to form an "I/Q" modulated signal and transmitted.

#### *3.2.4.1 Operational Description.*

The flow chart of FIG. 17 demonstrates the method of operation of the transmitter in the in-phase/quadrature-phase modulation ("I/Q") mode. In step 1702, a first information signal is generated by a first source. This information signal may be analog, digital, or any combination thereof. In step 1710, an in-phase oscillating signal (referred to as the "I" signal) is generated and in step 1704, it is modulated by the first information signal. This results in the "I" modulated signal as indicated in block 1706 wherein the phase of the "I" modulated signal is varied as a function of the first information signal.

In step 1714, a second information signal is generated. Again, this signal may be analog, digital, or any combination thereof, and may be different than the first information signal. In step 1712, the phase of "I" oscillating signal generated in step 1710 is shifted, creating a quadrature-phase oscillating signal (referred to as the "Q" signal). In step 1716, the "Q" signal is modulated by the second information signal. This results in the "Q" modulated signal as indicated in block 1718 wherein the phase of the "Q" modulated signal is varied as a function of the second information signal.

An "I" signal with a continuous periodic waveform is generated at step 1708 using the "I" modulated signal, and a "Q" signal with a continuous periodic waveform is generated at step 1720 using the "Q" modulated signal. In step 1722, the "I" periodic waveform and the "Q" periodic waveform are combined forming what is referred to as the "I/Q" periodic waveform as indicated in block 1724. As stated before, a continuous and periodic waveform, such as a "I/Q" rectangular wave as indicated in block 1724, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component

frequencies). In step 1726, the unwanted frequencies are removed, and as indicated in block 1728, the remaining frequency is at the desired EM output.

The "I/Q" EM signal is prepared for transmission in step 1730, and in step 1732, the "I/Q" EM signal is transmitted.

5

#### *3.2.4.2 Structural Description.*

FIG. 18 is a block diagram of a transmitter according to an embodiment of the invention. This embodiment of the transmitter is shown as an "I/Q" transmitter 1800. "I/Q" transmitter 1800 includes a local oscillator 1806, a phase shifter 1810, two phase modulators 1804 & 1816, two switch modules 1822 & 1828, a summer 1832, a filter 1836, and a transmission module 1840. The "I/Q" transmitter accepts two information signals 1802 & 1814 and outputs a transmitted signal 1420. The operation and structure of exemplary components are described below: an exemplary phase modulator is described below at sections 3.3.4-3.3.4.2; an exemplary local oscillator is described below at sections 3.3.2-3.3.2.2; an exemplary phase shifter is described below at sections 3.3.3-3.3.3.2; an exemplary switch module is described below at sections 3.3.6-3.3.6.2; an exemplary summer is described below at sections 3.3.8-3.3.8.2; an exemplary filter is described below at sections 3.3.9-3.3.9.2; and an exemplary transmission module is described below at sections 3.3.10-3.3.10.2.

Preferably, the local oscillator 1806, phase shifter 1810, phase modulators 1804 & 1816, switch modules 1822 & 1828, summer 1832, filter 1836, and transmission module 1840 process the information signal in the manner shown in the operational flowchart 1700. In other words, "I/Q" transmitter 1800 is the structural embodiment for performing the operational steps of flowchart 1700. However, it should be understood that the scope and spirit of the present invention includes other structural embodiments for performing the steps of flowchart 1700. The specifics of these other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the transmitter 1800 will now be described in detail with reference to the flowchart 1700. In step 1702, a first information signal 1802 from a source (not shown) is routed to the first phase modulator 1804. In step 1710, an "I" oscillating signal 1808 from local oscillator 1806 is generated and in step 1704, "I" oscillating signal 1808 is modulated by first information signal 1802 in the first phase

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modulator 1804, thereby producing an "I" modulated signal 1820. In step 1708, the first switch module 1822 generates a harmonically rich "I" signal 1824 with a continuous and periodic waveform.

5 In step 1714, a second information signal 1814 from a source (not shown) is routed to the second phase modulator 1816. In step 1712, the phase of oscillating signal 1808 is shifted by phase shifter 1810 to create "Q" oscillating signal 1812. In step 1716, "Q" oscillating signal 1812 is modulated by second information signal 1814 in the second phase modulator 1816, thereby producing "Q" modulated signal 1826. In step 1720, the second switch module 1828 generates a harmonically rich "Q" signal 1830 with a continuous and periodic waveform. Harmonically rich "I" signal 1824 and  
10 harmonically rich "Q" signal 1830 are preferably rectangular waves, such as square waves or pulses (although, the invention is not limited to this embodiment), and are comprised of pluralities of sinusoidal waves whose frequencies are integer multiples of the fundamental frequency of the waveforms. These sinusoidal waves are referred to  
15 as the harmonics of the underlying waveforms, and a Fourier analysis will determine the amplitude of each harmonic.

In step 1722, harmonically rich "I" signal 1824 and harmonically rich "Q" signal 1830 are combined by summer 1832 to create harmonically rich "I/Q" signal 1834. In step 1726, a filter 1836 filters out the undesired harmonic frequencies, and  
20 outputs an "I/Q" electromagnetic (EM) signal 1838 at the desired harmonic frequency. In step 1730, "I/Q" EM signal 1838 is routed to transmission module 1840 (optional), where it is prepared for transmission. In step 1732, the transmission module 1840 outputs a transmitted signal 1842.

25 It will be apparent to those skilled in the relevant art(s) that an alternate embodiment exists wherein the harmonically rich "I" signal 1824 and the harmonically rich "Q" signal 1830 may be filtered before they are summed, and further, another alternate embodiment exists wherein "I" modulated signal 1820 and "Q" modulated signal 1826 may be summed to create an "I/Q" modulated signal before being routed to a switch module.

### 3.2.5 Other Embodiments.

30 Other embodiments of the up-converter of the present invention being used as a transmitter (or in other applications) may use subsets and combinations of modulation

techniques, and may include modulating one or more information signals as part of the up-conversion process.

### *3.2.5.1 Combination of Modulation Techniques*

Combinations of modulation techniques that would be apparent to those skilled in the relevant art(s) based on the teachings disclosed herein include, but are not limited to, quadrature amplitude modulation (QAM), and embedding two forms of modulation onto a signal for up-conversion.

An exemplary circuit diagram illustrating the combination of two modulations is found in FIG. 62. This example uses AM combined with PM. The waveforms shown in FIGs. 63-70 illustrate the phase modulation of a digital information signal "A" 6202 combined with the amplitude modulation of an analog information signal "B" 6204. An oscillating signal 6216 (FIG. 64) and information signal "A" 6202 (FIG. 63) are received by phase modulator 1404, thereby creating a phase modulated signal 6208 (FIG. 65). Note that for illustrative purposes, and not limiting, the information signal is shown as a digital signal, and the phase modulation is shown as shifting the phase of the oscillating signal by 180°. Those skilled in the relevant art(s) will appreciate that the information signal could be analog (although typically it is digital), and that phase modulations other than 180° may also be used. FIG. 62 shows a pulse shaper 6216 receiving phase modulated signal 6208 and outputting a pulse-shaped PM signal 6210 (FIG. 66). The pulse shaper is optional, depending on the selection and design of the phase modulator 1404. Information signal "B" 6304 and bias signal 1604 (if required) are combined by summing module 1606 (optional) to create reference signal 6206 (FIG. 67). Pulse-shaped PM signal 6210 is routed to switch module 1410, 1614 where it gates the reference signal 6206 thereby producing a harmonically rich signal 6212 (FIG. 68). It can be seen that the amplitude of harmonically rich signal 6212 varies as a function of reference signal 6206, and the period and pulse width of harmonically rich signal 6212 are substantially the same as pulse-shaped PM signal 6210. FIGs. 69 and 70 only illustrate the fundamental and second harmonics of harmonically rich signal 6212. In fact, there may be an infinite number of harmonics, but for illustrative purposes (and not limiting) the first two harmonics are sufficient to illustrate that both the phase modulation and the amplitude modulation that are present on the harmonically rich signal 6212 are also present on each of the harmonics. Filter 1414,

1618 will remove the unwanted harmonics, and a desired harmonic 6214 is routed to transmission module 1418, 1622 (optional) where it is prepared for transmission. Transmission module 1418, 1622 then outputs a transmitted signal 1420, 1624. Those skilled in the relevant art(s) will appreciate that these examples are provided for illustrative purposes only and are not limiting.

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments include, but are not limited to, combinations of modulation techniques in an "I/Q" mode. Such alternate embodiments fall within the scope and spirit of the present invention.

### 3.3 *Methods and Systems for Implementing the Embodiments.*

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

#### 3.3.1 *The Voltage Controlled Oscillator (FM Mode).*

As discussed above, the frequency modulation (FM) mode embodiment of the invention uses a voltage controlled oscillator (VCO). See, as an example, VCO 1204 in FIG. 12. The invention supports numerous embodiments of the VCO. Exemplary embodiments of the VCO 2304 (FIG. 23) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

### *3.3.1.1 Operational Description.*

The information signal 2302 is accepted and an oscillating signal 2306 whose frequency varies as a function of the information signal 2302 is created. Oscillating signal 2306 is also referred to as frequency modulated intermediate signal 2306. The information signal 2302 may be analog or digital or a combination thereof, and may be conditioned to ensure it is within the desired range.

In the case where the information signal 2302 is digital, the oscillating signal 2306 may vary between discrete frequencies. For example, in a binary system, a first frequency corresponds to a digital "high," and a second frequency corresponds to a digital "low." Either frequency may correspond to the "high" or the "low," depending on the convention being used. This operation is referred to as frequency shift keying (FSK) which is a subset of FM. If the information signal 2302 is analog, the frequency of the oscillating signal 2306 will vary as a function of that analog signal, and is not limited to the subset of FSK described above.

The oscillating signal 2306 is a frequency modulated signal which can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

### *3.3.1.2 Structural Description.*

The design and use of a voltage controlled oscillator 2304 is well known to those skilled in the relevant art(s). The VCO 2304 may be designed and fabricated from discrete components, or it may be purchased "off the shelf." VCO 2304 accepts an information signal 2302 from a source. The information signal 2302 is at baseband

and generally is an electrical signal within a prescribed voltage range. If the information is digital, the voltage will be at discrete levels. If the information is analog, the voltage will be continuously variable between an upper and a lower level. The VCO 2304 uses the voltage of the information signal 2302 to cause a modulated oscillating signal 2306 to be output. The information signal 2302, because it is a baseband signal and is used to modulate the oscillating signal, may be referred to as the modulating baseband signal 2302.

The frequency of the oscillating signal 2306 varies as a function of the voltage of the modulating baseband signal 2302. If the modulating baseband signal 2302 represents digital information, the frequency of the oscillating signal 2306 will be at discrete levels. If, on the other hand, the modulating baseband signal 2302 represents analog information, the frequency of the oscillating signal 2306 will be continuously variable between its higher and lower frequency limits. The oscillating signal 2306 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The frequency modulated oscillating signal 2306 may then be used to drive a switch module 2802.

### 3.3.2 The Local Oscillator (PM, AM, and "I/Q" Modes).

As discussed above, the phase modulation (PM) and amplitude modulation (AM) mode embodiments of the invention use a local oscillator. So too does the in-phase/quadrature-phase modulation ("I/Q") mode embodiment. See, as an example, local oscillator 1406 in FIG. 14, local oscillator 1610 in FIG. 16, and local oscillator 1806 in FIG. 18. The invention supports numerous embodiments of the local oscillator. Exemplary embodiments of the local oscillator 2402 (FIG. 24) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### 3.3.2.1 Operational Description.

An oscillating signal 2404 is generated. The frequency of the signal 2404 may be selectable, but generally is not considered to be "variable." That is, the frequency may be selected to be a specific value for a specific implementation, but generally it

does not vary as a function of the information signal 2302 (i.e., the modulating baseband signal).

The oscillating signal 2404 generally is a sinusoidal wave, but it may also be a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

### 3.3.2.2 Structural Description.

The design and use of a local oscillator 2402 is well known to those skilled in the relevant art(s). A local oscillator 2402 may be designed and fabricated from discrete components or it may be purchased "off the shelf." A local oscillator 2402 is generally set to output a specific frequency. The output can be "fixed" or it can be "selectable," based on the design of the circuit. If it is fixed, the output is considered to be substantially a fixed frequency that cannot be changed. If the output frequency is selectable, the design of the circuit will allow a control signal to be applied to the local oscillator 2402 to change the frequency for different applications. However, the output frequency of a local oscillator 2402 is not considered to be "variable" as a function of an information signal 2302 such as the modulating baseband signal 2302. (If it were desired for the output frequency of an oscillator to be variable as a function of an information signal, a VCO would preferably be used.) The oscillating signal 2404 generally is a sinusoidal wave, but it may also be a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The output of a local oscillator 2402 may be an input to other circuit components such as a phase modulator 2606, a phase shifting circuit 2504, switch module 3102, etc.

### 3.3.3 The Phase Shifter ( "I/Q" Mode).

As discussed above, the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a phase shifter. See, as an example, phase shifter 1810 in FIG. 18. The invention supports numerous embodiments of the phase shifter. Exemplary embodiments of the phase shifter 2504 (FIG. 25) are described below. The invention is not limited to these embodiments. The description contained herein is for a "90° phase shifter." The 90° phase shifter is used for ease of explanation, and one skilled in the relevant art(s) will understand that other phase shifts can be used without departing from the intent of the present invention.

#### 3.3.3.1 Operational Description.

An "in-phase" oscillating signal 2502 is received and a "quadrature-phase" oscillating signal 2506 is output. If the in-phase ("I") signal 2502 is referred to as being a sine wave, then the quadrature-phase ("Q") signal 2506 can be referred to as being a cosine wave (i.e., the "Q" signal 2506 is 90° out of phase with the "I" signal 2502). However, they may also be rectangular waves, triangular waves, pulses, or any other continuous and periodic waveforms. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed. Regardless of the shapes of the waveforms, the "Q" signal 2506 is out of phase with the "I" signal 2506 by one-quarter period of the waveform. The frequency of the "I" and "Q" signals 2502 and 2506 are substantially equal.

The discussion contained herein will be confined to the more prevalent embodiment wherein there are two intermediate signals separated by 90°. This is not limiting on the invention. It will be apparent to those skilled in the relevant art(s) that

the techniques taught herein and applied to the "I/Q" embodiment of the present invention also apply to more exotic embodiments wherein the intermediate signals are shifted by some amount other than 90°, and also wherein there may be more than two intermediate frequencies.

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### *3.3.3.2 Structural Description.*

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The design and use of a phase shifter 2504 is well known to those skilled in the relevant art(s). A phase shifter 2504 may be designed and fabricated from discrete components or it may be purchased "off the shelf." A phase shifter accepts an "in-phase" ("I") oscillating signal 2502 from any of a number of sources, such as a VCO 2304 or a local oscillator 2402, and outputs a "quadrature-phase" ("Q") oscillating signal 2506 that is substantially the same frequency and substantially the same shape as the incoming "I" signal 2502, but with the phase shifted by 90°. Both the "I" and "Q" signals 2502 and 2506 are generally sinusoidal waves, but they may also be rectangular waves, triangular waves, pulses, or any other continuous and periodic waveforms. Regardless of the shapes of the waveforms, the "Q" signal 2506 is out of phase with the "I" signal 2502 by one-quarter period of the waveform. Both the "I" and "Q" signals 2502 and 2506 may be modulated.

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The output of a phase shifter 2504 may be used as an input to a phase modulator 2606.

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### *3.3.4 The Phase Modulator (PM and "I/Q" Modes).*

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As discussed above, the phase modulation (PM) mode embodiment including the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a phase modulator. See, as an example, phase modulator 1404 of FIG. 14 and phase modulators 1804 and 1816 of FIG. 18. The invention supports numerous embodiments of the phase modulator. Exemplary embodiments of the phase modulator 2606 (FIG. 26) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### *3.3.4.1 Operational Description.*

An information signal 2602 and an oscillating signal 2604 are accepted, and a phase modulated oscillating signal 2608 whose phase varies as a function of the information signal 2602 is output. The information signal 2602 may be analog or digital and may be conditioned to ensure it is within the desired range. The oscillating signal 2604 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed. The modulated oscillating signal 2608 is also referred to as the modulated intermediate signal 2608.

In the case where the information signal 2602 is digital, the modulated intermediate signal 2608 will shift phase between discrete values, the first phase (e.g., for a signal represented by  $\sin(\omega t + \theta_0)$ ) corresponding to a digital "high," and the second phase (e.g., for a signal represented by  $\sin(\omega t + \theta_0 + \delta)$ , where  $\delta$  represents the amount the phase has been shifted) corresponding to a digital "low." Either phase may correspond to the "high" or the "low," depending on the convention being used. This operation is referred to as phase shift keying (PSK) which is a subset of PM.

If the information signal 2602 is analog, the phase of the modulated intermediate signal 2608 will vary as a function of the information signal 2602 and is not limited to the subset of PSK described above.

The modulated intermediate signal 2608 is a phase modulated signal which can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform, and which has substantially the same period as the oscillating signal 2604.

#### *3.3.4.2 Structural Description.*

The design and use of a phase modulator 2606 is well known to those skilled in the relevant art(s). A phase modulator 2606 may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A phase modulator 2606 accepts an information signal 2602 from a source and an oscillating signal 2604 from a local oscillator 2402 or a phase shifter 2504. The information signal 2602 is at baseband and is generally an electrical signal within a prescribed voltage range. If the information is digital, the voltage will be at discrete levels. If the information is analog, the voltage will be continuously variable between an upper and a lower level as a function of the information signal 2602. The phase modulator 2606 uses the voltage of the information signal 2602 to modulate the oscillating signal 2604 and causes a modulated intermediate signal 2608 to be output. The information signal 2602, because it is a baseband signal and is used to modulate the oscillating signal, may be referred to as the modulating baseband signal 2604.

The modulated intermediate signal 2608 is an oscillating signal whose phase varies as a function of the voltage of the modulating baseband signal 2602. If the modulating baseband signal 2602 represents digital information, the phase of the modulated intermediate signal 2608 will shift by a discrete amount (e.g., the modulated intermediate signal 2608 will shift by an amount  $\delta$  between  $\sin(\omega t + \theta_0)$  and  $\sin(\omega t + \theta_0 + \delta)$ ). If, on the other hand, the modulating baseband signal 2602 represents analog information, the phase of the modulated intermediate signal 2608 will continuously shift between its higher and lower phase limits as a function of the information signal 2602. In one exemplary embodiment, the upper and lower limits of the modulated intermediate signal 2608 can be represented as  $\sin(\omega t + \theta_0)$  and  $\sin(\omega t + \theta_0 + \pi)$ . In other embodiments, the range of the phase shift may be less than  $\pi$ . The modulated intermediate signal 2608 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform.

The phase modulated intermediate signal 2608 may then be used to drive a switch module 2802.

### 3.3.5 The Summing Module (AM Mode).

As discussed above, the amplitude modulation (AM) mode embodiment of the invention uses a summing module. See, as an example, summing module 1606 in FIG.16. The invention supports numerous embodiments of the summing module.

Exemplary embodiments of the summing module 2706 (FIG. 27) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. It may also be used in the "I/Q" mode embodiment when the modulation is AM. The summing module 2706 need not be used in all AM embodiments.

#### *3.3.5.1 Operational Description.*

An information signal 2702 and a bias signal 2702 are accepted, and a reference signal is output. The information signal 2702 may be analog or digital and may be conditioned to ensure it is within the proper range so as not to damage any of the circuit components. The bias signal 2704 is usually a direct current (DC) signal.

In the case where the information signal 2702 is digital, the reference signal 2706 shifts between discrete values, the first value corresponding to a digital "high," and the second value corresponding to a digital "low." Either value may correspond to the "high" or the "low," depending on the convention being used. This operation is referred to as amplitude shift keying (ASK) which is a subset of AM.

If the information signal 2702 is analog, the value of the reference signal 2708 will vary linearly between upper and lower extremes which correspond to the upper and lower limits of the information signal 2702. Again, either extreme of the reference signal 2708 range may correspond to the upper or lower limit of the information signal 2702 depending on the convention being used.

The reference signal 2708 is a digital or analog signal and is substantially proportional to the information signal 2702.

#### *3.3.5.2 Structural Description.*

The design and use of a summing module 2706 is well known to those skilled in the relevant art(s). A summing module 2706 may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A summing module 2706 accepts an information signal 2702 from a source. The information signal 2702 is at baseband and generally is an electrical signal within a prescribed voltage range. If the information is digital, the information signal 2702 is at either of two discrete levels. If the information is analog, the information signal 2702 is continuously variable between

an upper and a lower level. The summing module 2706 uses the voltage of the information signal 2702 and combines it with a bias signal 2704. The output of the summing module 2706 is called the reference signal 2708. The purpose of the summing module 2706 is to cause the reference signal 2708 to be within a desired signal range. One skilled in the relevant art(s) will recognize that the information signal 2702 may be used directly, without being summed with a bias signal 2704, if it is already within the desired range. The information signal 2702 is a baseband signal, but typically, in an AM embodiment, it is not used to directly modulate an oscillating signal. The amplitude of the reference signal 2708 is at discrete levels if the information signal 2702 represents digital information. On the other hand, the amplitude of the reference signal 2708 is continuously variable between its higher and lower limits if the information signal 2702 represents analog information. The amplitude of the reference signal 2708 is substantially proportional to the information signal 2702, however, a positive reference signal 2708 need not represent a positive information signal 2702.

The reference signal 2708 is routed to the first input 3108 of a switch module 3102. In one exemplary embodiment, a resistor 2824 is connected between the output of the summing module 2706 (or the source of the information signal 2702 in the embodiment wherein the summing amplifier 2706 is not used) and the switch 3116 of the switch module 3102.

### 3.3.6 The Switch Module (FM, PM, and "I/Q" Modes).

As discussed above, the frequency modulation (FM), phase modulation (PM), and the in-phase/quadrature-phase modulation ("I/Q") mode embodiments of the invention use a switching assembly referred to as switch module 2802 (FIGs. 28A-28C). As an example, switch module 2802 is a component in switch module 1214 in FIG. 12, switch module 1410 in FIG. 14, and switch modules 1822 and 1828 in FIG. 18. The invention supports numerous embodiments of the switch module. Exemplary embodiments of the switch module 2802 are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. The switch module 2802 and its operation in the FM, PM, and "I/Q" mode embodiments is substantially the same as its operation in the AM mode embodiment, described in sections 3.3.7-3.3.7.2 below.

