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APPARATUS AND METHOD FOR MODULATING DIGITAL DATA

The present invention relates to the modulation of digital data using frequency shift keying (FSK) or phase shift keying (PSK). It is particularly applied to the modulation of a digital bit stream transmitted at a high data rate.

In Frequency Modulation (FM), data is used to vary the frequency of a carrier signal. The carrier signal has a given nominal frequency and this is altered (either increased or decreased) by the data signal. The characteristic equation of a FM signal is given by:

$$y(t) = A \cos[\omega_{IF}t + mf(t)] \quad (1)$$

where, $y(t)$ is the FM signal, ω_{IF} is an intermediate frequency (IF) of the FM carrier signal in radians/sec, $f(t)$ is the modulating (data) signal, m is the modulation index and A is the carrier amplitude. For radio transmission, the FM signal is then up-converted to a higher frequency for transmission from an antenna. For conventional audio FM radio signals, a frequency of approximately 100 MHz is used. To recover the original signal $f(t)$, the up-converted signal, $y'(t)$, is received through an antenna, down-converted to give $y(t)$ and then multiplied by $\sin(\omega_{IF}t)$ to give a signal $g(t)$ according to the following equation:

$$g(t) = \sin(\omega_{IF}t) A \cos[\omega_{IF}t + mf(t)] \quad (2)$$

where $\sin(\omega_{IF}t)$ is a locally generated IF equal to the IF used in the modulation of $f(t)$, used to separate the modulated signal from the nominal FM carrier. Expanding equation (2) gives:

$$\begin{aligned} g(t) &= A \sin(\omega_{IF}t) \{ \cos(\omega_{IF}t) \cos[mf(t)] - \sin(\omega_{IF}t) \sin[mf(t)] \} \\ &= \frac{1}{2} A \{ \sin[2\omega_{IF}t + mf(t)] - \sin[mf(t)] \} \end{aligned} \quad (3)$$

Generally, $\omega_{IF}t$ is large compared to the frequency of $mf(t)$ so a low-pass filter can be used to remove the high frequency term in $g(t)$, leaving:

$$g'(t) = -\frac{1}{2} A \sin[mf(t)] \quad (4)$$

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In cases where $mf(t)$ has small amplitude, $\sin[mf(t)]$ is approximately $mf(t)$ which leads us to:

$$g'(t) = -\frac{1}{2} A mf(t) \quad (5)$$

- 10 Therefore an FM signal, in which $\omega_{IF}t$ is large compared to the frequency of $f(t)$ and $mf(t)$ has small amplitude, can be demodulated by (i) multiplying the received signal by the same IF used in the modulation process and then, (ii) passing it through a low pass filter.

- 15 The transmission rate of the data may be increased without adversely affecting the bandwidth by modulating both the in-phase and quadrature component of the system. Data is transmitted on both the components allowing the transmission of twice as much data in the same bandwidth.

- 20 The SNR of a transmitted signal may be improved by applying a function, for example a logarithm function, to the transmitted signal. This can be used to alter the characteristics of the transmitted signal and improve the rejection of additive noise from the channel when the signal is demodulated.

- 25 It is known to transmit digital data using such an FM system. The digital data is first expressed as a serial bit stream representing the bytes and words of the original data. This bit stream is a series of discrete values, unlike an analog signal which can vary continuously. Therefore, examining equation (1) above shows that the modulated signal will switch between defined frequency values. A system such as this is known as Frequency Shift Keying (FSK).

- 30 A method of FSK modulation known in the art is to send the digital bit stream directly to a voltage controlled oscillator (VCO), for example a varactor diode in a tank circuit. As the digital bit stream has two defined values the VCO will output two frequencies, one of which corresponds to a "1" value and the other of which

corresponds to a "0" value.

To allow the signal to be transmitted efficiently over a channel which cannot transmit DC signal energy well, for example a radio channel, the digital bit stream is often encoded to reduce the DC content of the signal to as close to zero as possible.

- 5 Various techniques are known such as Manchester coding or Miller coding.

After coding, the data signal is filtered to remove the square edges and reduce the harmonics present, consequently reducing the bandwidth required for transmission. This filtered data signal is then fed into a standard FM Modulator.

- Therefore the transmitted signal does not switch abruptly between two well-defined
10 frequencies and the harmonics associated with a step change in frequency are eliminated.

FSK modulators implemented on programmable Digital Signal Processors (DSPs) are known. However the process requires many instruction cycles which demands the use of fast DSPs and increases the power consumption.

- 15 It is an aim of the present invention to provide an improved FSK or PSK modulator. It is a further aim to minimise the cost of production of an FSK or PSK modulator. A still further aim is to reduce the power consumption of an FSK or PSK modulator. A yet further aim is to increase the transmission rate of a communication system using FSK or PSK on the transmission channel without adversely affecting
20 the signal bandwidth.

According to a first aspect of the invention there is provided a modulator for modulating a