### 3.3.6.1 Operational Description.

A bias signal 2806 is gated as a result of the application of a modulated oscillating signal 2804, and a signal with a harmonically rich waveform 2814 is created. The bias signal 2806 is generally a fixed voltage. The modulated oscillating signal 2804 can be frequency modulated, phase modulated, or any other modulation scheme or combination thereof. In certain embodiments, such as in certain amplitude shift keying modes, the modulated oscillating signal 2804 may also be amplitude modulated. The modulated oscillating signal 2804 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, modulated oscillating signal 2804 would be a rectangular wave. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

The signal with harmonically rich waveform 2814, hereafter referred to as the harmonically rich signal 2814, is a continuous and periodic waveform that is modulated substantially the same as the modulated oscillating signal 2804. That is, if the modulated oscillating signal 2804 is frequency modulated, the harmonically rich signal 2814 will also be frequency modulated, and if the modulated oscillating signal 2804 is phase modulated, the harmonically rich signal 2814 will also be phase modulated. (In one embodiment, the harmonically rich signal 2814 is a substantially rectangular waveform.) As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich signal 2814 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself.

### 3.3.6.2 Structural Description.

The switch module 2802 of an embodiment of the present invention is comprised of a first input 2808, a second input 2810, a control input 2820, an output 2822, and a switch 2816. A bias signal 2806 is applied to the first input 2808 of the switch module 2802. Generally, the bias signal 2806 is a fixed voltage, and in one embodiment of the invention, a resistor 2824 is located between the bias signal 2806 and the switch 2816. The second input 2810 of the switch module 2802 is generally at electrical ground 2812. However, one skilled in the relevant art(s) will recognize that alternative embodiments exist wherein the second input 2810 may not be at electrical ground 2812, but rather a second signal 2818, provided that the second signal 2818 is different than the bias signal 2806.

A modulated oscillating signal 2804 is connected to the control input 2820 of the switch module 2802. The modulated oscillating signal 2804 may be frequency modulated or phase modulated. (In some circumstances and embodiments, it may be amplitude modulated, such as in on/off keying, but this is not the general case, and will not be described herein.) The modulated oscillating signal 2804 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. The modulated oscillating signal 2804 causes the switch 2816 to close and open.

The harmonically rich signal 2814 described in section 3.3.6.1 above, is found at the output 2822 of the switch module 2802. The harmonically rich signal 2814 is a continuous and periodic waveform that is modulated substantially the same as the modulated oscillating signal 2804. That is, if the modulated oscillating signal 2804 is frequency modulated, the harmonically rich signal 2814 will also be frequency modulated, and if the modulated oscillating signal 2804 is phase modulated, the harmonically rich signal 2814 will also be phase modulated. In one embodiment, the harmonically rich signal 2814 has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich signal 2814 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. Each of these sinusoidal

signals is also modulated substantially the same as the continuous and periodic waveform (i.e., the modulated oscillating signal 2804) from which it is derived.

The switch module 2802 operates as follows. When the switch 2816 is "open," the output 2822 of switch module 2802 is at substantially the same voltage level as bias signal 2806. Thus, since the harmonically rich signal 2814 is connected directly to the output 2822 of switch module 2802, the amplitude of harmonically rich signal 2814 is equal to the amplitude of the bias signal 2806. When the modulated oscillating signal 2804 causes the switch 2816 to become "closed," the output 2822 of switch module 2802 becomes connected electrically to the second input 2810 of switch module 2802 (e.g., ground 2812 in one embodiment of the invention), and the amplitude of the harmonically rich signal 2814 becomes equal to the potential present at the second input 2810 (e.g., zero volts for the embodiment wherein the second input 2810 is connected to electrical ground 2812). When the modulated oscillating signal 2804 causes the switch 2816 to again become "open," the amplitude of the harmonically rich signal 2814 again becomes equal to the bias signal 2806. Thus, the amplitude of the harmonically rich signal 2814 is at either of two signal levels, i.e., bias signal 2806 or ground 2812, and has a frequency that is substantially equal to the frequency of the modulated oscillating signal 2804 that causes the switch 2816 to open and close. The harmonically rich signal 2814 is modulated substantially the same as the modulated oscillating signal 2804. One skilled in the relevant art(s) will recognize that any one of a number of switch designs will fulfill the scope and spirit of the present invention as described herein.

In an embodiment of the invention, the switch 2816 is a semiconductor device, such as a diode ring. In another embodiment, the switch is a transistor, such as a field effect transistor (FET). In an embodiment wherein the FET is gallium arsenide (GaAs), switch module 2802 can be designed as seen in FIGs. 29A-29C, where the modulated oscillating signal 2804 is connected to the gate 2902 of the GaAs FET 2901, the bias signal 2806 is connected through a bias resistor 2824 to the source 2904 of the GaAs FET 2901, and electrical ground 2812 is connected to the drain 2906 of GaAs FET 2901. (In an alternate embodiment shown in FIG. 29C, a second signal 2818 may be connected to the drain 2906 of GaAs FET 2901.) Since the drain and the source of GaAs FETs are interchangeable, the bias signal 2806 can be applied to either the source 2904 or to the drain 2906. If there is concern that there might be some source-drain asymmetry in the GaAs FET, the switch module can be designed as shown in

FIGs. 30A-30C, wherein two GaAs FETs 3002 and 3004 are connected together, with the source 3010 of the first 3002 connected to the drain 3012 of the second 3004, and the drain 3006 of the first 3002 being connected to the source 3008 of the second 3004. This design arrangement will balance substantially all asymmetries.

5           An alternate implementation of the design includes a "dwell capacitor" wherein one side of a capacitor is connected to the first input of the switch and the other side of the capacitor is connected to the second input of the switch. The purpose of the design is to increase the apparent aperture of the pulse without actually increasing its width. Other switch designs and implementations will be apparent to persons skilled in the  
10           relevant art(s).

          The output 2822 of the switch module 2802, i.e., the harmonically rich signal 2814, can be routed to a filter 3504 in the FM and PM modes or to a Summer 3402 in the "I/Q" mode.

### 3.3.7   *The Switch Module (AM Mode).*

15           As discussed above, the amplitude modulation (AM) mode embodiment of the invention uses a switching assembly referred to as switch module 3102 (FIGs. 31A-31C). As an example, switch module 3102 is a component in switch module 1614 of FIG. 16. The invention supports numerous embodiments of the switch module. Exemplary embodiments of the switch module 3102 are described below. However, it  
20           should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments. The switch module 3102 and its operation in the AM mode embodiment is substantially the same as its operation in the FM, PM, and "I/Q" mode embodiments described in sections 3.3.6-3.3.6.2 above.

#### 3.3.7.1   *Operational Description.*

25           A reference signal 3106 is gated as a result of the application of an oscillating signal 3104, and a signal with a harmonically rich waveform 3114 is created. The reference signal 3106 is a function of the information signal 2702 and may, for example, be either the summation of the information signal 2702 with a bias signal 2704 or it may be the information signal 2702 by itself. In the AM mode, the  
30           oscillating signal 3104 is generally not modulated, but can be.

The oscillating signal 3104 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed. Again, as stated above, for ease of discussion, the term "rectangular waveform" will be used to refer to waveforms that are substantially rectangular, the term "square wave" will refer to those waveforms that are substantially square, the term "triangular wave" will refer to those waveforms that are substantially triangular, and the term "pulse" will refer to those waveforms that are substantially a pulse, and it is not the intent of the present invention that a perfect square wave, triangle wave, or pulse be generated or needed.

The signal with a harmonically rich waveform 3114, hereafter referred to as the harmonically rich signal 3114, is a continuous and periodic waveform whose amplitude is a function of the reference signal. That is, it is an AM signal. In one embodiment, the harmonically rich signal 3114 has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave, will have sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich signal 3114 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself.

Those skilled in the relevant art(s) will recognize that alternative embodiments exist wherein combinations of modulations (e.g., PM and ASK, FM and AM, etc.) may be employed simultaneously. In these alternate embodiments, the oscillating signal 3104 may be modulated. These alternate embodiments will be apparent to persons skilled in the relevant art(s), and thus will not be described herein.

### *3.3.7.2 Structural Description.*

The switch module 3102 of the present invention is comprised of a first input 3108, a second input 3110, a control input 3120, an output 3122, and a switch 3116. A reference signal 3106 is applied to the first input 3108 of the switch module 3102. Generally, the reference signal 3106 is a function of the information signal 2702, and may either be the summation of the information signal 2702 with a bias signal or it

may be the information signal 2702 by itself. In one embodiment of the invention, a resistor 3124 is located between the reference signal 3106 and the switch 3116. The second input 3110 of the switch module 3102 is generally at electrical ground 3112, however, one skilled in the relevant art(s) will recognize that alternative embodiments exist wherein the second input 3110 may not be at electrical ground 3112, but rather connected to a second signal 3118. In an alternate embodiment, the inverted value of the reference signal 3106 is connected to the second input 3110 of the switch module 3102.

An oscillating signal 3104 is connected to the control input 3120 of the switch module 3102. Generally, in the AM mode, the oscillating signal 3104 is not modulated, but a person skilled in the relevant art(s) will recognize that there are embodiments wherein the oscillating signal 3104 may be frequency modulated or phase modulated, but these will not be described herein. The oscillating signal 3104 can be a sinusoidal wave, a rectangular wave, a triangular wave, a pulse, or any other continuous and periodic waveform. In a preferred embodiment, it would be a rectangular wave. The oscillating signal 3104 causes the switch 3116 to close and open.

The harmonically rich signal 3114 described in section 3.3.7.1 above is found at the output 3122 of the switch module 3102. The harmonically rich signal 3114 is a continuous and periodic waveform whose amplitude is a function of the amplitude of the reference signal. In one embodiment, the harmonically rich signal 3114 has a substantially rectangular waveform. As stated before, a continuous and periodic waveform, such as a rectangular wave, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich signal 3114 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. As previously described, the relative amplitude of the harmonics of a continuous periodic waveform is generally a function of the ratio of the pulse width of the rectangular wave and the period of the fundamental frequency, and can be determined by doing a Fourier analysis of the periodic waveform. When the amplitude of the periodic waveform varies, as in the AM mode of the invention, the change in amplitude of the periodic waveform has a proportional effect on the absolute amplitude of the harmonics. In other words, the AM is embedded on top of each of the harmonics.

The description of the switch module 3102 is substantially as follows: When the switch 3116 is "open," the amplitude of the harmonically rich signal 3114 is substantially equal to the reference signal 3106. When the oscillating signal 3104 causes the switch 3116 to become "closed," the output 3122 of the switch module 3102 becomes connected electrically to the second input 3110 of the switch module 3102 (e.g., ground 3112 in one embodiment), and the amplitude of the harmonically rich signal 3114 becomes equal to the value of the second input 3110 (e.g., zero volts for the embodiment wherein the second input 3110 is connected to electrical ground 3112). When the oscillating signal 3104 causes the switch 3116 to again become "open," the amplitude of the harmonically rich signal 3114 again becomes substantially equal to the reference signal 3106. Thus, the amplitude of the harmonically rich signal 3114 is at either of two signal levels, i.e., reference signal 3106 or ground 3112, and has a frequency that is substantially equal to the frequency of the oscillating signal 3104 that causes the switch 3116 to open and close. In an alternate embodiment wherein the second input 3110 is connected to the second signal 3118, the harmonically rich signal 3114 varies between the reference signal 3106 and the second signal 3118. One skilled in the relevant art(s) will recognize that any one of a number of switch module designs will fulfill the scope and spirit of the present invention.

In an embodiment of the invention, the switch 3116 is a semiconductor device, such as a diode ring. In another embodiment, the switch is a transistor, such as, but not limited to, a field effect transistor (FET). In an embodiment wherein the FET is gallium arsenide (GaAs), the module can be designed as seen in FIGs. 32A-32C, where the oscillating signal 3104 is connected to the gate 3202 of the GaAs FET 3201, the reference signal 3106 is connected to the source 3204, and electrical ground 3112 is connected to the drain 3206 (in the embodiment where ground 3112 is selected as the value of the second input 3110 of the switch module 3102). Since the drain and the source of GaAs FETs are interchangeable, the reference signal 3106 can be applied to either the source 3204 or to the drain 3206. If there is concern that there might be some source-drain asymmetry in the GaAs FET 3201, the switch 3116 can be designed as shown in FIGs. 33A-33C, wherein two GaAs FETs 3302 and 3304 are connected together, with the source 3310 of the first 3302 connected to the drain 3312 of the second 3304, and the drain 3306 of the first 3302 being connected to the source 3308 of the second 3304. This design arrangement will substantially balance all asymmetries.

An alternate implementation of the design includes a "dwell capacitor" wherein one side of a capacitor is connected to the first input of the switch and the other side of the capacitor is connected to the second input of the switch. The purpose of the design is to increase the apparent aperture of the pulse without actually increasing its width. Other switch designs and implementations will be apparent to persons skilled in the relevant art(s).

The output 3122 of the switch module 3102, i.e., the harmonically rich signal 3114, can be routed to a filter 3504 in the AM mode.

### *3.3.8 The Summer ("I/Q" Mode).*

As discussed above, the in-phase/quadrature-phase modulation ("I/Q") mode embodiment of the invention uses a summer. See, as an example, summer 1832 in FIG. 18. The invention supports numerous embodiments of the summer. Exemplary embodiments of the summer 3402 (FIG. 34) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### *3.3.8.1 Operational Description.*

An "I" modulated signal 3404 and a "Q" modulated signal 3406 are combined and an "I/Q" modulated signal 3408 is generated. Generally, both "I" and "Q" modulated signals 3404 and 3406 are harmonically rich waveforms, which are referred to as the harmonically rich "I" signal 3404 and the harmonically rich "Q" signal 3406. Similarly, "I/Q" modulated signal 3408 is harmonically rich and is referred to as the harmonically rich "I/Q" signal. In one embodiment, these harmonically rich signals have substantially rectangular waveforms. As stated above, one skilled in the relevant art(s) will recognize the physical limitations to and mathematical obstacles against achieving exact or perfect waveforms and it is not the intent of the present invention that a perfect waveform be generated or needed.

In a typical embodiment, the harmonically rich "I" signal 3404 and the harmonically rich "Q" signal 3406 are phase modulated, as is the harmonically rich "I/Q" signal 3408. A person skilled in the relevant art(s) will recognize that other

modulation techniques, such as amplitude modulating the "I/Q" signal, may also be used in the "I/Q" mode without deviating from the scope and spirit of the invention.

As stated before, a continuous and periodic waveform, such as harmonically rich "I/Q" signal 3408, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, harmonically rich "I/Q" signal 3408 is composed of sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. These sinusoidal signals are also modulated substantially the same as the continuous and periodic waveform from which they are derived. That is, in this embodiment, the sinusoidal signals are phase modulated, and include the information from both the "I" modulated signal and the "Q" modulated signal.

### *3.3.8.2 Structural Description.*

The design and use of a summer 3402 is well known to those skilled in the relevant art(s). A summer 3402 may be designed and fabricated from discrete components, or it may be purchased "off the shelf." A summer 3402 accepts a harmonically rich "I" signal 3404 and a harmonically rich "Q" signal 3406, and combines them to create a harmonically rich "I/Q" signal 3408. In a preferred embodiment of the invention, the harmonically rich "I" signal 3404 and the harmonically rich "Q" signal 3406 are both phase modulated. When the harmonically rich "I" signal 3404 and the harmonically rich "Q" signal 3406 are both phase modulated, the harmonically rich "I/Q" signal 3408 is also phase modulated.

As stated before, a continuous and periodic waveform, such as the harmonically rich "I/Q" signal 3408, has sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform (the Fourier component frequencies). Thus, the harmonically rich "I/Q" signal 3408 is composed of "I/Q" sinusoidal signals at frequencies that are integer multiples of the fundamental frequency of itself. These "I/Q" sinusoidal signals are also phase modulated substantially the same as the continuous and periodic waveform from which they are derived (i.e., the harmonically rich "I/Q" signal 3408).

The output of the summer 3402 is then routed to a filter 3504.

### 3.3.9 The Filter (FM, PM, AM, and "I/Q" Modes).

As discussed above, all modulation mode embodiments of the invention use a filter. See, as an example, filter 1218 in FIG. 12, filter 1414 in FIG. 14, filter 1618 in FIG. 16, and filter 1836 in FIG. 18. The invention supports numerous embodiments of the filter. Exemplary embodiments of the filter 3504 (FIG. 35) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### 3.3.9.1 Operational Description.

A modulated signal with a harmonically rich waveform 3502 is accepted. It is referred to as the harmonically rich signal 3502. As stated above, a continuous and periodic waveform, such as the harmonically rich signal 3502, is comprised of sinusoidal components (harmonics) at frequencies that are integer multiples of the fundamental frequency of the underlying waveform from which they are derived. These are called the Fourier component frequencies. In one embodiment of the invention, the undesired harmonic frequencies are removed, and the desired frequency 3506 is output. In an alternate embodiment, a plurality of harmonic frequencies are output.

The harmonic components of the harmonically rich signal 3502 are modulated in the same manner as the harmonically rich signal 3502 itself. That is, if the harmonically rich signal 3502 is frequency modulated, all of the harmonic components of that signal are also frequency modulated. The same is true for phase modulation, amplitude modulation, and "I/Q" modulation.

#### 3.3.9.2 Structural Description.

The design and use of a filter 3504 is well known to those skilled in the relevant art(s). A filter 3504 may be designed and fabricated from discrete components or it may be purchased "off the shelf." The filter 3504 accepts the harmonically rich signal 3502 from the switch module 2802 or 3102 in the FM, PM, and AM modes, and from the summer 3402 in the "I/Q" mode. The harmonically rich signal 3502 is a continuous and periodic waveform. As such, it is comprised of sinusoidal components

(harmonics) that are at frequencies that are integer multiples of the fundamental frequency of the underlying harmonically rich signal 3502. The filter 3504 removes those sinusoidal signals having undesired frequencies. The signal 3506 that remains is at the desired frequency, and is called the desired output signal 3506.

5 To achieve this result, according to an embodiment of the invention, a filter 3504 is required to filter out the unwanted harmonics of the harmonically rich signal 3502.

10 The term "Q" is used to represent the ratio of the center frequency of the desired output signal 3506 to the half power band width. Looking at FIG. 36 we see a desired frequency 3602 of 900 MHz. The filter 3504 is used to ensure that only the energy at that frequency 3602 is transmitted. Thus, the bandwidth 3604 at half power (the so-called "3 dB down" point) should be as narrow as possible. The ratio of frequency 3602 to bandwidth 3604 is defined as "Q." As shown on FIG. 36, if the "3 dB down" point is at plus or minus 15 MHz, the value of Q will be  $900/(15+15)$  or 30.

15 With the proper selection of elements for any particular frequency, Qs on the order of 20 or 30 are achievable.

For crisp broadcast frequencies, it is desired that Q be as high as possible and practical, based on the given application and environment. The purpose of the filter 3504 is to filter out the unwanted harmonics of the harmonically rich signal. The circuits are tuned to eliminate all other harmonics except for the desired frequency 3506 (e.g., the 900 MHz harmonic 3602). Turning now to FIGs. 37A and 37B, we see examples of filter circuits. One skilled in the relevant art(s) will recognize that a number of filter designs will accomplish the desired goal of passing the desired frequency while filtering the undesired frequencies.

25 FIG. 37A illustrates a circuit having a capacitor in parallel with an inductor and shunted to ground. In FIG. 37B, a capacitor is in series with an inductor, and a parallel circuit similar to that in FIG. 37A is connected between the capacitor and inductor and shunted to ground.

30 The modulated signal at the desired frequency 3506 may then be routed to the transmission module 3804.

### 3.3.10 The Transmission Module (FM, PM, AM, and "I/Q" Modes).

As discussed above, the modulation mode embodiments of the invention preferably use a transmission module. See, as an example, transmission module 1222 in FIG. 12, transmission module 1418 in FIG. 14, transmission module 1622 in FIG. 16, and transmission module 1840 in FIG. 18. The transmission module is optional, and other embodiments may not include a transmission module. The invention supports numerous embodiments of the transmission module. Exemplary embodiments of the transmission module 3804 (FIG. 38) are described below. However, it should be understood that these examples are provided for illustrative purposes only. The invention is not limited to these embodiments.

#### *3.3.10.1 Operational Description.*

A modulated signal at the desired frequency 3802 is accepted and is transmitted over the desired medium, such as, but not limited to, over-the-air broadcast or point-to-point cable.

#### *3.3.10.2 Structural Description.*

The transmission module 3804 receives the signal at the desired EM frequency 3802. If it is intended to be broadcast over the air, the signal may be routed through an optional antenna interface and then to the antenna for broadcast. If it is intended for the signal to be transmitted over a cable from one point to another, the signal may be routed to an optional line driver and out through the cable. One skilled in the relevant art(s) will recognize that other transmission media may be used.

#### *3.3.11 Other Implementations.*

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Other implementation embodiments are possible and covered by the invention, such as but not limited to software, software/hardware, and firmware implementations of the systems and components of the invention. Alternate implementations and embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled

in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

#### 4. *Harmonic Enhancement.*

##### 4.1 *High Level Description.*

5 This section (including its subsections) provides a high-level description of harmonic enhancement according to the present invention. In particular, pulse shaping is described at a high-level. Also, a structural implementation for achieving this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this  
10 section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

15 It is noted that some embodiments of the invention include harmonic enhancement, whereas other embodiments do not.

##### 4.1.1 *Operational Description.*

To better understand the generation and extraction of harmonics, and the purpose behind shaping the waveforms to enhance the harmonics, the following discussion of Fourier analysis as it applies to the present invention is offered.

20 A discovery made by Baron Jean B. J. Fourier (1768-1830) showed that continuous and periodic waveforms are comprised of a plurality of sinusoidal components, called harmonics. More importantly, the frequency of these components are integer multiples of the frequency of the original waveform (called the fundamental frequency). The amplitude of each of these component waveforms depends on the  
25 shape of the original waveform. The derivations and proofs of Baron Fourier's analysis are well known to those skilled in the relevant art(s).

The most basic waveform which is continuous and periodic is a sine wave. It has but one harmonic, which is at the fundamental frequency. This is also called the first harmonic. Since it only has one component, the amplitude of the harmonic

component is equal to the amplitude of the original waveform, i.e., the sine wave itself. The sine wave is not considered to be "harmonically rich."

An impulse train is the other extreme case of a periodic waveform. Mathematically, it is considered to have zero width. The mathematical analysis in this case shows that there are harmonics at all multiples of the frequency of the impulse. That is, if the impulse has a frequency of  $F_r$ , then the harmonics are sinusoidal waves at  $1 \cdot F_r$ ,  $2 \cdot F_r$ ,  $3 \cdot F_r$ ,  $4 \cdot F_r$ , etc. As the analysis also shows in this particular case, the amplitude of all of the harmonics are equal. This is indeed, a "harmonically rich" waveform, but is realistically impractical with current technology.

A more typical waveform is a rectangular wave, which is a series of pulses. Each pulse will have a width (called a pulse width, or " $\tau$ "), and the series of pulses in the waveform will have a period (" $T$ " which is the inverse of the frequency, i.e.,  $T=1/F_r$ , where " $F_r$ " is the fundamental frequency of the rectangular wave). One form of rectangular wave is the square wave, where the signal is at a first state (e.g., high) for the same amount of time that it is at the second state (e.g., low). That is, the ratio of the pulse width to period ( $\tau/T$ ) is 0.5. Other forms of rectangular waves, other than square waves, are typically referred to simply as "pulses," and have  $\tau/T < 0.5$  (i.e., the signal will be "high" for a shorter time than it is "low"). The mathematical analysis shows that there are harmonics at all of the multiples of the fundamental frequency of the signal. Thus, if the frequency of the rectangular waveform is  $F_r$ , then the frequency of the first harmonic is  $1 \cdot F_r$ , the frequency of the second harmonic is  $2 \cdot F_r$ , the frequency of the third harmonic is  $3 \cdot F_r$ , and so on. There are some harmonics for which the amplitude is zero. In the case of a square wave, for example, the "null points" are the even harmonics. For other values of  $\tau/T$ , the "null points" can be determined from the mathematical equations. The general equation for the amplitude of the harmonics in a rectangular wave having an amplitude of  $A_{\text{pulse}}$  is as follows:

$$\text{Amplitude}(n^{\text{th}} \text{ harmonic}) = A_r = \{[A_{\text{pulse}}][(2/\pi)/n]\sin[n \cdot \pi \cdot (\tau/T)]\} \quad \text{Eq. 1}$$

Table 6000 of FIG. 60 shows the amplitudes of the first fifty harmonics for rectangular waves having six different  $\tau/T$  ratios. The  $\tau/T$  ratios are 0.5 (a square wave), 0.25, 0.10, 0.05, 0.01, and 0.005. (One skilled in the relevant art(s) will recognize that  $A_{\text{pulse}}$  is set to unity for mathematical comparison.) From this limited example, it can be seen that the ratio of pulse width to period is a significant factor in determining the relative

amplitudes of the harmonics. Notice too, that for the case where  $\tau/T=0.5$  (i.e., a square wave), the relationship stated above (i.e., only odd harmonics are present) holds. Note that as  $\tau/T$  becomes small (i.e., the pulse approaches an impulse), the amplitudes of the harmonics becomes substantially "flat." That is, there is very little decrease in the relative amplitudes of the harmonics. One skilled in the relevant art(s) will understand how to select the desired pulse width for any given application based on the teachings contained herein. It can also be shown mathematically and experimentally that if a signal with a continuous and periodic waveform is modulated, that modulation is also present on every harmonic of the original waveform.

From the foregoing, it can be seen how pulse width is an important factor in assuring that the harmonic waveform at the desired output frequency has sufficient amplitude to be useful without requiring elaborate filtering or unnecessary amplification.

Another factor in assuring that the desired harmonic has sufficient amplitude is how the switch 2816 and 3116 (FIGs. 28A and 31A) in the switch module 2802 and 3102 responds to the control signal that causes the switch to close and to open (i.e., the modulated oscillating signal 2804 of FIG. 28 and the oscillating signal 3104 of FIG. 31). In general, switches have two thresholds. In the case of a switch that is normally open, the first threshold is the voltage required to cause the switch to close. The second threshold is the voltage level at which the switch will again open. The convention used herein for ease of illustration and discussion (and not meant to be limiting) is for the case where the switch is closed when the control signal is high, and open when the control signal is low. It would be apparent to one skilled in the relevant art(s) that the inverse could also be used. Typically, these voltages are not identical, but they may be. Another factor is how rapidly the switch responds to the control input once the threshold voltage has been applied. The objective is for the switch to close and open such that the bias/reference signal is "crisply" gated. That is, preferably, the impedance through the switch must change from a high impedance (an open switch) to a low impedance (a closed switch) and back again in a very short time so that the output signal is substantially rectangular.

It is an objective of this invention in the transmitter embodiment that the intelligence in the information signal is to be transmitted. That is, the information is modulated onto the transmitted signal. In the FM and PM modes, to achieve this objective, the information signal is used to modulate the oscillating signal 2804. The

oscillating signal 2804 then causes the switch 2816 to close and open. The information that is modulated onto the oscillating signal 2804 must be faithfully reproduced onto the signal that is output from the switch circuit (i.e., the harmonically rich signal 2814). For this to occur efficiently, in embodiments of the invention, the switch 2816 preferably closes and opens crisply so that the harmonically rich signal 2814 changes rapidly from the bias/reference signal 2806 (or 3106) to ground 2812 (or the second signal level 2818 in the alternate embodiment). This rapid rise and fall time is desired so that the harmonically rich signal 2814 will be "harmonically rich." (In the case of AM, the oscillating signal 3104 is not modulated, but the requirement for "crispness" still applies.)

For the switch 2816 to close and open crisply, the oscillating signal 2804 must also be crisp. If the oscillating signal 2804 is sinusoidal, the switch 2816 will open and close when the threshold voltages are reached, but the pulse width of the harmonically rich signal 2814 may not be as small as is needed to ensure the amplitude of the desired harmonic of the harmonically rich signal 2814 is sufficiently high to allow transmission without elaborate filtering or unnecessary amplification. Also, in the embodiment wherein the switch 2816 is a GaAs FET 2901, if the oscillating signal 2804 that is connected to the gate 2902 of the GaAs FET 2901 (i.e., the signal that causes the switch 2816 to close and open) is a sinusoidal wave, the GaAs FET 2901 will not crisply close and open, but will act more like an amplifier than a switch. (That is, it will conduct during the time that the oscillating signal is rising and falling below the threshold voltages, but will not be a "short.") In order to make use of the benefits of a GaAs FET's capability to close and open at high frequencies, the oscillating signal 2804 connected to the gate 2902 preferably has a rapid rise and fall time. That is, it is preferably a rectangular waveform, and preferably has a pulse width to period ratio the same as the pulse width to period ratio of the harmonically rich signal 2814.

As stated above, if a signal with a continuous and periodic waveform is modulated, that modulation occurs on every harmonic of the original waveform. Thus, in the FM and PM modes, when the information is modulated onto the oscillating signal 2804 and the oscillating signal 2804 is used to cause the switch 2816 to close and open, the resulting harmonically rich signal 2814 that is output from the switch module 2802 will also be modulated. If the oscillating signal 2804 is crisp, the switch 2816 will close and open crisply, the harmonically rich signal 2814 will be

harmonically rich, and each of the harmonics of the harmonically rich signal 2814 will have the information modulated on it.

Because it is desired that the oscillating signal 2804 be crisp, harmonic enhancement may be needed in some embodiments. Harmonic enhancement may also be called "pulse shaping" since the purpose is to shape the oscillating signal 2804 into a string of pulses of a desired pulse width. If the oscillating signal is sinusoidal, harmonic enhancement will shape the sinusoidal signal into a rectangular (or substantially rectangular) waveform with the desired pulse width to period ratio. If the oscillating signal 2804 is already a square wave or a pulse, harmonic enhancement will shape it to achieve the desired ratio of pulse width to period. This will ensure an efficient transfer of the modulated information through the switch.

Three exemplary embodiments of harmonic enhancement are described below for illustrative purposes. However, the invention is not limited to these embodiments. Other embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

#### *4.1.2 Structural Description.*

The shape of the oscillating signal 2804 causes the switch 2816 to close and open. The shape of the oscillating signal 2804 and the selection of the switch 2816 will determine how quickly the switch 2816 closes and opens, and how long it stays closed compared to how long it stays open. This then will determine the "crispness" of the harmonically rich signal 2814. (That is, whether the harmonically rich signal 2814 is substantially rectangular, trapezoidal, triangular, etc.) As shown above, in order to ensure that the desired harmonic has the desired amplitude, the shape of the oscillating signal 2804 should be substantially optimized.

The harmonic enhancement module (HEM) 4602 (FIG. 46) is also referred to as a "pulse shaper." It "shapes" the oscillating signals 2804 and 3104 that drive the switch modules 2802 and 3102 described in sections 3.3.6-3.3.6.2 and 3.3.7-3.3.7.2. Harmonic enhancement module 4602 preferably transforms a continuous and periodic waveform 4604 into a string of pulses 4606. The string of pulses 4606 will have a period, "T," determined by both the frequency of the continuous and periodic waveform 4604 and the design of the pulse shaping circuit within the harmonic enhancement module 4602. Also, each pulse will have a pulse width, " $\tau$ ," determined

by the design of the pulse shaping circuit. The period of the pulse stream, "T," determines the frequency of the switch closing (the frequency being the inverse of the period), and the pulse width of the pulses, " $\tau$ ," determines how long the switch stays closed.

5 In the embodiment described above in sections 3.3.6-3.3.6.2 (and 3.3.7-3.3.7.2), when the switch 2816 (or 3116) is open, the harmonically rich signal 2814 (or 3114) will have an amplitude substantially equal to the bias signal 2806 (or reference signal 3106). When the switch 2816 (or 3116) is closed, the harmonically rich signal 2814 (or 3114) will have an amplitude substantially equal to the potential of signal 2812 or 10 2818 (or 3112 or 3118) of the second input 2810 (or 3110) of the switch module 2802 (or 3102). Thus, for the case where the oscillating signal 2804 (or 3104) driving the switch module 2802 (or 3102) is substantially rectangular, the harmonically rich signal 2814 (or 3114) will have substantially the same frequency and pulse width as the shaped oscillating signal 2804 (or 3104) that drives the switch module 2802 (or 3102). 15 This is true for those cases wherein the oscillating signal 2804 (or 3104) is a rectangular wave. One skilled in the relevant art(s) will understand that the term "rectangular wave" can refer to all waveforms that are substantially rectangular, including square waves and pulses.

The purpose of shaping the signal is to control the amount of time that the 20 switch 2816 (or 3116) is closed. As stated above, the harmonically rich signal 2814 (or 3114) has a substantially rectangular waveform. Controlling the ratio of the pulse width of the harmonically rich signal 2814 (or 3114) to its period will result in the shape of the harmonically rich signal 2814 (or 3114) being substantially optimized so that the relative amplitudes of the harmonics are such that the desired harmonic can be 25 extracted without unnecessary and elaborate amplification and filtering.

#### 4.2 Exemplary Embodiments.

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to 30 these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to

persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

*4.2.1 First Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create One Pulse per Cycle.*

5 *4.2.1.1 Operational Description.*

According to this embodiment, a continuous periodic waveform 4604 is received and a string of pulses 4606 is output. The continuous periodic waveform 4604 may be a square wave or any other continuous periodic waveform that varies from a value recognized as a "digital low" to a value recognized as a "digital high." One pulse is generated per cycle of the continuous and periodic waveform 4604. The description given herein will be for the continuous periodic waveform 4604 that is a square wave, but one skilled in the relevant art(s) will appreciate that other waveforms may also be "shaped" into waveform 4606 by this embodiment.

*4.2.1.2 Structural Description.*

15 In this first embodiment of a harmonic enhancement module 4602, herein after referred to as a pulse shaping circuit 4602, a continuous periodic waveform 4604 that is a square wave is received by the pulse shaping circuit 4602. The pulse shaping circuit 4602 is preferably comprised of digital logic devices that result in a string of pulses 4606 being output that has one pulse for every pulse in the continuous periodic waveform 4604, and preferably has a  $\tau/T$  ratio less than 0.5.

*4.2.2 Second Embodiment: When a Square Wave Feeds the Harmonic Enhancement Module to Create Two Pulses per Cycle.*

*4.2.2.1 Operational Description.*

25 In this embodiment, a continuous periodic waveform 4604 is received and a string of pulses 4606 is output. In this embodiment, there are two pulses output for

every period of the continuous periodic waveform 4604. The continuous periodic waveform 4604 may be a square wave or any other continuous periodic waveform that varies from a value recognized as a "digital low" to a value recognized as a "digital high." The description given herein will be for a continuous periodic waveform 4604 that is a square wave, but one skilled in the relevant art(s) will appreciate that other waveforms may also be "shaped" into waveform 4606 by this embodiment.

#### *4.2.2.2 Structural Description.*

In this second embodiment of a pulse shaping circuit 4602, a continuous periodic waveform 4604 that is a square wave is received by the pulse shaping circuit 4602. The pulse shaping circuit 4602 is preferably comprised of digital logic devices that result in a string of pulses 4606 being output that has two pulses for every pulse in the continuous periodic waveform 4604, and preferably has a  $\tau/T$  ratio less than 0.5.

#### *4.2.3 Third Embodiment: When Any Waveform Feeds the Module.*

##### *4.2.3.1 Operational Description.*

In this embodiment, a continuous periodic waveform 4604 of any shape is received and a string of pulses 4606 is output.

##### *4.2.3.2 Structural Description.*

In this third embodiment of a pulse shaping circuit 4602, a continuous periodic waveform 4604 of any shape is received by the pulse shaping circuit 4602. The pulse shaping circuit 4602 is preferably comprised of a series of stages, each stage shaping the waveform until it is substantially a string of pulses 4606 with preferably a  $\tau/T$  ratio less than 0.5.

#### *4.2.4 Other Embodiments.*

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments,

differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

#### 4.3 *Implementation Examples.*

5 Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives  
10 (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

##### 4.3.1 *First Digital Logic Circuit.*

15 An exemplary implementation of the first embodiment described in sections 4.2.1-4.2.1.2 is illustrated in FIG. 39. In particular, the circuit shown in FIG. 39A is a typical circuit design for a pulse shaping circuit 4602 using digital logic devices. Also shown in FIGs. 39B-39D are representative waveforms at three nodes within the circuit. In this embodiment, pulse shaper 3900 uses an inverter 3910 and an AND gate  
20 3912 to produce a string of pulses. An inverter, such as inverter 3910, changes the sign of the input, and an AND gate, such as AND gate 3912, outputs a digital "high" when all of the input signals are digital "highs." The input to pulse shaper 3900 is waveform 3902, and, for illustrative purposes, is shown here as a square wave. The output of inverter 3910 is waveform 3904, which is also a square wave. However, because of the  
25 circuitry of the inverter 3910, there is a delay between the application of the input and the corresponding sign change of the output. If waveform 3902 starts "low," waveform 3904 will be "high" because it has been inverted by inverter 3910. When waveform 3902 switches to "high," AND gate 3912 will momentarily see two "high" signals, thus causing its output waveform 3906 to be "high." When inverter 3910 has inverted its  
30 input (waveform 3902) and caused waveform 3904 to become "low," AND gate 3912

will then see only one "high" signal, and the output waveform 3906 will become "low." Thus, the output waveform 3906 will be "high" for only the period of time that both waveforms 3902 and 3904 are high, which is the time delay of the inverter 3910. Accordingly, as is apparent from FIGs. 39B-39D, pulse shaper 3900 receives a square wave and generates a string of pulses, with one pulse generated per cycle of the square wave.

#### 4.3.2 Second Digital Logic Circuit.

An exemplary implementation of the second embodiment described in sections 4.2.2-4.2.2.2 is illustrated in FIG. 40. In particular, the circuit of FIG. 40A is a typical circuit design for a pulse shaping circuit 4602 using digital logic devices. Also shown in FIGs. 40B-40D are representative waveforms at three nodes within the circuit. In this embodiment, pulse shaping circuit 4000 uses an inverter 4010 and an exclusive NOR (XNOR) gate 4012. An XNOR, such as XNOR 4012, outputs a digital "high" when both inputs are digital "highs" and when both signals are digital "lows." Waveform 4002, which is shown here as a square wave identical to that shown above as waveform 3902, begins in the "low" state. Therefore, the output of inverter 4010 will begin at the "high" state. Thus, XNOR gate 4012 will see one "high" input and one "low" input, and its output waveform 4006 will be "low." When waveform 4002 changes to "high," XNOR gate 4012 will have two "high" inputs until the waveform 4004 switches to "low." Because it sees two "high" inputs, its output waveform 4006 will be "high." When waveform 4004 becomes "low," XNOR gate 4012 will again see one "high" input (waveform 4002) and one "low" input (waveform 4004). When waveform 4002 switches back to "low," XNOR gate 4012 will see two "low" inputs, and its output will become "high." Following the time delay of inverter 4010, waveform 4004 will change to "high," and XNOR gate 4012 will again see one "high" input (waveform 4004) and one "low" input (waveform 4002). Thus, waveform 4006 will again switch to "low." Accordingly, as is apparent from FIGs. 40B-40D, pulse shaper 4000 receives a square wave and generates a string of pulses, with two pulses generated per cycle of the square wave.

#### 4.3.3 Analog Circuit.

An exemplary implementation of the third embodiment described in sections 4.2.3-4.2.3.2 is illustrated in FIG. 41. In particular, the circuit shown in FIG. 41 is a typical pulse shaping circuit 4602 where an input signal 4102 is shown as a sine wave. Input signal 4102 feeds the first circuit element 4104, which in turn feeds the second, and so on. Typically, three circuit elements 4104 produce incrementally shaped waveforms 4120, 4122, and 4124 before feeding a capacitor 4106. The output of capacitor 4106 is shunted to ground 4110 through a resistor 4108 and also feeds a fourth circuit element 4104. An output signal 4126 is a pulsed output, with a frequency that is a function of the frequency of input signal 4102.

An exemplary circuit for circuit elements 4104 is shown in FIG. 43. Circuit 4104 is comprised of an input 4310, an output 4312, four FETs 4302, two diodes 4304, and a resistor 4306. One skilled in the relevant art(s) would recognize that other pulse shaping circuit designs could also be used without deviating from the scope and spirit of the invention.

#### 4.3.4 Other Implementations.

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

##### 4.3.4.1 Multiple apertures

In an alternate embodiment of the invention, a plurality of pulses are used to create multiple apertures from the switch module. The generation of the plurality of pulses can be through a number of techniques. The purpose of using multiple apertures is because of the optimizing effect it has on the amplitude of the harmonic content of the output waveform.

Looking to FIG. 78, it can be seen that a local oscillator 7802 generates an oscillating signal 7810. For ease of discussion, and not meant to be limiting, oscillating signal 7810 is routed through a pulse shaper 7812 to create a string of pulses

7804. String of pulses 7804 is routed to a multiple aperture generation module 7806. The output of multiple aperture generation module 7806 is a string of multiple pulses 7808.

5 In FIG. 79, string of pulses 7804 is seen being accepted by multiple aperture generation module 7806. String of pulses 7804 is then routed to one or more delays 7904(i). FIG. 79 illustrates a first delay 7904(a) that outputs a first delayed string of pulses 7906(a). First delayed string of pulses 7906(a) is substantially similar to string of pulses 7804, except that it is delayed in time by a desired period. String of pulses 7804 and first delayed string of pulses 7906(a) are then routed to an "NOR" gate that  
10 outputs a string of multiple pulses 7808 that has a pulse at every point in time that string of pulses 7804 has a pulse and at every point in time that first delayed string of pulses 7906(a) has a pulse. Similarly, other delays such as a delay 7904(n) also delay string of pulses 7804 by desired periods to create  $n^{\text{th}}$  delayed string of pulses 7906(n). When string of pulses 7804 and first through  $n^{\text{th}}$  delayed strings of pulses 7906(a) -  
15 7906(n) are combined by "NOR" gate 7904, string of multiple pulses 7808 is created having  $n + 1$  pulses for every cycle of string of pulses 7804.

FIG. 80 illustrates a pulse train 8002 that is one pulse per cycle of string of pulses 7804. Similarly, a pulse train 8004 illustrates two pulses per cycle of string of pulses 7804; a pulse train 8006 illustrates three pulses per cycle of string of pulses 7804; a pulse train 8008 illustrates four pulses per cycle of string of pulses 7804; and a  
20 pulse train 8006 illustrates five pulses per cycle of string of pulses 7804. In this example, the desired output frequency is 900 MHz and the frequency of the string of pulses is 180 MHz. Thus, the fifth harmonic is the desired harmonic, and the optimum pulse width of the pulses in string of pulses 7804 is one-fifth of the period of string of  
25 pulses 7804. In this example, each of the additional pulses are separated from the leading pulse by a period of time equal to the pulse width, and, additionally, they each have a pulse width that is substantially equal to the pulse width of the pulses in string of pulses 7804.

FIGs. 81 through 85 illustrate the advantages of using multiple apertures per cycle. In FIG. 81, the 900 MHz harmonic resulting from the use of a single pulse per cycle (i.e., pulse train 8002) is shown by a spectrum 8102. In FIG. 82, the 900 MHz harmonic resulting from the use of two pulses per cycle (i.e., pulse train 8004) is shown by a spectrum 8202. In FIG. 83, the 900 MHz harmonic resulting from the use of  
30 three pulses per cycle (i.e., pulse train 8006) is shown by a spectrum 8302. In FIG.

84, the 900 MHz harmonic resulting from the use of four pulses per cycle (i.e., pulse train 8008) is shown by a spectrum 8402. In FIG. 85, the 900 MHz harmonic resulting from the use of five pulses per cycle (i.e., pulse train 8010) is shown by a spectrum 8502. FIG. 86 illustrates the relative amplitude of these five spectra, 8102, 8202, 8302, 8402, and 8502. As can be seen, the desired harmonic amplitude is increased and the undesired harmonics decreased as a function of the number of pulses per cycle. This increase in amplitude will be another consideration during the design of a transmitter.

An alternate embodiment to improve the harmonic content of the output signal is shown in circuit 8702 of FIG. 87. A string of pulses as shown in FIG. 90 is phase shifted and inverted and the two strings of pulses are combined to create the bi-polar string of pulses shown in FIG. 89. The effect of the bi-polar string of pulses is to suppress the even harmonics and increase the amplitude of the odd harmonics. This output is shown in FIG. 88.

## 5. *Amplifier Module.*

### 5.1 *High Level Description.*

This section (including its subsections) provides a high-level description of the amplifier module according to the present invention. In particular, amplification is described at a high-level. Also, a structural implementation for achieving signal amplification is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

#### 5.1.1 *Operational Description.*

Even though the present invention is intended to be used without requiring amplification, there may be circumstance when, in the embodiment of the present invention wherein it is being used as a transmitter, it may prove desirable to amplify

the modulated signal before it is transmitted. In another embodiment of the invention wherein it is being used as a stable signal source for a frequency or phase comparator, it may also be desirable to amplify the resultant signal at the desired frequency.

The requirement may come about for a number of reasons. A first may be that the bias/reference signal is too low to support the desired use. A second may be because the desired output frequency is very high relative to the frequency of the oscillating signal that controls the switch. A third reason may be that the shape of the harmonically rich signal is such that the amplitude of the desired harmonic is low.

In the first case, recall that the amplitude of the bias/reference signal determines the amplitude of the harmonically rich signal which is present at the output of the switch circuit. (See sections 3.3.6-3.3.6.2 and 3.3.7-3.3.7.2.) Further recall that the amplitude of the harmonically rich signal directly impacts the amplitude of each of the harmonics. (See the equation in section 4.1, above.)

In the second instance, if the frequency of the oscillating signal is relatively low compared to the desired output frequency of the up-converter, a high harmonic will be needed. As an example, if the oscillating signal is 60 MHz, and the desired output frequency is at 900 MHz, the 15<sup>th</sup> harmonic will be needed. In the case where  $\tau/T$  is 0.1, it can be seen from Table 6000 of FIG. 60 that the amplitude of the 15<sup>th</sup> harmonic ( $A_{15}$ ) is 0.0424, which is 21.5% of the amplitude of the first harmonic ( $A_1 = 0.197$ ). There may be instances wherein this is insufficient for the desired use, and consequently it must be amplified.

The third circumstance wherein the amplitude of the output may need to be amplified is when the shape of the harmonically rich signal is not "crisp" enough to provide harmonics with enough amplitude for the desired purpose. If, for example, the harmonically rich signal is substantially triangular, and given the example above where the oscillating signal is 60 MHz and the desired output signal is 900 MHz, the 15<sup>th</sup> harmonic of the triangular wave is 0.00180. This is significantly lower than the amplitude of the 15<sup>th</sup> harmonic of the "0.1" rectangular wave (shown above to be 0.0424) and can be mathematically shown to be 0.4% of the amplitude of the 1<sup>st</sup> harmonic of the triangular wave (which is 0.405). Thus, in this example, the 1<sup>st</sup> harmonic of the triangular wave has an amplitude that is larger than the amplitude of the 1<sup>st</sup> harmonic of the "0.1" rectangular wave, but at the 15<sup>th</sup> harmonic, the triangular wave is significantly lower than the "0.1" rectangular wave.

Another reason that the desired harmonic may need to be amplified is that circuit elements such as the filter may cause attenuation in the output signal for which a designer may wish to compensate.

5 The desired output signal can be amplified in a number of ways. One is to amplify the bias/reference signal to ensure that the amplitude of the harmonically rich wave form is high. A second is to amplify the harmonically rich waveform itself. A third is to amplify the desired harmonic only. The examples given herein are for illustrative purposes only and are not meant to be limiting on the present invention. Other techniques to achieve amplification of the desired output signal would be  
10 apparent to those skilled in the relevant art(s).

### 5.1.2 *Structural Description.*

In one embodiment, a linear amplifier is used to amplify the bias/reference signal. In another embodiment, a linear amplifier is used to amplify the harmonically rich signal. And in yet another embodiment, a linear amplifier is used to amplify the  
15 desired output signal. Other embodiments, including the use of non-linear amplifiers, will be apparent to persons skilled in the relevant art(s).

## 5.2 *Exemplary Embodiment.*

An embodiment related to the method(s) and structure(s) described above is presented in this section (and its subsections). This embodiment is described herein for  
20 purposes of illustration, and not limitation. The invention is not limited to this embodiment. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiment described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

### 5.2.1 *Linear Amplifier.*

25 The exemplary linear amplifier described herein will be directed towards an amplifier composed of solid state electronic devices to be inserted in the circuit at one or more points. Other amplifiers suitable for use with the invention will be apparent to

persons skilled in the relevant art(s). As shown in FIG. 47, an amplifier module 4702 receives a signal requiring amplification 4704 and outputs an amplified signal 4706. It would be apparent to one skilled in the relevant art(s) that a plurality of embodiments may be employed without deviating from the scope and intent of the invention described herein.

#### *5.2.1.1 Operational Description.*

The desired output signal can be amplified in a number of ways. Such amplification as described in the section may be in addition to the techniques described above to enhance the shape of the harmonically rich signal by pulse shaping of the oscillating signal that causes the switch to close and open.

#### *5.2.1.2 Structural Description.*

In one embodiment, a linear amplifier is placed between the bias/reference signal and the switch module. This will increase the amplitude of the bias/reference signal, and as a result, will raise the amplitude of the harmonically rich signal that is the output of the switch module. This will have the effect of not only raising the amplitude of the harmonically rich signal, it will also raise the amplitude of all of the harmonics. Some potential limitation of this embodiment are: the amplified bias/reference signal may exceed the voltage design limit for the switch in the switch circuit; the harmonically rich signal coming out of the switch circuit may have an amplitude that exceeds the voltage design limits of the filter; and/or unwanted distortion may occur from having to amplify a wide bandwidth signal.

A second embodiment employs a linear amplifier between the switch module and the filter. This will raise the amplitude of the harmonically rich signal. It will also raise the amplitude of all of the harmonics of that signal. In an alternate implementation of this embodiment, the amplifier is tuned so that it only amplifies the desired frequencies. Thus, it acts both as an amplifier and as a filter. A potential limitation of this embodiment is that when the harmonically rich signal is amplified to raise a particular harmonic to the desired level the amplitude of the whole waveform is amplified as well. For example, in the case where the amplitude of the pulse,  $A_{\text{pulse}}$ , is equal to 1.0, to raise the 15<sup>th</sup> harmonic from 0.0424 volts to 0.5 volts, the amplitude of

each pulse in the harmonically rich signal,  $A_{\text{pulse}}$ , will increase from 1.0 to 11.8 volts. This may well exceed the voltage design limit of the filter.

A third embodiment of an amplifier module will place a linear amplifier between the filter and the transmission module. This will only raise the amplitude of the desired harmonic, rather than the entire harmonically rich signal.

Other embodiments, such as the use of non-linear amplifiers, will be apparent to one skilled in the relevant art(s), and will not be described herein.

### 5.2.2 Other Embodiments.

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

### 5.3 Implementation Examples.

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These components and methods are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention.

#### 5.3.1 Linear Amplifier.

Although described below as if it were placed after the filter, the amplifier may also be placed before the filter without deviating from the intent of the invention

##### 5.3.1.1 Operational Description.

According to embodiments of the invention, a linear amplifier receives a first signal at a first amplitude, and outputs a second signal at a second amplitude, wherein the second signal is proportional to the first signal. It is an objective of an amplifier that the information embedded onto the first signal waveform will also be embedded onto the second signal. Typically, it is desired that there be as little distortion in the information as possible.

In a preferred embodiment, the second signal is higher in amplitude than the first signal, however, there may be implementations wherein it is desired that the second signal be lower than the first signal (i.e., the first signal will be attenuated).

### *5.3.1.2 Structural Description.*

The design and use of a linear amplifier is well known to those skilled in the relevant art(s). A linear amplifier may be designed and fabricated from discrete components, or it may be purchased "off the shelf."

Exemplary amplifiers are seen in FIG. 48. In the exemplary circuit diagram of FIG. 48A, six transistors are used in a wideband amplifier. In the more basic exemplary circuit of FIG. 48B, the amplifier is composed of one transistor, four resistors, and a capacitor. Those skilled in the relevant art(s) will recognize that numerous alternative designs may be used.

### *5.3.2 Other Implementations.*

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

## *6. Receiver/Transmitter System.*

The present invention is for a method and system for up-conversion of electromagnetic signals. In one embodiment, the invention is a source of a stable high frequency reference signal. In a second embodiment, the invention is a transmitter.

This section describes a third embodiment. In the third embodiment, the transmitter of the present invention to be used in a receiver/transmitter communications system. This third embodiment may also be referred to as the communications system embodiment, and the combined receiver/transmitter circuit is referred to as a "transceiver." There are several alternative enhancements to the communications systems embodiment.

The following sections describe systems and methods related to exemplary embodiments for a receiver/transmitter system. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

### ***6.1 High Level Description.***

This section provides a high-level description of a receiver/transmitter system according to the present invention. The implementations are described herein for illustrative purposes, and are not limiting. In particular, any number of functional and structural implementations may be used, several of which are described in this section. The details of such functional and structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

According to a first embodiment of the transmitter of the present invention is used with a traditional superheterodyne receiver. In this embodiment, the transmitter and the receiver can operate either in a full-duplex mode or in a half-duplex mode. In a full duplex mode, the transceiver can transmit and receive simultaneously. In the half-duplex mode, the transceiver can either transmit or receive, but cannot do both simultaneously. The full-duplex and the half-duplex modes will be discussed together for this embodiment.

A second embodiment of the transceiver is for the transmitter of the present invention to be used with a universal frequency down conversion circuit being used as a receiver. In this embodiment the transceiver is used in a half-duplex mode.

A third embodiment of the transceiver is for the transmitter of the present invention to be used with a universal frequency down conversion circuit, where the transceiver is used in a full-duplex mode.

These embodiments of the transceiver are described below.

## 6.2 Exemplary Embodiments and Implementation Examples.

Various embodiments related to the method(s) and structure(s) described above and exemplary operational and/or structural implementations related to those embodiments are presented in this section (and its subsections). These embodiments, components, and methods are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments or to the particular examples of components and methods described herein. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention, and the invention is intended and adapted to include such alternatives.

### 6.2.1 First Embodiment: The Transmitter of the Present Invention Being Used in a Circuit with a Superheterodyne Receiver.

A typical superheterodyne receiver is shown in FIG. 49. An antenna 4904 receives a signal 4902. Typically, signal 4902 is a radio frequency (RF) signal which is routed to a filter 4910 and an amplifier 4908. The filter 4910 removes all but a frequency range that includes the desired frequency, and the amplifier 4908 ensures that the signal strength will be sufficient for further processing. The output of amplifier 4908 is a signal 4911.

A local oscillator 4914 generates an oscillating signal 4916 which is combined with signal 4911 by mixer 4912. The output of mixer 4912 is a signal 4934 which is amplified by an amplifier 4918 and filtered by a filter 4920. The purpose of amplifier

4918 is to ensure that the strength of signal 4934 is sufficient for further processing, and the purpose of filter 4920 is to remove the undesired frequencies.

A second local oscillator 4924 generates a second oscillating signal 4926 which is combined with the amplified/filtered signal 4934 by a mixer 4922. The output of mixer 4922 is signal 4936. Again, an amplifier 4928 and a filter 4930 ensure that the signal 4936 is at the desired amplitude and frequency. The resulting signal is then routed to decoder 4932 where the intelligence is extracted to obtain baseband signal 4938.

Signal 4934 is referred to as the first intermediate frequency (IF) signal, and signal 4936 is referred to as the second IF signal. Thus, the combination of local oscillator 4914 and mixer 4912 can be referred to as the first IF stage, and the combination of local oscillator 4924 and mixer 4922 can be referred to as the second IF stage.

Exemplary frequencies for the circuit of FIG. 49 are as follows. Signal 4902 may be 900 MHz. The oscillator signal 4916 may be at 830 MHz, which will result in the frequency of the first IF signal, signal 4934, being at 70 MHz. If the second oscillating signal 4926 is at 59 MHz, the second IF signal, signal 4936, would be at 11 MHz. This frequency is typical of second IF frequencies.

Other superheterodyne receiver configurations are well known and these can be used in the transceiver embodiments of the invention. Also, the exemplary frequencies mentioned above are provided for illustrative purposes only, and are not limiting.

FIG. 50 shows a transmitter of the present invention in a transceiver circuit with a typical superheterodyne receiver. Accordingly, FIG. 50 illustrates an exemplary transceiver circuit of the invention. The transceiver includes a receiver module 5001, which is implemented using any superheterodyne receiver configuration, and which is described above. The transceiver also includes a transmitter module 5003, which is described below.

In the FM and PM modes, an information signal 5004 modulates an intermediate signal to produce the oscillating signal 5002. Oscillating signal 5002 is shaped by signal shaper 5010 to produce a string of pulses 5008 (see the discussion above regarding the benefits of harmonic enhancement). The string of pulses 5008 drives the switch module 5012. In the FM/PM modes, a bias/reference signal 5006 is also received by switch module 5012. The output of switch module 5012 is a harmonically rich signal 5022. Harmonically rich signal 5022 is comprised of a

plurality of sinusoidal components, and is routed to a "high Q" filter that will remove all but the desired output frequency(ies). The desired output frequency 5024 is amplified by an amplifier 5016 and routed to a transmission module 5018 which outputs a transmission signal 5026 which is routed to a duplexer 5020. The purpose of  
5 duplexer 5020 is to permit a single antenna to be used simultaneously for both receiving and transmitting signals. The combination of received signal 4902 and transmission signal 5026 is a duplexed signal 5028.

In the AM mode, the same circuit of FIG. 50 applies, except: (1) an information signal 5030 replaces information signal 5004; (2) bias/reference signal 5006 is a  
10 function of the information signal 5030; and (3) oscillating signal 5002 is not modulated.

This description is for the full-duplex mode of the transceiver wherein the transmitting portion of the communications system is a separate circuit than the receiver portion. A possible embodiment of a half-duplex mode is described below.

Alternate embodiments of the transceiver are possible. For example, FIGs. 51A through 51D illustrate an embodiment of the transceiver wherein it may be desired, for cost or other considerations, for an oscillator to be shared by both the transmitter portion and the receiver portion of the circuit. To do this, a trade off must be made in selecting the frequency of the oscillator. In FIG. 51A, a local oscillator 5104 generates  
15 an oscillating signal 5106 which is mixed with signal 4911 to generate a first IF signal 5108. A local oscillator 5110 generates a second oscillating signal 5112 which is mixed with the first IF signal 5108 to generate a second IF signal 5114. For the example herein, the frequencies of the oscillating signals 5106 and 5112 will be lower than the frequencies of signal 4911 and first IF signal 5108, respectively. (One skilled  
20 in the relevant art(s) will recognize that, because the mixers 4912 and 4922 create both the sum and the difference of the signals they receive, the oscillator frequencies could be higher than the signal frequencies.)

As described in the example above, a typical second IF frequency is 11 MHz. The selection of this IF frequency is less flexible than is the selection of the first IF frequency, since the second IF frequency is routed to a decoder where the signal is demodulated and decoded. Typically, demodulators and decoders are designed to  
30 receive signals at a predetermined, fixed frequency, e.g., 11 MHz. If this is the case, the combination of the first IF signal 5108 and the second oscillating signal 5112 must generate a second IF signal with a second IF frequency of 11 MHz. Recall that the

received signal 4902 was 900 MHz in the example above. To achieve the second IF signal frequency of 11 MHz, the frequencies of the oscillating signals 4916 and 4926 were set at 830 MHz and 59 MHz. Before setting the frequencies of the oscillating signals 5106 and 5112, the desired frequency of the transmitted signal must be determined. If it, too, is 900 MHz, then the frequency of the oscillating signal that causes the switch in the present invention to open and close must be a "sub-harmonic" of 900 MHz. That is, it must be the quotient of 900 MHz divided by an integer. (In other words, 900 MHz must be a harmonic of the oscillating signal that drives the switch.) The table below is a list of some of the sub-harmonics of 900 MHz:

| <u>sub-harmonic</u> | <u>frequency</u> |
|---------------------|------------------|
| 1 <sup>st</sup>     | 900 MHz          |
| 2 <sup>nd</sup>     | 450              |
| 3 <sup>rd</sup>     | 300              |
| 4 <sup>th</sup>     | 225              |
| 5 <sup>th</sup>     | 180              |
| 10 <sup>th</sup>    | 90               |
| 15 <sup>th</sup>    | 60               |

Recall that the frequency of the second oscillating signal 4926 in FIGs. 49 and 50 was 59 MHz. Notice that the frequency of the 15<sup>th</sup> sub-harmonic is 60 MHz. If the frequency of oscillating signal 5112 of FIG. 51 were set at 60 MHz, it could also be used as the oscillating signal to operate the switches in switch module 5126 of FIG. 51B and switch module 5136 of FIG. 51C. If this were done, the frequency of the first IF signal would be 71 MHz (rather than 70 MHz in the previous example of a stand-alone receiver), as indicated below:

$$\begin{aligned}
 \text{First IF frequency} &= \text{Second IF frequency} + \text{Second oscillating frequency} \\
 &= 11 \text{ MHz} + 60 \text{ MHz} \\
 &= 71 \text{ MHz}
 \end{aligned}$$

The frequency of the first oscillating signal 5106 can be determined from the values of the first IF frequency and the frequency of the received signal 4902. In this example, the frequency of the received signal is 900 MHz and the frequency of the first IF signal is 71 MHz. Therefore, the frequency of the first oscillating signal 5106 must be 829 MHz, as indicated below:

$$\begin{aligned}\text{First oscillating frequency} &= \text{Freq of received signal} - \text{First IF freq} \\ &= 900 \text{ MHz} - 71 \text{ MHz} \\ &= 829 \text{ MHz}\end{aligned}$$

Thus the frequencies of the oscillating signals 5106 and 5112 are 829 MHz and 60 MHz, respectively.

In FIG. 51B, the PM embodiment is shown. The second oscillating signal 5112 is routed to a phase modulator 5122 where it is modulated by the information signal 5120 to generate a PM signal 5132. PM signal 5132 is routed to a harmonic enhancement module 5124 to create a string of pulses 5133. The string of pulses 5133 is also a phase modulated signal and is used to cause the switch in switch module 5126 to open and close. Also entering switch module 5126 is a bias signal 5128. The output of switch module 5126 is a harmonically rich signal 5134.

In FIG. 51C, the AM embodiment is shown. The second oscillating signal 5112 directly enters the harmonic enhancement module 5124 to create a string of pulses 5138. String of pulses 5138 (not modulated in this embodiment) then enters a switch module 5136 where it causes a switch to open and close. Also entering switch module 5136 is a reference signal 5140. Reference signal is created by summing module 5130 by combining information signal 5120 with bias signal 5128. It is well known to those skilled in the relevant art(s) that the information signal 5120 may be used as the reference signal without being combined with the bias signal 5128. The output of switch module 5136 is a harmonically rich signal 5134.

The scope of the invention includes an FM embodiment wherein the oscillator 5110 of the receiver circuit is used as a source for an oscillating signal for the transmitter circuit. In the embodiments discussed above, the FM embodiment requires a voltage controlled oscillator (VCO) rather than a simple local oscillator. There are circuit designs that would be apparent to those skilled in the relevant art(s) based on the discussion contained herein, wherein a VCO is used in place of a local oscillator in the receiver circuit.

In FIG. 51D, the harmonically rich signal 5134 is filtered by a filter 5142, which removes all but the desired output frequency 5148. The desired output frequency 5148 is amplified by amplifier module 5146 and routed to transmission module 5150. The output of transmission module 5150 is a transmission signal 5144. Transmission signal 5144 is then routed to the antenna 4904 for transmission.

Those skilled in the relevant art(s) will understand that there are numerous combinations of oscillator frequencies, stages, and circuits that will meet the scope and intent of this invention. Thus, the description included herein is for illustrative purposes only and not meant to be limiting.

5                                   **6.2.2 Second Embodiment: The Transmitter of the Present Invention  
Being Used with a Universal Frequency Down-Converter in a  
Half-Duplex Mode.**

10                   An exemplary receiver using universal frequency down conversion techniques is shown in FIG. 52 and described in section 6.3, below. An antenna 5202 receives an electromagnetic (EM) signal 5220. EM signal 5220 is routed through a capacitor 5204 to a first terminal of a switch 5210. The other terminal of switch 5210 is connected to ground 5212 in this exemplary embodiment. A local oscillator 5206 generates an oscillating signal 5228 which is routed through a pulse shaper 5208. The result is a string of pulses 5230. The selection of the oscillator 5206 and the design of the pulse shaper 5208 control the frequency and pulse width of the string of pulses 5230. The string of pulses 5230 control the opening and closing of switch 5210. As a result of the opening and closing of switch 5210, a down converted signal 5222 results. Down converted signal 5222 is routed through an amplifier 5214 and a filter 5216, and a filtered signal 5224 results. In a preferred embodiment, filtered signal 5224 is at baseband, and a decoder 5218 may only be needed to convert digital to analog or to remove encryption before outputting the baseband information signal. This then is a universal frequency down conversion receiver operating in a direct down conversion mode, in that it receives the EM signal 5220 and down converts it to baseband signal 5226 without requiring an IF or a demodulator. In an alternate embodiment, the filtered signal 5224 may be at an "offset" frequency. That is, it is at an intermediate frequency, similar to that described above for the second IF signal in a typical superheterodyne receiver. In this case, the decoder 5218 would be used to demodulate the filtered signal so that it could output a baseband signal 5226.

20                   An exemplary transmitter using the present invention is shown in FIG. 53. In the FM and PM embodiments, an information signal 5302 modulates an oscillating signal 5306 which is routed to a pulse shaping circuit 5310 which outputs a string of pulses 5311. The string of pulses 5311 controls the opening and closing of the switch

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5312. One terminal of switch 5312 is connected to ground 5314, and the second terminal of switch 5312 is connected through a resistor 5330 to a bias/reference signal 5308. In the FM and PM modes, bias/reference signal 5308 is preferably a non-varying signal, often referred to simply as the bias signal. In the AM mode, the oscillating signal 5306 is not modulated, and the bias/reference signal is a function of the information signal 5304. In one embodiment, information signal 5304 is combined with a bias voltage to generate the reference signal 5308. In an alternate embodiment, the information signal 5304 is used without being combined with a bias voltage. Typically, in the AM mode, this bias/reference signal is referred to as the reference signal to distinguish it from the bias signal used in the FM and PM modes. The output of switch 5312 is a harmonically rich signal 5316 which is routed to a "high Q" filter which removes the unwanted frequencies that exist as harmonic components of harmonically rich signal 5316. Desired frequency 5320 is amplified by amplifier module 5322 and routed to transmission module 5324 which outputs a transmission signal 5326. Transmission signal is output by antenna 5328 in this embodiment.

For the FM and PM modulation modes, FIGs. 54A, 54B, and 54C show the combination of the present invention of the transmitter and the universal frequency down-conversion receiver in the half-duplex mode according to an embodiment of the invention. That is, the transceiver can transmit and receive, but it cannot do both simultaneously. It uses a single antenna 5402, a single oscillator 5444/5454 (depending on whether the transmitter is in the FM or PM modulation mode), a single pulse shaper 5438, and a single switch 5420 to transmit and to receive. In the receive function, "Receiver/transmitter" (R/T) switches 5406, 5408, and 5446/5452 (FM or PM) would all be in the receive position, designated by (R). The antenna 5402 receives an EM signal 5404 and routes it through a capacitor 5407. In the FM modulation mode, oscillating signal 5436 is generated by a voltage controlled oscillator (VCO) 5444. Because the transceiver is performing the receive function, switch 5446 connects the input to the VCO 5444 to ground 5448. Thus, VCO 5444 will operate as if it were a simple oscillator. In the PM modulation mode, oscillating signal 5436 is generated by local oscillator 5454 which is routed through phase modulator 5456. Since the transceiver is performing the receive function, switch 5452 is connected to ground 5448, and there is no modulating input to phase modulator. Thus, local oscillator 5454 and phase modulator 5456 operate as if they were a simple oscillator. One skilled in the relevant art(s) will recognize based on the discussion contained

herein that there are numerous embodiments wherein an oscillating signal 5436 can be generated to control the switch 5420.

Oscillating signal 5436 is shaped by pulse shaper 5438 to produce a string of pulses 5440. The string of pulses 5440 cause the switch 5420 to open and close. As a result of the switch opening and closing, a down converted signal 5409 is generated. The down converted signal 5409 is amplified and filtered to create a filtered signal 5413. In an embodiment, filtered signal 5413 is at baseband and, as a result of the down conversion, is demodulated. Thus, a decoder 5414 may not be required except to convert digital to analog or to decrypt the filtered signal 5413. In an alternate embodiment, the filtered signal 5413 is at an "offset" frequency, so that the decoder 5414 is needed to demodulate the filtered signal and create a demodulated baseband signal.

When the transceiver is performing the transmit function, the R/T switches 5406, 5408, and 5446/5452 (FM or PM) are in the (T) position. In the FM modulation mode, an information signal 5450 is connected by switch 5446 to VCO 5444 to create a frequency modulated oscillating signal 5436. In the PM modulation mode switch 5452 connects information signal 5450 to the phase modulator 5456 to create a phase modulated oscillating signal 5436. Oscillation signal 5436 is routed through pulse shaper 5438 to create a string of pulses 5440 which in turn cause switch 5420 to open and close. One terminal of switch 5420 is connected to ground 5442 and the other is connected through switch R/T 5408 and resistor 5423 to a bias signal 5422. The result is a harmonically rich signal 5424 which is routed to a "high Q" filter 5426 which removes the unwanted frequencies that exist as harmonic components of harmonically rich signal 5424. Desired frequency 5428 is amplified by amplifier module 5430 and routed to transmission module 5432 which outputs a transmission signal 5434. Again, because the transceiver is performing the transmit function, R/T switch 5406 connects the transmission signal to the antenna 5402.

In the AM modulation mode, the transceiver operates in the half duplex mode as shown in FIG. 55. The only distinction between this modulation mode and the FM and PM modulation modes described above, is that the oscillating signal 5436 is generated by a local oscillator 5502, and the switch 5420 is connected through the R/T switch 5408 and resistor 5423 to a reference signal 5506. Reference signal 5506 is generated when information signal 5450 and bias signal 5422 are combined by a summing module 5504. It is well known to those skilled in the relevant art(s) that the

information signal 5450 may be used as the reference signal 5506 without being combined with the bias signal 5422, and may be connected directly (through resistor 5423 and R/T switch 5408) to the switch 5420.

**6.2.3 Third Embodiment: The Transmitter of the Present Invention  
Being Used with a Universal Frequency Down Converter in a  
Full-Duplex Mode.**

The full-duplex mode differs from the half-duplex mode in that the transceiver can transmit and receive simultaneously. Referring to FIG. 56, to achieve this, the transceiver preferably uses a separate circuit for each function. A duplexer 5604 is used in the transceiver to permit the sharing of an antenna 5602 for both the transmit and receive functions.

The receiver function performs as follows. The antenna 5602 receives an EM signal 5606 and routes it through a capacitor 5607 to one terminal of a switch 5626. The other terminal of switch 5626 is connected to ground 5628, and the switch is driven as a result of a string of pulses 5624 created by local oscillator 5620 and pulse shaper 5622. The opening and closing of switch 5626 generates a down converted signal 5614. Down converted signal 5614 is routed through an amplifier 5608 and a filter 5610 to generate filtered signal 5616. Filtered signal 5616 may be at baseband and be demodulated or it may be at an "offset" frequency. If filtered signal 5616 is at an offset frequency, decoder 5612 will demodulate it to create the demodulated baseband signal 5618. In a preferred embodiment, however, the filtered signal 5616 will be a demodulated baseband signal, and decoder 5612 may not be required except to convert digital to analog or to decrypt filtered signal 5616. This receiver portion of the transceiver can operate independently from the transmitter portion of the transceiver.

The transmitter function is performed as follows. In the FM and PM modulation modes, an information signal 5648 modulates an oscillating signal 5630. In the AM modulation mode, the oscillating signal 5630 is not modulated. The oscillating signal is shaped by pulse shaper 5632 and a string of pulses 5634 is created. This string of pulses 5634 causes a switch 5636 to open and close. One terminal of switch 5636 is connected to ground 5638, and the other terminal is connected through a resistor 5647 to a bias/reference signal 5646. In the FM and PM modulation modes,

bias/reference signal 5646 is referred to as a bias signal 5646, and it is substantially non-varying. In the AM modulation mode, an information signal 5650 may be combined with the bias signal to create what is referred to as the reference signal 5646. The reference signal 5646 is a function of the information signal 5650. It is well known to those skilled in the relevant art(s) that the information signal 5650 may be used as the bias/reference signal 5646 directly without being summed with a bias signal. A harmonically rich signal 5652 is generated and is filtered by a "high Q" filter 5640, thereby producing a desired signal 5654. The desired signal 5654 is amplified by amplifier 5642 and routed to transmission module 5644. The output of transmission module 5644 is transmission signal 5656. Transmission signal 5656 is routed to duplexer 5604 and then transmitted by antenna 5602. This transmitter portion of the transceiver can operate independently from the receiver portion of the transceiver.

Thus, as described above, the transceiver embodiment the present invention as shown in FIG. 56 can perform full-duplex communications in all modulation modes.

#### *6.2.4 Other Embodiments and Implementations.*

Other embodiments and implementations of the receiver/transmitter of the present invention would be apparent to one skilled in the relevant art(s) based on the discussion herein.

The embodiments and implementations described above are provided for purposes of illustration. These embodiments and implementations are not intended to limit the invention. Alternatives, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments and implementations fall within the scope and spirit of the present invention.

#### *6.3 Summary Description of Down-conversion Using a Universal Frequency Translation Module.*

The following discussion describes down-converting using a Universal Frequency Translation Module. FIG. 71A illustrates an aliasing module 6400 for down-conversion using a universal frequency translation (UFT) module 6402 which down-converts an EM input signal 6404. In particular embodiments, aliasing module

6400 includes a switch 6408 and a capacitor 6410. The electronic alignment of the circuit components is flexible. That is, in one implementation, the switch 6408 is in series with input signal 6404 and capacitor 6410 is shunted to ground (although it may be other than ground in configurations such as differential mode). In a second implementation (see FIG. 71B), the capacitor 6410 is in series with the input signal 6404 and the switch 6408 is shunted to ground (although it may be other than ground in configurations such as differential mode). Aliasing module 6400 with UFT module 6402 can be easily tailored to down-convert a wide variety of electromagnetic signals using aliasing frequencies that are well below the frequencies of the EM input signal 6404.

In one implementation, aliasing module 6400 down-converts the input signal 6404 to an intermediate frequency (IF) signal. In another implementation, the aliasing module 6400 down-converts the input signal 6404 to a demodulated baseband signal. In yet another implementation, the input signal 6404 is a frequency modulated (FM) signal, and the aliasing module 6400 down-converts it to a non-FM signal, such as a phase modulated (PM) signal or an amplitude modulated (AM) signal. Each of the above implementations is described below.

In an embodiment, the control signal 6406 includes a train of pulses that repeat at an aliasing rate that is equal to, or less than, twice the frequency of the input signal 6404. In this embodiment, the control signal 6406 is referred to herein as an aliasing signal because it is below the Nyquist rate for the frequency of the input signal 6404. Preferably, the frequency of control signal 6406 is much less than the input signal 6404.

The train of pulses 6418 as shown in FIG. 71E controls the switch 6408 to alias the input signal 6404 with the control signal 6406 to generate a down-converted output signal 6412. More specifically, in an embodiment, switch 6408 closes on a first edge of each pulse 6420 of FIG. 71E and opens on a second edge of each pulse. When the switch 6408 is closed, the input signal 6404 is coupled to the capacitor 6410, and charge is transferred from the input signal to the capacitor 6410. The charge stored during successive pulses forms down-converted output signal 6412.

Exemplary waveforms are shown in FIGS. 71C-71G.

FIG. 71C illustrates an analog amplitude modulated (AM) carrier signal 6414 that is an example of input signal 6404. For illustrative purposes, in FIG. 71D, an analog AM carrier signal portion 6416 illustrates a portion of the analog AM carrier

signal 6414 on an expanded time scale. The analog AM carrier signal portion 6416 illustrates the analog AM carrier signal 6414 from time  $t_0$  to time  $t_1$ .

FIG. 71E illustrates an exemplary aliasing signal 6418 that is an example of control signal 6406. Aliasing signal 6418 is on approximately the same time scale as the analog AM carrier signal portion 6416. In the example shown in FIG. 71E, the aliasing signal 6418 includes a train of pulses 6420 having negligible apertures that tend towards zero (the invention is not limited to this embodiment, as discussed below). The pulse aperture may also be referred to as the pulse width as will be understood by those skilled in the art(s). The pulses 6420 repeat at an aliasing rate, or pulse repetition rate of aliasing signal 6418. The aliasing rate is determined as described below.

As noted above, the train of pulses 6420 (i.e., control signal 6406) control the switch 6408 to alias the analog AM carrier signal 6416 (i.e., input signal 6404) at the aliasing rate of the aliasing signal 6418. Specifically, in this embodiment, the switch 6408 closes on a first edge of each pulse and opens on a second edge of each pulse. When the switch 6408 is closed, input signal 6404 is coupled to the capacitor 6410, and charge is transferred from the input signal 6404 to the capacitor 6410. The charge transferred during a pulse is referred to herein as an under-sample. Exemplary under-samples 6422 form down-converted signal portion 6424 (FIG. 71F) that corresponds to the analog AM carrier signal portion 6416 (FIG. 71D) and the train of pulses 6420 (FIG. 71E). The charge stored during successive under-samples of AM carrier signal 6414 form the down-converted signal 6424 (FIG. 71F) that is an example of down-converted output signal 6412 (FIGs. 71A and 71B). In FIG. 71G a demodulated baseband signal 6426 represents the demodulated baseband signal 6424 after filtering on a compressed time scale. As illustrated, down-converted signal 6426 has substantially the same "amplitude envelope" as AM carrier signal 6414. Therefore, FIGs. 71C-71G illustrate down-conversion of AM carrier signal 6414.

The waveforms shown in FIGs. 71C-71G are discussed herein for illustrative purposes only, and are not limiting.

The aliasing rate of control signal 6406 determines whether the input signal 6404 is down-converted to an IF signal, down-converted to a demodulated baseband signal, or down-converted from an FM signal to a PM or an AM signal. Generally, relationships between the input signal 6404, the aliasing rate of the control signal 6406, and the down-converted output signal 6412 are illustrated below:

$$(\text{Freq. of input signal 6404}) = n \cdot (\text{Freq. of control signal 6406}) \pm$$

$$(\text{Freq. of down-converted output signal 6412})$$

For the examples contained herein, only the "+" condition will be discussed. The value of  $n$  represents a harmonic or sub-harmonic of input signal 6404 (e.g.,  $n = 0.5, 1, 2, 3, \dots$ ).

When the aliasing rate of control signal 6406 is off-set from the frequency of input signal 6404, or off-set from a harmonic or sub-harmonic thereof, input signal 6404 is down-converted to an IF signal. This is because the under-sampling pulses occur at different phases of subsequent cycles of input signal 6404. As a result, the under-samples form a lower frequency oscillating pattern. If the input signal 6404 includes lower frequency changes, such as amplitude, frequency, phase, etc., or any combination thereof, the charge stored during associated under-samples reflects the lower frequency changes, resulting in similar changes on the down-converted IF signal. For example, to down-convert a 901 MHz input signal to a 1 MHz IF signal, the frequency of the control signal 6406 would be calculated as follows:

$$(\text{Freq}_{\text{input}} - \text{Freq}_{\text{IF}})/n = \text{Freq}_{\text{control}}$$

$$(901 \text{ MHz} - 1 \text{ MHz})/n = 900/n$$

For  $n = 0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal 6406 would be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc.

Alternatively, when the aliasing rate of the control signal 6406 is substantially equal to the frequency of the input signal 6404, or substantially equal to a harmonic or sub-harmonic thereof, input signal 6404 is directly down-converted to a demodulated baseband signal. This is because, without modulation, the under-sampling pulses occur at the same point of subsequent cycles of the input signal 6404. As a result, the under-samples form a constant output baseband signal. If the input signal 6404 includes lower frequency changes, such as amplitude, frequency, phase, etc., or any combination thereof, the charge stored during associated under-samples reflects the lower frequency changes, resulting in similar changes on the demodulated baseband signal. For example, to directly down-convert a 900 MHz input signal to a demodulated baseband signal (i.e., zero IF), the frequency of the control signal 6406 would be calculated as follows:

$$\begin{aligned}(\text{Freq}_{\text{input}} - \text{Freq}_{\text{IF}})/n &= \text{Freq}_{\text{control}} \\(900 \text{ MHz} - 0 \text{ MHz})/n &= 900 \text{ MHz}/n\end{aligned}$$

For  $n = 0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal 6406 should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc.

Alternatively, to down-convert an input FM signal to a non-FM signal, a frequency within the FM bandwidth must be down-converted to baseband (i.e., zero IF). As an example, to down-convert a frequency shift keying (FSK) signal (a sub-set of FM) to a phase shift keying (PSK) signal (a subset of PM), the mid-point between a lower frequency  $F_1$  and an upper frequency  $F_2$  (that is,  $[(F_1 + F_2) \div 2]$ ) of the FSK signal is down-converted to zero IF. For example, to down-convert an FSK signal having  $F_1$  equal to 899 MHz and  $F_2$  equal to 901 MHz, to a PSK signal, the aliasing rate of the control signal 6406 would be calculated as follows:

$$\begin{aligned}\text{Frequency of the input} &= (F_1 + F_2) \div 2 \\&= (899 \text{ MHz} + 901 \text{ MHz}) \div 2 \\&= 900 \text{ MHz}\end{aligned}$$

Frequency of the down-converted signal = 0 (i.e., baseband)

$$\begin{aligned}(\text{Freq}_{\text{input}} - \text{Freq}_{\text{IF}})/n &= \text{Freq}_{\text{control}} \\(900 \text{ MHz} - 0 \text{ MHz})/n &= 900 \text{ MHz}/n\end{aligned}$$

For  $n = 0.5, 1, 2, 3$ , etc., the frequency of the control signal 6406 should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc. The frequency of the down-converted PSK signal is substantially equal to one half the difference between the lower frequency  $F_1$  and the upper frequency  $F_2$ .

As another example, to down-convert a FSK signal to an amplitude shift keying (ASK) signal (a subset of AM), either the lower frequency  $F_1$  or the upper frequency  $F_2$  of the FSK signal is down-converted to zero IF. For example, to down-convert an FSK signal having  $F_1$  equal to 900 MHz and  $F_2$  equal to 901 MHz, to an ASK signal, the aliasing rate of the control signal 6406 should be substantially equal to:

$$(900 \text{ MHz} - 0 \text{ MHz})/n = 900 \text{ MHz}/n, \text{ or}$$

$$(901 \text{ MHz} - 0 \text{ MHz})/n = 901 \text{ MHz}/n.$$

For the former case of  $900 \text{ MHz}/n$ , and for  $n = 0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal 6406 should be substantially equal to 1.8 GHz, 900 MHz, 450 MHz, 300 MHz, 225 MHz, etc. For the latter case of  $901 \text{ MHz}/n$ , and for  $n = 0.5, 1, 2, 3, 4$ , etc., the frequency of the control signal 6406 should be substantially equal to 1.802 GHz, 901 MHz, 450.5 MHz, 300.333 MHz, 225.25 MHz, etc. The frequency of the down-converted AM signal is substantially equal to the difference between the lower frequency  $F_1$  and the upper frequency  $F_2$  (i.e., 1 MHz).

In an embodiment, the pulses of the control signal 6406 have negligible apertures that tend towards zero. This makes the UFT module 6402 a high input impedance device. This configuration is useful for situations where minimal disturbance of the input signal may be desired.

In another embodiment, the pulses of the control signal 6406 have non-negligible apertures that tend away from zero. This makes the UFT module 6402 a lower input impedance device. This allows the lower input impedance of the UFT module 6402 to be substantially matched with a source impedance of the input signal 6404. This also improves the energy transfer from the input signal 6404 to the down-converted output signal 6412, and hence the efficiency and signal to noise (s/n) ratio of UFT module 6402.

When the pulses of control signal 6406 have non-negligible apertures, aliasing module 6400 is referred to interchangeably herein as an energy transfer module or a gated transfer module, and control signal 6406 is referred to as an energy transfer signal. Exemplary systems and methods for generating and optimizing control signal 6406 and for otherwise improving energy transfer and/or signal to noise ratio in an energy transfer module are described below.

### 6.3.1 *Optional Energy Transfer Signal Module*

FIG. 93 illustrates an energy transfer system 9301 that includes an optional energy transfer signal module 9302, which can perform any of a variety of functions or combinations of functions including, but not limited to, generating an energy transfer signal 9309.

In an embodiment, optional energy transfer signal module 9302 includes an aperture generator, an example of which is illustrated in FIG. 92C as an aperture generator 9220. Aperture generator 9220 generates non-negligible aperture pulses 9226 from an input signal 9224. Input signal 9224 can be any type of periodic signal, including, but not limited to, a sinusoid, a square wave, a saw-tooth wave, etc. Systems for generating input signal 9224 are described below.

The width or aperture of pulses 9226 is determined by delay through branch 9222 of aperture generator 9220. Generally, as the desired pulse width increases, the difficulty in meeting the requirements of aperture generator 9220 decrease. In other words, to generate non-negligible aperture pulses for a given EM input frequency, the components used in exemplary aperture generator 9220 do not require as fast reaction times as those that are required in an under-sampling system operating with the same EM input frequency.

The exemplary logic and implementation shown in aperture generator 9220 are provided for illustrative purposes only, and are not limiting. The actual logic employed can take many forms. Exemplary aperture generator 9220 includes an optional inverter 9228, which is shown for polarity consistency with other examples provided herein.

An exemplary implementation of aperture generator 9220 is illustrated in FIG. 92D. Additional examples of aperture generation logic are provided in FIGs. 92A and 92B. FIG. 92A illustrates a rising edge pulse generator 9240, which generates pulses 9226 on rising edges of input signal 9224. FIG. 92B illustrates a falling edge pulse generator 9250, which generates pulses 9226 on falling edges of input signal 9224.

In an embodiment, input signal 9224 is generated externally of optional energy transfer signal module 9302, as illustrated in FIG. 93. Alternatively, input signal 9224 is generated internally by optional energy transfer signal module 9302. Input signal 9224 can be generated by an oscillator, as illustrated in FIG. 92E by an oscillator 9230. Oscillator 9230 can be internal to optional energy transfer signal module 9302 or external to optional energy transfer signal module 9302. Oscillator 9230 can be external to energy transfer system 9301. The output of oscillator 9230 may be any periodic waveform.

The type of down-conversion performed by energy transfer system 9301 depends upon the aliasing rate of energy transfer signal 9309, which is determined by the frequency of pulses 9226. The frequency of pulses 9226 is determined by the frequency of input signal 9224.

For example, when the frequency of input signal 9224 is substantially equal to a harmonic or a sub-harmonic of EM signal 9303, EM signal 9303 is directly down-converted to baseband (e.g. when EM signal is an AM signal or a PM signal), or converted from FM to a non-FM signal. When the frequency of input signal 9224 is substantially equal to a harmonic or a sub-harmonic of a difference frequency, EM signal 9303 is down-converted to an intermediate signal.

Optional energy transfer signal module 9302 can be implemented in hardware, software, firmware, or any combination thereof.

### 6.3.2 *Smoothing the Down-Converted Signal*

Referring to FIG. 71A, down-converted output signal 6412 may be smoothed by filtering as desired.

### 6.3.3 *Impedance Matching*

Referring to FIGs. 71A and 71B, energy transfer module 6400 has input and output impedances generally defined by (1) the duty cycle of the switch module (i.e., UFT module 6402), and (2) the impedance of the storage module (e.g., capacitor 6410), at the frequencies of interest (e.g. at the EM input, and intermediate/baseband frequencies).

Starting with an aperture width of approximately one-half of the period of the EM signal being down-converted as a preferred embodiment, this aperture width (e.g. the "closed time") can be decreased. As the aperture width is decreased, the characteristic impedance at the input and the output of the energy transfer module increases. Alternatively, as the aperture width increases from one-half of the period of the EM signal being down-converted, the impedance of the energy transfer module decreases.

One of the steps in determining the characteristic input impedance of the energy transfer module could be to measure its value. In an embodiment, the energy transfer module's characteristic input impedance is 300 ohms. An impedance matching circuit can be used to efficiently couple an input EM signal that has a source impedance of, for example, 50 ohms, with the energy transfer module's impedance of, for example, 300 ohms. Matching these impedances can be accomplished in various manners, including

providing the necessary impedance directly or the use of an impedance match circuit as described below.

Referring to FIG. 94, an impedance matched aliasing module 9402 is shown comprising an input impedance match module 9406, an aliasing module 9404, and an output impedance match module 9408. By way of example, and not meant to be limiting, FIG. 94 illustrates a specific embodiment using an RF signal 9414 as an input. Assuming that an impedance 9412 is, for example, a relatively low impedance of approximately 50 Ohms, and an input impedance 9416 is, for example, approximately 300 Ohms, an initial configuration for input impedance match module 9406 can be configured as shown in FIG. 96 and include an inductor 9606 and a capacitor 9608. The configuration of inductor 9606 and capacitor 9608 is a possible configuration when going from a low impedance to a high impedance. Inductor 9606 and capacitor 9608 constitute an "L network" matched filter. The calculation of the values for inductor 9606 and capacitor 9608 is well known to those skilled in the relevant arts.

The output characteristic impedance can be impedance matched to take into consideration the desired output frequencies. One of the steps in determining the characteristic output impedance of the energy transfer module could be to measure its value. Balancing the very low impedance of the storage module at the input EM frequency, the storage module should have an impedance at the desired output frequencies that is preferably greater than or equal to the load that is intended to be driven (for example, in an embodiment, storage module impedance at a desired 1MHz output frequency is 2K ohm and the desired load to be driven is 50 ohms). An additional benefit of impedance matching is that filtering of unwanted signals can also be accomplished with the same components.

In an embodiment, the energy transfer module's characteristic output impedance is, for example, 2K ohms. An impedance matching circuit can be used to efficiently couple the down-converted signal with an output impedance of, for example, 2K ohms, to a load of, for example, 50 ohms. Matching these impedances can be accomplished in various manners, including providing the necessary load impedance directly or the use of an impedance match circuit as described below.

When matching from a high impedance to a low impedance, a capacitor 9614 and an inductor 9616 can be configured as shown in FIG. 96. Capacitor 9614 and inductor 9616 constitute an "L network" matched filter. The calculation of the values for capacitor 9614 and inductor 9616 is well known to those skilled in the relevant arts.

The configuration of input impedance match module 9406 and output impedance match module 9408 are considered to be initial starting points for impedance matching, in accordance with the present invention. In some situations, the initial designs may be suitable without further optimization. In other situations, the initial designs can be optimized in accordance with other various design criteria and considerations.

As other optional optimizing structures and/or components are used, their affect on the characteristic impedance of the energy transfer module should be taken into account in the match along with their own original criteria.

#### 6.3.4 Tanks and Resonant Structures

Resonant tank and other resonant structures can be used to further optimize the energy transfer characteristics of the invention. For example, resonant structures, resonant about the input frequency, can be used to store energy from the input signal when the switch is open, a period during which one may conclude that the architecture would otherwise be limited in its maximum possible efficiency. Resonant tank and other resonant structures can include, but are not limited to, surface acoustic wave (SAW) filters, dielectric resonators, diplexers, capacitors, inductors, etc.

An exemplary embodiment is shown in FIG. 106A. Two additional embodiments are shown in FIG. 101 and FIG. 109. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention. These implementations take advantage of properties of series and parallel (tank) resonant circuits.

FIG. 106A illustrates parallel tank circuits in a differential implementation. A first parallel resonant or tank circuit (tank1) consists of a capacitor 10638 and an inductor 10620. A second tank circuit (tank2) consists of a capacitor 10634 and an inductor 10636.

As is understood by one skilled in the relevant art(s), parallel tank circuits provide:

- low impedance to frequencies below resonance;
- low impedance to frequencies above resonance; and
- high impedance to frequencies at and near resonance.

In the illustrated example of FIG. 106A, the first and second tank circuits resonate at approximately 920 MHz. At and near resonance, the impedance of these circuits is relatively high. Therefore, in the circuit configuration shown in FIG 106A, both tank circuits appear as relatively high impedance to the input frequency of 950 MHz, while simultaneously appearing as relatively low impedance to frequencies in the desired output range of 50 MHz.

An energy transfer signal 10642 controls a switch 10614. When energy transfer signal 10642 controls switch 10614 to open and close, high frequency signal components will not pass through tank1 or tank2. However, the lower signal components (50MHz in this embodiment) generated by the system will pass through tank1 and tank2 with little attenuation. The effect of tank1 and tank2 is to further separate the input and output signals from the same node, thereby producing a more stable input and output impedance. Capacitors 10618 and 10640 act to store the 50 MHz output signal energy between energy transfer pulses.

Further energy transfer optimization is provided by placing an inductor 10610 in series with a storage capacitor 10612 as shown. In the illustrated example, the series resonant frequency of this circuit arrangement is approximately 1 GHz. This circuit increases the energy transfer characteristic of the system. The ratio of the impedance of inductor 10610 and the impedance of storage capacitor 10612 is preferably kept relatively small so that the majority of the energy available will be transferred to storage capacitor 10612 during operation. Exemplary output signals A and B are illustrated in FIGs. 106B and 106C, respectively.

In FIG. 106A, circuit components 10604 and 10606 form an input impedance match. Circuit components 10632 and 10630 form an output impedance match into a 50 ohm resistor 10628. Circuit components 10622 and 10624 form a second output impedance match into a 50 ohm resistor 10626. Capacitors 10608 and 10612 act as storage capacitors for the embodiment. A voltage source 10646 and a resistor 10602 generate a 950 MHz signal with a 50 ohm output impedance, which are used as the input to the circuit. A circuit element 10616 includes a 150 MHz oscillator and a pulse generator, which are used to generate energy transfer signal 10642.

FIG. 101 illustrates a shunt tank circuit 10110 in a single-ended to-single-ended system 10112. Similarly, FIG. 109 illustrates a shunt tank circuit 10910 in a system 10912. Shunt tank circuits 10110 and 10910 lower driving source impedance, which improves transient response. Shunt tank circuits 10110 and 10910 are able store the

energy from the input signal and provide a low driving source impedance to transfer that energy throughout the aperture of the closed switch. The transient nature of the switch aperture can be viewed as having a response that, in addition to including the input frequency, has large component frequencies above the input frequency, (i.e. higher frequencies than the input frequency are also able to effectively pass through the aperture). Resonant circuits or structures, for example shunt tank circuits 10110 or 10910, can take advantage of this by being able to transfer energy throughout the transient frequency response of the switch (i.e. the capacitor in the resonant tank appears as a low driving source impedance during the transient period of the aperture).

The exemplary tank and resonant structures described above are for illustrative purposes and are not limiting. Alternate configurations can be used. The various resonant tanks and structures discussed can be combined or used independently as is now apparent.

### 6.3.5 Charge and Power Transfer Concepts

Concepts of charge transfer are now described with reference to FIGs. 117A-F. FIG. 117A illustrates a circuit 11702, including a switch S and a capacitor 11706 having a capacitance "C." The switch S is controlled by a control signal 11708, which includes pulses 11710 having apertures of duration "T."

In FIG. 117B, Equation 13a illustrates that the charge "q" on a capacitor having a capacitance "C," such as the capacitor 11706, is proportional to the voltage "V" across the capacitor, where:

q = Charge in Coulombs

C = Capacitance in Farads

V = Voltage in Volts

Where the voltage "V" is represented by Equation 13b and where

A = Input Signal Amplitude,

Equation 13a can be rewritten as Equation 13c. The change in charge over time is illustrated as " $\Delta q(t)$ " in Equation 14a, which can be rewritten as Equation 14b. Using the trigonometric identity of Equation 15, Equation 14b becomes Equation 16, which can be rewritten as Equation 17.

Note that the sine term in Equation 17 is a function of the aperture "T" only. Thus, " $\Delta q(t)$ " is at a maximum when "T" is equal to an odd multiple of  $\pi$  (i.e.,  $\pi$ ,  $3\pi$ ,

$5\pi, \dots$ ). Therefore, capacitor 11706 experiences the greatest change in charge when the aperture "T" has a value of  $\pi$  or a time interval representative of 180 degrees of the input sinusoid. Conversely, when "T" is equal to  $2\pi, 4\pi, 6\pi, \dots$ , minimal charge is transferred.

5 Equations 18, 19, and 20 solve for "q(t)" by integrating Equation 13a, allowing the charge on capacitor 11706 with respect to time to be graphed on the same axis as the input sinusoid, "sin(t)," as illustrated in the graph of FIG. 117C. As the aperture "T" decreases in value or tends toward an impulse, the phase between the charge on the capacitor "C" (or "q(t)") and "sin(t)" tend toward zero. This is illustrated in the graph  
10 of FIG. 117D, which indicates that the maximum impulse charge transfer occurs near the input voltage maxima. As this graph indicates, considerably less charge is transferred as the value of "T" decreases.

Power/charge relationships are illustrated in Equations 21-26 of FIG. 117E, where it is shown that power is proportional to charge, and transferred charge is  
15 inversely proportional to insertion loss.

Concepts of insertion loss are illustrated in FIG. 117F. Generally, the noise figure of a lossy passive device is numerically equal to the device insertion loss. Alternatively, the noise figure for any device cannot be less than its insertion loss. Insertion loss can be expressed by Equation 27 or 28.

20 From the above discussion, it is observed that as the aperture "T" increases, more charge is transferred from the input to capacitor 11706, which increases power transfer from the input to the output. It has been observed that it is not necessary to accurately reproduce the input voltage at the output because relative modulated amplitude and phase information is retained in the transferred power.

### 25 *6.3.6 Optimizing and Adjusting the Non-Negligible Aperture Width/Duration*

#### *6.3.6.1 Varying the Input and Output Impedances*

In an embodiment of the invention, the energy transfer signal (i.e., control signal 6406 in FIG. 71A), is used to vary the input impedance seen by EM Signal 6404  
30 and to vary the output impedance driving a load. An example of this embodiment is

described below using a gated transfer module 9701 shown in FIG. 97A. The method described below is not limited to gated transfer module 9701.

In FIG. 97A, when switch 9706 is closed, the impedance looking into circuit 9702 is substantially the impedance of a storage module, illustrated here as a storage capacitance 9708, in parallel with the impedance of a load 9712. When switch 9706 is open, the impedance at a point 9714 approaches infinity. It follows that the average impedance at point 9714 can be varied from the impedance of the storage module illustrated in parallel with load 9712, to the highest obtainable impedance when switch 9706 is open, by varying the ratio of the time that switch 9706 is open to the time switch 9706 is closed. Switch 9706 is controlled by an energy transfer signal 9710. Thus the impedance at point 9714 can be varied by controlling the aperture width of the energy transfer signal in conjunction with the aliasing rate.

An exemplary method of altering energy transfer signal 9710 of FIG. 97A is now described with reference to FIG. 95A, where a circuit 9502 receives an input oscillating signal 9506 and outputs a pulse train shown as doubler output signal 9504. Circuit 9502 can be used to generate energy transfer signal 9710. Exemplary waveforms of 9504 are shown on FIG. 95C.

It can be shown that by varying the delay of the signal propagated by an inverter 9508, the width of the pulses in the doubler output signal 9504 can be varied. Increasing the delay of the signal propagated by inverter 9508, increases the width of the pulses. The signal propagated by inverter 9508 can be delayed by introducing a R/C low pass network in the output of inverter 9508. Other means of altering the delay of the signal propagated by inverter 9508 will be well known to those skilled in the art.

#### *6.3.6.2 Real Time Aperture Control*

In an embodiment, the aperture width/duration is adjusted in real time. For example, referring to the timing diagrams in FIGs. 110B-F, a clock signal 11014 (FIG. 110B) is used to generate an energy transfer signal 11016 (FIG. 110F), which includes energy transfer pluses 11018, having variable apertures 11020. In an embodiment, clock signal 11014 is inverted as illustrated by an inverted clock signal 11022 (FIG. 110D). Clock signal 11014 is also delayed, as illustrated by a delayed clock signal 11024 (FIG. 110E). Inverted clock signal 11022 and delayed clock signal 11024 are then combined by an AND gate 11008, generating energy transfer signal 11016, which

is "high" - energy transfer pulses 11018 - when delayed clock signal 11024 and inverted clock signal 11022 are both "high." The amount of delay imparted to delayed clock signal 11024 substantially determines the width or duration of variable apertures 11020. By varying the delay in real time, the apertures are adjusted in real time.

5 In an alternative implementation, inverted clock signal 11022 is delayed relative to clock signal 11014, and then combined with clock signal 11014 by AND gate 11008. Alternatively, clock signal 11014 is delayed and then inverted. The result is then combined with clock signal 11014 by AND gate 11008.

FIG. 110A illustrates an exemplary real time aperture control system 11002 that can be used to adjust apertures in real time. Real time aperture control system 11002 includes an RC circuit 11004, which includes a voltage variable capacitor 11012 and a resistor 11026. Real time aperture control system 11002 also includes an inverter 11006 and an AND gate 11008. Optionally, AND gate 11008 includes an optional enable input 11010 for enabling/disabling AND gate 11008. Real time aperture control system 11002 optionally includes an amplifier 11028.

Operation of real time aperture control system 11002 is described with reference to the timing diagrams of FIGs. 110B-F. Real time aperture control system 11002 receives clock signal 11014, which is provided to both inverter 11006 and to RC circuit 11004. Inverter 11006 outputs inverted clock signal 11022 and presents it to AND gate 11008. RC circuit 11004 delays clock signal 11014 and outputs delayed clock signal 11024. The delay is determined primarily by the capacitance of voltage variable capacitor 11012. Generally, as the capacitance decreases, the delay decreases.

20 Delayed clock signal 11024 is optionally amplified by optional amplifier 11028, before being presented to AND gate 11008. Amplification is desired, for example, where the RC constant of RC circuit 11004 attenuates the signal below the threshold of AND gate 11008.

AND gate 11008 combines delayed clock signal 11024, inverted clock signal 11022, and optional enable signal 11010, to generate energy transfer signal 11016. Apertures 11020 are adjusted in real time by varying the voltage to voltage variable capacitor 11012.

30 In an embodiment, apertures 11020 are controlled to optimize power transfer. For example, in an embodiment, apertures 11020 are controlled to maximize power transfer. Alternatively, apertures 11020 are controlled for variable gain control (e.g.

automatic gain control - AGC). In this embodiment, power transfer is reduced by reducing apertures 11020.

As can now be readily seen from this disclosure, many of the aperture circuits presented, and others, can be modified as in circuits illustrated in FIGs. 92A-D. Modification or selection of the aperture can be done at the design level to remain a fixed value in the circuit, or in an alternative embodiment, may be dynamically adjusted to compensate for, or address, various design goals such as receiving RF signals with enhanced efficiency that are in distinctively different bands of operation, e.g. RF signals at 900 MHz and 1.8 GHz.

### 6.3.7 Adding a Bypass Network

In an embodiment of the invention, a bypass network is added to improve the efficiency of the energy transfer module. Such a bypass network can be viewed as a means of synthetic aperture widening. Components for a bypass network are selected so that the bypass network appears substantially lower impedance to transients of the switch module (i.e., frequencies greater than the received EM signal) and appears as a moderate to high impedance to the input EM signal (e.g., greater than 100 Ohms at the RF frequency).

The time that the input signal is now connected to the opposite side of the switch module is lengthened due to the shaping caused by this network, which in simple realizations may be a capacitor or series resonant inductor-capacitor. A network that is series resonant above the input frequency would be a typical implementation. This shaping improves the conversion efficiency of an input signal that would otherwise, if one considered the aperture of the energy transfer signal only, be relatively low in frequency to be optimal.

For example, referring to FIG. 107 a bypass network 10702 (shown in this instance as a capacitor 10712), is shown bypassing a switch module 10704. In this embodiment bypass network 10702 increases the efficiency of the energy transfer module when, for example, less than optimal aperture widths were chosen for a given input frequency on an energy transfer signal 10706. Bypass network 10702 could be of different configurations than shown in FIG 107. Such an alternate is illustrated in FIG.103. Similarly, FIG. 108 illustrates another exemplary bypass network 10802, including a capacitor 10804

The following discussion will demonstrate the effects of a minimized aperture and the benefit provided by a bypassing network. Beginning with an initial circuit having a 550ps aperture in FIG. 111, the peak-to-peak output ( $V_{pp}$ ) is seen to be 2.8mV $_{pp}$  applied to a 50 ohm load in FIG. 115A. Changing the aperture to 270ps as shown in FIG. 112 results in a diminished output of 2.5V $_{pp}$  applied to a 50 ohm load as shown in FIG. 115B. To compensate for this loss, a bypass network may be added, a specific implementation is provided in FIG. 113. The result of this addition is that 3.2V $_{pp}$  can now be applied to the 50 ohm load as shown in FIG. 116A. The circuit with the bypass network in FIG. 113 also had three values adjusted in the surrounding circuit to compensate for the impedance changes introduced by the bypass network and narrowed aperture. FIG. 114 verifies that those changes added to the circuit, but without the bypass network, did not themselves bring about the increased efficiency demonstrated by the embodiment in FIG. 113 with the bypass network. FIG. 116B shows the result of using the circuit in FIG. 114 in which only 1.88V $_{pp}$  was able to be applied to a 50 ohm load.

### 6.3.8 *Modifying the Energy Transfer Signal Using Feedback*

FIG. 93 shows an embodiment of a system 9301 which uses down-converted Signal 9307 as a feedback 9306 to control various characteristics of the energy transfer module 9305 to modify the down-converted signal 9307.

Generally, the amplitude of the down-converted signal 9307 varies as a function of the frequency and phase differences between the EM signal 9303 and the energy transfer signal 9309. In an embodiment, the down-converted signal 9307 is used as the feedback 9306 to control the frequency and phase relationship between the EM signal 9303 and the energy transfer signal 9309. This can be accomplished using the exemplary logic in FIG 98A. The exemplary circuit in FIG. 98A can be included in optional energy transfer signal module 9302. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention. In this embodiment a state-machine is used as an example.

In the example of FIG. 98A, a state machine 9804 reads an analog to digital converter, A/D 9802, and controls a digital to analog converter, DAC 9806. In an embodiment, state machine 9804 includes 2 memory locations, *Previous* and *Current*,

to store and recall the results of reading A/D 9802. In an embodiment, state machine 9804 uses at least one memory flag.

DAC 9806 controls an input to a voltage controlled oscillator, VCO 9808. VCO 9808 controls a frequency input of a pulse generator 9810, which, in an embodiment, is substantially similar to the pulse generator shown in FIG. 92C. Pulse generator 9810 generates energy transfer signal 9309.

In an embodiment, state machine 9804 operates in accordance with a state machine flowchart 9819 in FIG. 98B. The result of this operation is to modify the frequency and phase relationship between energy transfer signal 9309 and EM signal 9303, to substantially maintain the amplitude of down-converted signal 9307 at an optimum level.

The amplitude of down-converted signal 9307 can be made to vary with the amplitude of energy transfer signal 9309. In an embodiment where a switch module 9111 is a FET as shown in FIG 91A, wherein a gate 9104 receives energy transfer signal 9113, the amplitude of energy transfer signal 9113 can determine the "on" resistance of the FET, which affects the amplitude of down-converted signal 9115. Optional energy transfer signal module 9302, as shown in FIG. 98C, can be an analog circuit that enables an automatic gain control function. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention.

### ***6.3.9 Other Implementations***

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

### ***6.3.10 Exemplary Energy Transfer Down-Converters***

Exemplary implementations are described below for illustrative purposes. The invention is not limited to these examples.

FIG. 99 is a schematic diagram of an exemplary circuit to down convert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock.

FIG. 100 shows exemplary simulation waveforms for the circuit of FIG. 99. Waveform 9902 is the input to the circuit showing the distortions caused by the switch closure. Waveform 9904 is the unfiltered output at the storage unit. Waveform 9906 is the impedance matched output of the downconverter on a different time scale.

FIG. 101 is a schematic diagram of an exemplary circuit to downconvert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock. The circuit has additional tank circuitry to improve conversion efficiency.

FIG. 102 shows exemplary simulation waveforms for the circuit of FIG. 101. Waveform 10102 is the input to the circuit showing the distortions caused by the switch closure. Waveform 10104 is the unfiltered output at the storage unit. Waveform 10106 is the output of the downconverter after the impedance match circuit.

FIG. 103 is a schematic diagram of an exemplary circuit to downconvert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock. The circuit has switch bypass circuitry to improve conversion efficiency.

FIG. 104 shows exemplary simulation waveforms for the circuit of FIG. 103. Waveform 10302 is the input to the circuit showing the distortions caused by the switch closure. Waveform 10304 is the unfiltered output at the storage unit. Waveform 10306 is the output of the downconverter after the impedance match circuit.

FIG. 105 shows a schematic of the exemplary circuit in FIG. 99 connected to an FSK source that alternates between 913 and 917 MHz, at a baud rate of 500 Kbaud.

## ***7. Designing a Transmitter According to an Embodiment of the Present Invention.***

This section (including its subsections) provides a high-level description of an exemplary process to be used to design a transmitter according to an embodiment of the present invention. The techniques described herein are also applicable to designing a frequency up-converter for any application, and for designing the applications

5 themselves. The descriptions are contained herein for illustrative purposes and are not limiting. Alternatives (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternatives fall within the scope and spirit of the present invention, and the invention is intended and adapted to include such alternative.

10 The discussion herein describes an exemplary process to be used to design a transmitter according to an embodiment of the present invention. An exemplary circuit for a transmitter of the present invention operating in the FM embodiment is shown in FIG. 57A. Likewise, FIG. 57B illustrates the transmitter of the present invention operating in the PM embodiment, and FIG. 57C shows the transmitter of the present invention operating in the AM embodiment. These circuits have been shown in previous figures, but are presented here to facilitate the discussion of the design. As the "I/Q" embodiment of the present invention is a subset of the PM embodiment, it will not be shown in a separate figure here, since the design approach will be very similar to that for the PM embodiment.

15 Depending on the application and on the implementation, some of the design considerations may not apply. For example, and without limitation, in some cases it may not be necessary to optimize the pulse width or to include an amplifier.

### 20 7.1 *Frequency of the Transmission Signal.*

25 The first step in the design process is to determine the frequency of the desired transmission signal 5714. This is typically determined by the application for which the transmitter is to be used. The present invention is for a transmitter that can be used for all frequencies within the electromagnetic (EM) spectrum. For the examples herein, the explanation will focus on the use of the transmitter in the 900 MHz to 950 MHz range. Those skilled in the relevant art(s) will recognize that the analysis contained herein may be used for any frequency or frequency range.

### 7.2 *Characteristics of the Transmission Signal.*

Once the frequency of the desired transmission signal 5714 is known, the characteristics of the signal must be determined. These characteristics include, but are not limited to, whether the transmitter will operate at a fixed frequency or over a range of frequencies, and if it is to operate over a range of frequencies, whether those frequencies are continuous or are divided into discrete "channels." If the frequency range is divided into discrete channels, the spacing between the channels must be ascertained. As an example, cordless phones operating in this frequency range may operate on discrete channels that are 50 KHz apart. That is, if the cordless phones operate in the 905 MHz to 915 MHz range (inclusive), the channels could be found at 905.000, 905.050, 905.100, ... , 914.900, 914.950, and 915.000.

### 7.3 *Modulation Scheme.*

Another characteristic that must be ascertained is the desired modulation scheme that is to be used. As described above in sections 2.1-2.2.4, above, these modulation schemes include FM, PM, AM, etc., and any combination or subset thereof, specifically including the widely used "I/Q" subset of PM. Just as the frequency of the desired transmission signal 5714 is typically determined by the intended application, so too is the modulation scheme.

### 7.4 *Characteristics of the Information Signal.*

The characteristics of an information signal 5702 are also factors in the design of the transmitter circuit. Specifically, the bandwidth of the information signal 5702 defines the minimum frequency for an oscillating signal 5704, 5738, 5744 (for the FM, PM, and AM modes, respectively).

### 7.5 *Characteristics of the Oscillating Signal.*

The desired frequency of the oscillating signal 5704, 5738, 5744 is also a function of the frequency and characteristics of the desired transmission signal 5714. Also, the frequency and characteristics of the desired transmission signal 5714 are

factors in determining the pulse width of the pulses in a string of pulses 5706. Note that the frequency of the oscillating signal 5704, 5738, 5744 is substantially the same as the frequency of the string of pulses 5706. (An exception, which is discussed below, is when a pulse shaping circuit 5722 increases the frequency of the oscillating signal 5704, 5738, 5744 in a manner similar to that described above in section 4.3.2.) Note also that the frequency and pulse width of the string of pulses 5706 is substantially the same as the frequency and pulse width of a harmonically rich signal 5708.

### *7.5.1 Frequency of the Oscillating Signal.*

The frequency of the oscillating signal 5704, 5738, 5744 must be a subharmonic of the frequency of the desired transmission signal 5714. A subharmonic is the quotient obtained by dividing the fundamental frequency, in this case the frequency of the desired transmission signal 5714, by an integer. When describing the frequency of certain signals, reference is often made herein to a specific value. It is understood by those skilled in the relevant art(s) that this reference is to the nominal center frequency of the signal, and that the actual signal may vary in frequency above and below this nominal center frequency based on the desired modulation technique being used in the circuit. As an example to be used herein, if the frequency of the desired transmission signal is 910 MHz, and it is to be used in an FM mode where, for example, the frequency range of the modulation is 40 KHz, the actual frequency of the signal will vary  $\pm 20$  KHz around the nominal center frequency as a function of the information being transmitted. That is, the frequency of the desired transmission signal will actually range between 909.980 MHz and 910.020 MHz.

The first ten subharmonics of a 910.000 MHz signal are given below.

| <u>harmonic</u> | <u>frequency</u> |
|-----------------|------------------|
| 1 <sup>st</sup> | 910.000 MHz      |
| 2 <sup>nd</sup> | 455.000          |
| 3 <sup>rd</sup> | 303.333...       |
| 4 <sup>th</sup> | 227.500          |
| 5 <sup>th</sup> | 182.000          |

WO 00/24116

- 117 -

PCT/US99/24127

|                  |            |
|------------------|------------|
| 6 <sup>th</sup>  | 151.666... |
| 7 <sup>th</sup>  | 130.000    |
| 8 <sup>th</sup>  | 113.750    |
| 9 <sup>th</sup>  | 101.111... |
| 10 <sup>th</sup> | 91.000     |

5

The oscillating signal 5704, 5738, 5744 can be at any one of these frequencies or, if desired, at a lower subharmonic. For discussion herein, the 9<sup>th</sup> subharmonic will be chosen. Those skilled in the relevant art(s) will understand that the analysis herein applies regardless of which harmonic is chosen. Thus the nominal center frequency of the oscillating signal 5704, 5738, 5744 will be 101.1111 MHz. Recalling that in the FM mode, the frequency of the desired transmission signal 5714 is actually  $910.000 \text{ MHz} \pm 0.020 \text{ MHz}$ , it can be shown that the frequency of the oscillating signal 5704 will vary  $\pm 0.00222 \text{ MHz}$  (i.e., from 101.10889 MHz to 101.11333 MHz). The frequency and frequency sensitivity of the oscillating signal 5704 will drive the selection or design of the voltage controlled oscillator (VCO) 5720.

15

Another frequency consideration is the overall frequency range of the desired transmission signal. That is, if the transmitter is to be used in the cordless phone of the above example and will transmit on all channels between 905 MHz and 915 MHz, the VCO 5720 (for the FM mode) or the local oscillator (LO) 5734 (for the PM and AM modes) will be required to generate oscillating frequencies 5704, 5738, 5744 that range from 100.5556 MHz to 101.6667 MHz. (That is, the 9<sup>th</sup> subharmonic of  $910 \text{ MHz} \pm 5 \text{ MHz}$ ). In some applications, such as the cellular phone, the frequencies will change automatically, based on the protocols of the overall cellular system (e.g., moving from one cell to an adjacent cell). In other applications, such as a police radio, the frequencies will change based on the user changing channels.

20

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In some applications, different models of the same transmitter will transmit signals at different frequencies, but each model will, itself, only transmit a single frequency. A possible example of this might be remote controlled toy cars, where each toy car operates on its own frequency, but, in order for several toy cars to operate in the same area, there are several frequencies at which they could operate. Thus, the design of the VCO 5720 or LO 5734 will be such that it is able to be tuned to a set frequency

30

when the circuit is fabricated, but the user will typically not be able to adjust the frequency.

It is well known to those skilled in the relevant art(s) that several of the criteria to be considered in the selection or design of an oscillator (VCO 5720 or LO 5734) include, but are not limited to, the nominal center frequency of the desired transmission signal 5714, the frequency sensitivity caused by the desired modulation scheme, the range of all possible frequencies for the desired transmission signal 5714, and the tuning requirements for each specific application. Another important criterion is the determination of the subharmonic to be used, but unlike the criteria listed above which are dependent on the desired application, there is some flexibility in the selection of the subharmonic.

#### 7.5.2 *Pulse Width of the String of Pulses.*

Once the frequency of the oscillating signal 5704, 5738, 5744 has been selected, the pulse width of the pulses in the stream of pulses 5706 must be determined. (See sections 4-4.3.4, above, for a discussion of harmonic enhancement and the impact the pulse-width-to-period ratio has on the relative amplitudes of the harmonics in a harmonically rich signal 5708.) In the example used above, the 9<sup>th</sup> subharmonic was selected as the frequency of the oscillating signal 5704, 5738, 5744. In other words, the frequency of the desired transmission signal will be the 9<sup>th</sup> harmonic of the oscillating signal 5704, 5738, 5744. One approach in selecting the pulse width might be to focus entirely on the frequency of the oscillating signal 5704, 5738, 5744 and select a pulse width and observe its operation in the circuit. For the case where the harmonically rich signal 5708 has a unity amplitude, and the pulse-width-to-period ratio is 0.1, the amplitude of the 9<sup>th</sup> harmonic will be 0.0219. Looking again at Table 6000 and FIG. 58 it can be seen that the amplitude of the 9<sup>th</sup> harmonic is higher than that of the 10<sup>th</sup> harmonic (which is zero) but is less than half the amplitude of the 8<sup>th</sup> harmonic. Because the 9<sup>th</sup> harmonic does have an amplitude, this pulse-width-to-period ratio could be used with proper filtering. Typically, a different ratio might be selected to try and find a ratio that would provide a higher amplitude.

Looking at *Eq. 1* in section 4.1.1, it is seen that the relative amplitude of any harmonic is a function of the number of the harmonic and the pulse-width-to-period ratio of the underlying waveform. Applying calculus of variations to the equation, the pulse-width-to-period ratio that yields the highest amplitude harmonic for any given harmonic can be determined.

From *Eq. 1*, where  $A_n$  is the amplitude of the  $n^{\text{th}}$  harmonic,

$$A_n = [A_{\text{pulse}}][(2/\pi)/n]\sin\{n\pi(\tau/T)\} \quad \text{Eq. 2}$$

If the amplitude of the pulse,  $A_{\text{pulse}}$ , is set to unity (i.e., equal to 1), the equation becomes

$$A_n = [2/(n\pi)]\sin[n\pi(\tau/T)] \quad \text{Eq. 3}$$

From this equation, it can be seen that for any value of  $n$  (the harmonic) the amplitude of that harmonic,  $A_n$ , is a function of the pulse-width-to-period ratio,  $\tau/T$ . To determine the highest value of  $A_n$  for a given value of  $n$ , the first derivative of  $A_n$  with respect to  $\tau/T$  is taken. This gives the following equations.

$$\delta(A_n)/\delta(\tau/T) = \delta\{[2/(n\pi)]\sin[n\pi(\tau/T)]\}/\delta(\tau/T) \quad \text{Eq. 4}$$

$$= [2/(n\pi)]\delta[\sin[n\pi(\tau/T)]]/\delta(\tau/T) \quad \text{Eq. 5}$$

$$= [2/(n\pi)]\cos[n\pi(\tau/T)] \quad \text{Eq. 6}$$

From calculus of variations, it is known that when the first derivative is set equal to zero, the value of the variable that will yield a relative maximum (or minimum) can be determined.

$$\delta(A_n)/\delta(\tau/T) = 0 \quad \text{Eq. 7}$$

$$[2/(n\pi)]\cos[n\pi(\tau/T)] = 0 \quad \text{Eq. 8}$$

$$\cos[n\pi(\tau/T)] = 0 \quad \text{Eq. 9}$$

From trigonometry, it is known that for *Eq. 9* to be true,

WO 00/24116

- 120 -

PCT/US99/24127

$$n \cdot \pi \cdot (\tau/T) = \pi/2 \quad (\text{or } 3\pi/2, 5\pi/2, \text{ etc.}) \quad \text{Eq. 10}$$

$$\tau/T = (\pi/2)/(n \cdot \pi) \quad \text{Eq. 11}$$

$$\tau/T = 1/(2 \cdot n) \quad (\text{or } 3/(2 \cdot n), 5/(2 \cdot n), \text{ etc.}) \quad \text{Eq. 12}$$

The above derivation is well known to those skilled in the relevant art(s). From *Eq. 12*, it can be seen that if the pulse-width-to-period ratio is equal to  $1/(2 \cdot n)$ , the amplitude of the harmonic should be substantially optimum. For the case of the 9<sup>th</sup> harmonic, *Eq. 12* will yield a pulse-width-to-period ratio of  $1/(2 \cdot 9)$  or 0.0556. For the amplitude of this 9<sup>th</sup> harmonic, Table 6100 of FIG. 61 shows that it is 0.0796. This is an improvement over the previous amplitude for a pulse-width-to-period ratio of 0.1. Table 6100 also shows that the 9<sup>th</sup> harmonic for this pulse-width-to-period ratio has the highest amplitude of any 9<sup>th</sup> harmonic, which bears out the derivation above. The frequency spectrum for a pulse-width-to-period ratio of 0.0556 is shown in FIG. 59. (Note that other pulse-width-to-period ratios of  $3/(2 \cdot n)$ ,  $5/(2 \cdot n)$ , etc., will have amplitudes that are equal to but not larger than this one.)

This is one approach to determining the desired pulse-width-to-period ratio. Those skilled in the relevant art(s) will understand that other techniques may also be used to select a pulse-width-to-period ratio.

### 7.6 Design of the Pulse Shaping Circuit.

Once the determination has been made as to the desired frequency of the oscillating signal 5704, 5738, 5744 and of the pulse width, the pulse shaping circuit 5722 can be designed. Looking back to sections 4-4.3.4 it can be seen that the pulse shaping circuit 5722 can not only produce a pulse of a desired pulse width, but it can also cause the frequency of the string of pulses 5706 to be higher than the frequency of the oscillating signal 5704, 5738, 5744. Recall that the pulse-width-to-period ratio applies to the pulse-width-to-period ratio of the harmonically rich signal 5708 and not to the pulse-width-to-period ratio of the oscillating signal 5704, 5738, 5744, and that the frequency and pulse width of the harmonically rich signal 5708 mirrors the frequency and pulse width of the string of pulses 5706. Thus, if in the selection of the VCO 5720 or LO 5734 it was desired to choose an oscillator that is lower than that

required for the selected harmonic, the pulse shaping circuit 5733 can be used to increase the frequency. Going back to the previous example, the frequency of the oscillating signal 5704, 5738, 5744 could be 50.5556 MHz rather than 101.1111 MHz if the pulse shaping circuit 5722 was designed such as discussed in sections 4.2.2-4.2.2.2 (shown in FIGs. 40A-40D) not only to shape the pulse, but also to double the frequency. While that discussion was specifically for a square wave input, those skilled in the relevant art(s) will understand that similar techniques will apply to non-rectangular waveforms (e.g., a sinusoidal wave). This use of the pulse shaping circuit to double the frequency has a possible advantage in that it allows the design and selection of an oscillator (VCO 5720 or LO 5734) with a lower frequency, if that is a consideration.

It should also be understood that the pulse shaping circuit 5722 is not always required. If the design or selection of the VCO 5720 or LO 5734 was such that the oscillating signal 5704, 5738, 5744 was a substantially rectangular wave, and that substantially rectangular wave had a pulse-width-to-period ratio that was adequate, the pulse shaping circuit 5722 could be eliminated.

### ***7.7 Selection of the Switch.***

The selection of a switch 5724 can now be made. The switch 5724 is shown in the examples of FIGs. 57A, 57B, and 57C as a GaAs FET. However, it may be any switching device of any technology that can open and close "crisply" enough to accommodate the frequency and pulse width of the string of pulses 5706.

#### ***7.7.1 Optimized Switch Structures.***

##### **Switches of different sizes**

In an embodiment, the switch modules discussed herein can be implemented as a series of switches operating in parallel as a single switch. The series of switches can be transistors, such as, for example, field effect transistors (FET), bi-polar transistors, or any other suitable circuit switching devices. The series of switches can be

comprised of one type of switching device, or a combination of different switching devices.

For example, FIG. 73 illustrates a switch module 7300. In FIG. 73, the switch module is illustrated as a series of FETs 7302a-n. The FETs 7302a-n can be any type of FET, including, but not limited to, a MOSFET, a JFET, a GaAs FET, etc. Each of FETs 7302a-n includes a gate 7304a-n, a source 7306a-n, and a drain 7308a-n. The series of FETs 7302a-n operate in parallel. Gates 7304a-n are coupled together, sources 7306a-n are coupled together, and drains 7308a-n are coupled together. Each of gates 7304a-n receives the control signal 2804, 3104 to control the switching action between corresponding sources 7306a-n and drains 7308a-n. Generally, the corresponding sources 7306a-n and drains 7308a-n of each of FETs 7302a-n are interchangeable. There is no numerical limit to the number of FETs. Any limitation would depend on the particular application, and the "a-n" designation is not meant to suggest a limit in any way.

In an embodiment, FETs 7302a-n have similar characteristics. In another embodiment, one or more of FETs 7302a-n have different characteristics than the other FETs. For example, FETs 7302a-n may be of different sizes. In CMOS, generally, the larger size a switch is (meaning the larger the area under the gate between the source and drain regions), the longer it takes for the switch to turn on. The longer turn on time is due in part to a higher gate to channel capacitance that exists in larger switches. Smaller CMOS switches turn on in less time, but have a higher channel resistance. Larger CMOS switches have lower channel resistance relative to smaller CMOS switches. Different turn on characteristics for different size switches provides flexibility in designing an overall switch module structure. By combining smaller switches with larger switches, the channel conductance of the overall switch structure can be tailored to satisfy given requirements.

In an embodiment, FETs 7302a-n are CMOS switches of different relative sizes. For example, FET 7302a may be a switch with a smaller size relative to FETs 7302b-n. FET 7302b may be a switch with a larger size relative to FET 7302a, but smaller size relative to FETs 7302c-n. The sizes of FETs 7302c-n also may be varied relative to each other. For instance, progressively larger switch sizes may be used. By varying the sizes of FETs 7302a-n relative to each other, the turn on characteristic

curve of the switch module can be correspondingly varied. For instance, the turn on characteristic of the switch module can be tailored such that it more closely approaches that of an ideal switch. Alternately, the switch module could be tailored to produce a shaped conductive curve.

5 By configuring FETs 7302a-n such that one or more of them are of a relatively smaller size, their faster turn on characteristic can improve the overall switch module turn on characteristic curve. Because smaller switches have a lower gate to channel capacitance, they can turn on more rapidly than larger switches.

10 By configuring FETs 7302a-n such that one or more of them are of a relatively larger size, their lower channel resistance also can improve the overall switch module turn on characteristics. Because larger switches have a lower channel resistance, they can provide the overall switch structure with a lower channel resistance, even when combined with smaller switches. This improves the overall switch structure's ability to drive a wider range of loads. Accordingly, the ability to tailor switch sizes relative to  
15 each other in the overall switch structure allows for overall switch structure operation to more nearly approach ideal, or to achieve application specific requirements, or to balance trade-offs to achieve specific goals, as will be understood by persons skilled in the relevant arts(s) from the teachings herein.

20 It should be understood that the illustration of the switch module as a series of FETs 7302a-n in FIG. 73 is for example purposes only. Any device having switching capabilities could be used to implement the switch module, as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

### **Reducing Overall Switch Area**

25 Circuit performance also can be improved by reducing overall switch area. As discussed above, smaller switches (i.e., smaller area under the gate between the source and drain regions) have a lower gate to channel capacitance relative to larger switches. The lower gate to channel capacitance allows for lower circuit sensitivity to noise spikes. FIG. 74A illustrates an embodiment of a switch module, with a large overall switch area. The switch module of FIG. 74A includes twenty FETs 7402-7440. As  
30 shown, FETs 7402-7440 are the same size ("Wd" and "l<sub>ng</sub>" parameters are equal).

Input source 7446 produces the input EM signal. Pulse generator 7448 produces the energy transfer signal for FETs 7402-7440. Capacitor C1 is the storage element for the input signal being sampled by FETs 7402-7440. FIGS. 74B-74Q illustrate example waveforms related to the switch module of FIG. 74A. FIG. 74B shows a received 1.01 GHz EM signal to be sampled and downconverted to a 10 MHz intermediate frequency signal. FIG. 74C shows an energy transfer signal having an aliasing rate of 200 MHz, which is applied to the gate of each of the twenty FETs 7402-7440. The energy transfer signal includes a train of energy transfer pulses having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses repeat at the aliasing rate. FIG. 74D illustrates the affected received EM signal, showing effects of transferring energy at the aliasing rate, at point 7442 of FIG. 74A. FIG. 74E illustrates a down-converted signal at point 7444 of FIG. 74A, which is generated by the down-conversion process.

FIG. 74F illustrates the frequency spectrum of the received 1.01 GHz EM signal. FIG. 74G illustrates the frequency spectrum of the received energy transfer signal. FIG. 74H illustrates the frequency spectrum of the affected received EM signal at point 7442 of FIG. 74A. FIG. 74I illustrates the frequency spectrum of the down-converted signal at point 7444 of FIG. 74A.

FIGS. 74J-74M respectively further illustrate the frequency spectrums of the received 1.01 GHz EM signal, the received energy transfer signal, the affected received EM signal at point 7442 of FIG. 74A, and the down-converted signal at point 7444 of FIG. 74A, focusing on a narrower frequency range centered on 1.00 GHz. As shown in FIG. 74L, a noise spike exists at approximately 1.0 GHz on the affected received EM signal at point 7442 of FIG. 74A. This noise spike may be radiated by the circuit, causing interference at 1.0 GHz to nearby receivers.

FIGS. 74N-74Q respectively illustrate the frequency spectrums of the received 1.01 GHz EM signal, the received energy transfer signal, the affected received EM signal at point 7442 of FIG. 74A, and the down-converted signal at point 7444 of FIG. 74A, focusing on a narrow frequency range centered near 10.0 MHz. In particular, FIG. 74Q shows that an approximately 5 mV signal was downconverted at approximately 10 MHz.

FIG 75A illustrates an alternative embodiment of the switch module, this time with fourteen FETs 7502-7528 shown, rather than twenty FETs 7402-7440 as shown in FIG. 74A. Additionally, the FETs are of various sizes (some "Wd" and "Lg" parameters are different between FETs).

5           FIGS. 75B-75Q, which are example waveforms related to the switch module of FIG. 75A, correspond to the similarly designated figures of FIGS. 74B-74Q. As FIG. 75L shows, a lower level noise spike exists at 1.0 GHz than at the same frequency of FIG. 74L. This correlates to lower levels of circuit radiation. Additionally, as FIG. 75Q shows, the lower level noise spike at 1.0 GHz was achieved with no loss in  
10           conversion efficiency. This is represented in FIG. 75Q by the approximately 5 mV signal downconverted at approximately 10 MHz. This voltage is substantially equal to the level downconverted by the circuit of FIG. 74A. In effect, by decreasing the number of switches, which decreases overall switch area, and by reducing switch area on a switch-by-switch basis, circuit parasitic capacitance can be reduced, as would be  
15           understood by persons skilled in the relevant art(s) from the teachings herein. In particular this may reduce overall gate to channel capacitance, leading to lower amplitude noise spikes and reduced unwanted circuit radiation.

          It should be understood that the illustration of the switches above as FETs in FIGS. 74A-74Q and 75A-75Q is for example purposes only. Any device having  
20           switching capabilities could be used to implement the switch module, as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

### **Charge injection cancellation**

          In embodiments wherein the switch modules discussed herein are comprised of  
25           a series of switches in parallel, in some instances it may be desirable to minimize the effects of charge injection. Minimizing charge injection is generally desirable in order to reduce the unwanted circuit radiation resulting therefrom. In an embodiment, unwanted charge injection effects can be reduced through the use of complementary n-channel MOSFETs and p-channel MOSFETs. N-channel MOSFETs and p-channel  
30           MOSFETs both suffer from charge injection. However, because signals of opposite

polarity are applied to their respective gates to turn the switches on and off, the resulting charge injection is of opposite polarity. Resultingly, n-channel MOSFETs and p-channel MOSFETs may be paired to cancel their corresponding charge injection. Hence, in an embodiment, the switch module may be comprised of n-channel MOSFETs and p-channel MOSFETS, wherein the members of each are sized to minimize the undesired effects of charge injection.

FIG 77A illustrates an alternative embodiment of the switch module, this time with fourteen n-channel FETs 7702-7728 and twelve p-channel FETs 7730-7752 shown, rather than twenty FETs 7402-7440 as shown in FIG. 74A. The n-channel and p-channel FETs are arranged in a complementary configuration. Additionally, the FETs are of various sizes (some "Wd" and "lmg" parameters are different between FETs).

FIGS. 77B-77Q, which are example waveforms related to the switch module of FIG. 77A, correspond to the similarly designated figures of FIGS. 74B-74Q. As FIG. 77L shows, a lower level noise spike exists at 1.0 GHz than at the same frequency of FIG. 74L. This correlates to lower levels of circuit radiation. Additionally, as FIG. 77Q shows, the lower level noise spike at 1.0 GHz was achieved with no loss in conversion efficiency. This is represented in FIG. 77Q by the approximately 5 mV signal downconverted at approximately 10 MHz. This voltage is substantially equal to the level downconverted by the circuit of FIG. 74A. In effect, by arranging the switches in a complementary configuration, which assists in reducing charge injection, and by tailoring switch area on a switch-by-switch basis, the effects of charge injection can be reduced, as would be understood by persons skilled in the relevant art(s) from the teachings herein. In particular this leads to lower amplitude noise spikes and reduced unwanted circuit radiation.

It should be understood that the use of FETs in FIGS. 77A-77Q in the above description is for example purposes only. From the teachings herein, it would be apparent to persons of skill in the relevant art(s) to manage charge injection in various transistor technologies using transistor pairs.

### Overlapped capacitance

The processes involved in fabricating semiconductor circuits, such as MOSFETs, have limitations. In some instances, these process limitations may lead to circuits that do not function as ideally as desired. For instance, a non-ideally fabricated MOSFET may suffer from parasitic capacitances, which in some cases may cause the surrounding circuit to radiate noise. By fabricating circuits with structure layouts as close to ideal as possible, problems of non-ideal circuit operation can be minimized.

FIG. 76A illustrates a cross-section of an example n-channel enhancement-mode MOSFET 7600, with ideally shaped n+ regions. MOSFET 7600 includes a gate 7602, a channel region 7604, a source contact 7606, a source region 7608, a drain contact 7610, a drain region 7612, and an insulator 7614. Source region 7608 and drain region 7612 are separated by p-type material of channel region 7604. Source region 7608 and drain region 7612 are shown to be n+ material. The n+ material is typically implanted in the p-type material of channel region 7604 by an ion implantation/diffusion process. Ion implantation/diffusion processes are well known by persons skilled in the relevant art(s). Insulator 7614 insulates gate 7602 which bridges over the p-type material. Insulator 7614 generally comprises a metal-oxide insulator. The channel current between source region 7608 and drain region 7612 for MOSFET 7600 is controlled by a voltage at gate 7602.

Operation of MOSFET 7600 shall now be described. When a positive voltage is applied to gate 7602, electrons in the p-type material of channel region 7604 are attracted to the surface below insulator 7614, forming a connecting near-surface region of n-type material between the source and the drain, called a channel. The larger or more positive the voltage between the gate contact 7606 and source region 7608, the lower the resistance across the region between.

In FIG. 76A, source region 7608 and drain region 7612 are illustrated as having n+ regions that were formed into idealized rectangular regions by the ion implantation process. FIG. 76B illustrates a cross-section of an example n-channel enhancement-mode MOSFET 7616 with non-ideally shaped n+ regions. Source region 7620 and drain region 7622 are illustrated as being formed into irregularly shaped regions by the ion implantation process. Due to uncertainties in the ion implantation/diffusion process, in practical applications, source region 7620 and drain region 7622 do not form rectangular regions as shown in FIG. 76A. FIG. 76B shows source region 7620

and drain region 7622 forming exemplary irregular regions. Due to these process uncertainties, the n+ regions of source region 7620 and drain region 7622 also may diffuse further than desired into the p-type region of channel region 7618, extending underneath gate 7602. The extension of the source region 7620 and drain region 7622 underneath gate 7602 is shown as source overlap 7624 and drain overlap 7626. Source overlap 7624 and drain overlap 7626 are further illustrated in FIG. 76C. FIG. 76C illustrates a top-level view of an example layout configuration for MOSFET 7616. Source overlap 7624 and drain overlap 7626 may lead to unwanted parasitic capacitances between source region 7620 and gate 7602, and between drain region 7622 and gate 7602. These unwanted parasitic capacitances may interfere with circuit function. For instance, the resulting parasitic capacitances may produce noise spikes that are radiated by the circuit, causing unwanted electromagnetic interference.

As shown in FIG. 76C, an example MOSFET 7616 may include a gate pad 7628. Gate 7602 may include a gate extension 7630, and a gate pad extension 7632. Gate extension 7630 is an unused portion of gate 7602 required due to metal implantation process tolerance limitations. Gate pad extension 7632 is a portion of gate 7602 used to couple gate 7602 to gate pad 7628. The contact required for gate pad 7628 requires gate pad extension 7632 to be of non-zero length to separate the resulting contact from the area between source region 7620 and drain region 7622. This prevents gate 7602 from shorting to the channel between source region 7620 and drain region 7622 (insulator 7614 of FIG. 76B is very thin in this region). Unwanted parasitic capacitances may form between gate extension 7630 and the substrate (FET 7616 is fabricated on a substrate), and between gate pad extension 7632 and the substrate. By reducing the respective areas of gate extension 7630 and gate pad extension 7632, the parasitic capacitances resulting therefrom can be reduced. Accordingly, embodiments address the issues of uncertainty in the ion implantation/diffusion process. It will be obvious to persons skilled in the relevant art(s) how to decrease the areas of gate extension 7630 and gate pad extension 7632 in order to reduce the resulting parasitic capacitances.

It should be understood that the illustration of the n-channel enhancement-mode MOSFET is for example purposes only. The present invention is applicable to

depletion mode MOSFETs, and other transistor types, as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

### 7.7.2 *Phased D2D - Splitter in CMOS.*

FIG. 72A illustrates an embodiment of a splitter circuit 7200 implemented in CMOS. This embodiment is provided for illustrative purposes, and is not limiting. In an embodiment, splitter circuit 7200 is used to split a local oscillator (LO) signal into two oscillating signals that are approximately 90° out of phase. The first oscillating signal is called the I-channel oscillating signal. The second oscillating signal is called the Q-channel oscillating signal. The Q-channel oscillating signal lags the phase of the I-channel oscillating signal by approximately 90°. Splitter circuit 7200 includes a first I-channel inverter 7202, a second I-channel inverter 7204, a third I-channel inverter 7206, a first Q-channel inverter 7208, a second Q-channel inverter 7210, an I-channel flip-flop 7212, and a Q-channel flip-flop 7214.

FIGS. 72F-J are example waveforms used to illustrate signal relationships of splitter circuit 7200. The waveforms shown in FIGS. 72F-J reflect ideal delay times through splitter circuit 7200 components. LO signal 7216 is shown in FIG. 72F. First, second, and third I-channel inverters 7202, 7204, and 7206 invert LO signal 7216 three times, outputting inverted LO signal 7218, as shown in FIG. 72G. First and second Q-channel inverters 7208 and 7210 invert LO signal 7216 twice, outputting non-inverted LO signal 7220, as shown in FIG. 72H. The delay through first, second, and third I-channel inverters 7202, 7204, and 7206 is substantially equal to that through first and second Q-channel inverters 7208 and 7210, so that inverted LO signal 7218 and non-inverted LO signal 7220 are approximately 180° out of phase. The operating characteristics of the inverters may be tailored to achieve the proper delay amounts, as would be understood by persons skilled in the relevant art(s).

I-channel flip-flop 7212 inputs inverted LO signal 7218. Q-channel flip-flop 7214 inputs non-inverted LO signal 7220. In the current embodiment, I-channel flip-flop 7212 and Q-channel flip-flop 7214 are edge-triggered flip-flops. When either flip-flop receives a rising edge on its input, the flip-flop output changes state. Hence, I-channel flip-flop 7212 and Q-channel flip-flop 7214 each output signals that are

approximately half of the input signal frequency. Additionally, as would be recognized by persons skilled in the relevant art(s), because the inputs to I-channel flip-flop 7212 and Q-channel flip-flop 7214 are approximately  $180^\circ$  out of phase, their resulting outputs are signals that are approximately  $90^\circ$  out of phase. I-channel flip-flop 7212 outputs I-channel oscillating signal 7222, as shown in FIG. 72I. Q-channel flip-flop 7214 outputs Q-channel oscillating signal 7224, as shown in FIG. 72J. Q-channel oscillating signal 7224 lags the phase of I-channel oscillating signal 7222 by  $90^\circ$ , also as shown in a comparison of FIGS. 72I and 72J.

FIG. 72B illustrates a more detailed circuit embodiment of the splitter circuit 7200 of FIG. 72. The circuit blocks of FIG. 72B that are similar to those of FIG. 72A are indicated by corresponding reference numbers. FIGS. 72C-D show example output waveforms relating to the splitter circuit 7200 of FIG. 72B. FIG. 72C shows I-channel oscillating signal 7222. FIG. 72D shows Q-channel oscillating signal 7224. As is indicated by a comparison of FIGS. 72C and 72D, the waveform of Q-channel oscillating signal 7224 of FIG. 72D lags the waveform of I-channel oscillating signal 7222 of FIG. 72C by approximately  $90^\circ$ .

It should be understood that the illustration of the splitter circuit 7200 in FIGS. 72A and 72B is for example purposes only. Splitter circuit 7200 may be comprised of an assortment of logic and semiconductor devices of a variety of types, as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

### 7.8 *Design of the Filter.*

The design of the filter 5726 is determined by the frequency and frequency range of the desired transmission signal 5714. As discussed above in sections 3.3.9-3.3.9.2, the term "Q" is used to describe the ratio of the center frequency of the output of the filter to the bandwidth of the "3 dB down" point. The trade offs that were made in the selection of the subharmonic to be used is a factor in designing the filter. That is, if, as an excursion to the example given above, the frequency of the desired transmission signal were again 910 MHz, but the desired subharmonic were the 50<sup>th</sup> subharmonic, then the frequency of that 50<sup>th</sup> subharmonic would be 18.2000 MHz. This

means that the frequencies seen by the filter will be 18.200 MHz apart. Thus, the "Q" will need to be high enough to avoid allowing information from the adjacent frequencies being passed through. The other consideration for the "Q" of the filter is that it must not be so tight that it does not permit the usage of the entire range of  
5 desired frequencies.

### 7.9 *Selection of an Amplifier.*

An amplifier module 5728 will be needed if the signal is not large enough to be transmitted or if it is needed for some downstream application. This can occur because the amplitude of the resultant harmonic is too small. It may also occur if the filter 5726  
10 has attenuated the signal.

### 7.10 *Design of the Transmission Module.*

A transmission module 5730, which is optional, ensures that the output of the filter 5726 and the amplifier module 5728 is able to be transmitted. In the implementation wherein the transmitter is used to broadcast EM signals over the air,  
15 the transmission module matches the impedance of the output of the amplifier module 5728 and the input of an antenna 5732. This technique is well known to those skilled in the relevant art(s). If the signal is to be transmitted over a point-to-point line such as a telephone line (or a fiber optic cable) the transmission module 5730 may be a line driver (or an electrical-to-optical converter for fiber optic implementation).

**Claims**

1. A method of up-converting, comprising:
  - (1) gating a first reference signal under the control of a first modulated information signal to generate a first gated signal; and
  - (2) isolating at least one harmonic of the first gated signal to generate a first up-converted information signal.
2. A method according to claim 1, wherein step (2) includes:
  - (2A) gating a second reference signal under the control of a second modulated information signal to generate a second gated signal, wherein the frequency of the second modulated information signal is substantially equal to the frequency of the first modulated information signal and the second modulated information signal is substantially 90 degrees out of phase with the first modulated information signal;
  - (2B) combining the first gated signal and the second gated signal to create a combined gated signal; and
  - (2C) isolating at least one harmonic of the combined gated signal to generate an in-phase/quadrature-phase (I/Q) up-converted signal.
3. A method according to claim 1 or 2, wherein step (1) includes:
  - (a) shaping the first modulated information signal to create a first string of modulated pulses; and
  - (b) gating the first reference signal under the control of the first string of modulated pulses to generate said first gated signal.
4. A method according to claim 2, wherein step (1) includes:
  - (a) shaping the first modulated information signal to create a first string of modulated pulses; and
  - (b) gating the first reference signal under the control of the first string of modulated pulses to generate said first gated signal; andwherein step (2A) includes:
  - (a) shaping the second modulated information signal to create a second

string of modulated pulses; and

(b) gating the second reference signal under the control of the second string of modulated pulses to generate said second gated signal.

5. A method according to claim 3 or claim 4, wherein said shaping step (1)(a) further includes:

regulating a control pulse width of said first string of modulated pulses so that a first shaping ratio thereof is substantially equal to one-half of  $m$ , where  $m$  is an integer,

wherein the first shaping ratio is the ratio of the first control pulse width to the period of the first up-converted information signal.

6. A method according to claim 4, wherein shaping step (1)(a) further includes:

regulating the control pulse width of said first string of modulated pulses so that the first shaping ratio thereof is substantially equal to one-half of  $m$ , where  $m$  is an integer, and shaping step (2A)(a) further includes:

regulating the control pulse width of said second string of modulated pulses so that the second shaping ratio thereof is substantially equal to one half of  $n$ , where  $n$  is an integer,

wherein the first shaping ratio is the ratio of the first control pulse width to the period of the I/Q up-converted signal, and the second shaping ratio is the ratio of the second control pulse width to the period of the I/Q up-converted signal.

7. A method according to claim 5 or claim 6, wherein the or each shaping ratio is substantially equal to 0.5.

8. A method according to any one of claims 2, 4, or 6, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are analog signals.

9. A method according to any one of claims 2, 4, or 6, wherein an information signal

from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are digital signals.

10. A method according to any one of claims 2, 4, or 6, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are frequency modulated.

11. A method according to any one of claims 2, 4, or 6, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are phase modulated.

12. A method according to claim 1, wherein said first reference signal is a further information signal, and said first up-converted signal has an amplitude that is a function of said further information signal.

13. A method according to claim 2, wherein said second reference signal is an additional information signal, and said second up-converted signal has an amplitude that is a function of said additional information signal.

14. A method according to claim 12, wherein said further information signal is a digital information signal having a plurality of states.

15. A method according to claim 13, wherein said additional information signal is a digital information signal having a plurality of states.

16. An apparatus for up-converting, comprising:  
first gating means for gating a first reference signal under the control of a first modulated information signal to generate a first gated signal; and  
isolating means for isolating at least one harmonic of the first gated signal to

generate a first up-converted information signal.

17. Apparatus according to claim 16, further comprising:

second gating means for gating a second reference signal under the control of a second modulated information signal to generate a second gated signal, wherein the frequency of the second modulated information signal is substantially equal to the frequency of the first modulated information signal and the second modulated information signal is substantially 90 degrees out of phase with the first modulated information signal;

combining means for combining the first gated signal and the second gated signal to create a combined gated signal; and

isolating means for isolating at least one harmonic of the combined gated signal to generate an in-phase/quadrature-phase (I/Q) up-converted signal.

18. Apparatus according to claim 16 or claim 17, wherein said first gating means includes:

first shaping means for shaping the first modulated information signal to create a first string of modulated pulses; and

first shaped gating means for gating the first reference signal under the control of the first string of modulated pulses to generate said first gated signal.

19. Apparatus according to claim 17, wherein said first gating means includes:

first shaping means for shaping the first modulated information signal to create a first string of modulated pulses; and

first shaped gating means for gating the first reference signal under the control of the first string of modulated pulses to generate said first gated signal; and wherein

said second gating means includes:

second shaping means for shaping the second modulated information signal to create a second string of modulated pulses; and

shaped second gating means for gating the second reference signal under the control of the second string of modulated pulses to generate said second gated signal.

20. Apparatus according to claim 18 or claim 19, wherein said first shaping means further comprises:

regulating means for regulating the control pulse width of the first string of modulated pulses so that the first shaping ratio thereof is substantially equal to one-half of  $m$  where  $m$  is an integer,

wherein the first shaping ratio is the ratio of the controlled pulse width to the period of the first up-converted information signal.

21. Apparatus according to claim 19, wherein said first shaping means further comprises:

first regulating means for regulating the control pulse width of said first string of modulated pulses so that a first shaping ratio thereof is substantially equal to one-half of  $m$ , where  $m$  is an integer; and

second regulating means for regulating the control pulse width of said second string of modulated pulses so that a second shaping ratio is substantially equal to one-half of  $n$ , where  $n$  is an integer,

wherein the first shaping ratio is the ratio of the control pulse width of the first string of modulated pulses to the period of the I/Q up-converted signal, and the second shaping ratio is the ratio of the control pulse width of the second string of modulated pulses to the period of the I/Q up-converted signal.

22. Apparatus according to claim 20 or claim 21, wherein the or each shaping ratio is substantially equal to 0.5.

23. Apparatus according to any one of claims 17, 19, or 21, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are analog signals.

24. Apparatus according to any one of claims 17, 19, or 21, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are

digital signals.

25. Apparatus according to any one of claims 17, 19, or 21, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are frequency modulated.

26. Apparatus according to any one of claims 17, 19, or 21, wherein an information signal from which the first modulated information signal was generated and an information signal from which the second modulated information signal was generated are phase modulated.

27. Apparatus according to claim 16; wherein said first reference signal is a further information signal, and said first up-converted signal has an amplitude that is a function of said further information signal.

28. Apparatus according to claim 17, wherein said second reference signal is an additional information signal, and said second up-converted signal has an amplitude that is a function of said additional information signal.

29. Apparatus according to claim 27, wherein said further information signal is a digital information signal having a plurality of states.

30. Apparatus according to claim 28, wherein said additional information signal is a digital information signal having a plurality of states.

31. A method of modulating and up-converting, comprising:

- (1) gating a first information signal under the control of a first oscillating signal to generate a first gated information signal; and
- (2) isolating one or more harmonics of the first gated information signal to generate a first up-converted and modulated signal.

32. A method according to claim 31, wherein step (2) further includes:

(2A) gating a second information signal under the control of a second oscillating signal to generate a second gated information signal, wherein the frequency of the second oscillating signal is substantially equal to the frequency of the first oscillating signal and the second oscillating signal is substantially 90 degrees out of phase with the first oscillating signal;

(2B) combining the first gated information signal and the second gated information signal to create a combined gated information signal; and

(2C) isolating at least one harmonic of the combined gated information signal to generate an in-phase/quadrature-phase (I/Q) up-converted and modulated signal.

33. A method according to claim 31 or claim 32, wherein step (1) includes:

(a) shaping said first oscillating signal to create a first string of pulses;  
and

(b) gating the first information signal under the control of the first string of pulses to generate said first gated information signal.

34. A method according to claim 32, wherein step (1) includes:

(a) shaping said first oscillating signal to create a first string of pulses;  
and

(b) gating the first information signal under the control of the first string of pulses to generate said first gated information signal; and wherein

step (2A) includes:

(a) shaping said second oscillating signal to create a second string of pulses; and

(b) gating the second information signal under the control of the second string of pulses to generate said second gated information signal.

35. A method according to claim 33 or claim 34, wherein shaping step (1)(a) further comprises:

regulating the control pulse width of said first string of pulses so that the first shaping ratio thereof is substantially equal to one-half of  $m$ , where  $m$  is an

integer,

wherein the first shaping ratio is the ratio of the control pulse width of said first string of pulses to the period of the first up-converted and modulated signal.

36. A method according to claim 34, wherein shaping step (1)(a) further includes:

regulating the control pulse width of the first string of pulses so that the first shaping ratio thereof is substantially equal to one-half of  $m$ , where  $m$  is an integer; and

wherein shaping step (2A)(a) further includes:

regulating the control pulse width of the second string of pulses so that the second shaping ratio thereof is substantially equal to one-half of  $n$ , where  $n$  is an integer,

wherein the first shaping ratio is the ratio of the control pulse width of the first string of pulses to the period of the I/Q up-converted and modulated signal and the second shaping ratio is the ratio of the control pulse width of the second string of pulses to the period of the I/Q up-converted and modulated signal.

37. A method according to claim 35 or claim 36, wherein the or each shaping ratio is substantially equal to 0.5.

38. A method according to any one of claims 32, 34, or 36, wherein the first information signal and the second information signal are analog signals.

39. A method according to any one of claims 32, 34, or 36, wherein the first information signal and the second information signal are digital signals.

40. A method according to claim 39, wherein the first information signal and the second information signal are digital signals having more than two states.

41. An apparatus for modulating and up-converting, comprising:

first gating means for gating a first information signal under the control of a first oscillating signal to generate a first gated information signal; and

first isolating means for isolating one or more harmonics of the first gated information signal to generate a first up-converted and modulated signal.

42. Apparatus according to claim 41, further comprising:

second gating means for gating a second information signal under the control of a second oscillating signal to generate a second gated information signal, wherein the frequency of the second oscillating signal is substantially equal to the frequency of the first oscillating signal and the second oscillating signal is substantially 90 degrees out of phase with the first oscillating signal;

combining means for combining the first gated information signal and the second gated information signal to create a combined gated information signal; and

isolating means for isolating at least one harmonic of the combined gated information signal to generate an in-phase/quadrature-phase (I/Q) up-converted and modulated signal.

43. Apparatus according to claim 41 or claim 42, wherein said first gating means further includes:

first shaping means for shaping said first oscillating signal to create a first string of pulses; and

first shaped gating means for gating the first information signal under the control of the first string of pulses to generate said first gated information signal.

44. Apparatus according to claim 42, wherein said first gating means further includes:

first shaping means for shaping said first oscillating signal to create a first string of pulses; and

first shaped gating means for gating the first information signal under the control of the first string of pulses to generate said first gated information signal; and

wherein said second gating means further comprises:

second shaping means for shaping said second oscillating signal to create a second string of pulses; and

shaped second gating means for gating the second information signal under the control of the second string of pulses to generate said second gated information signal.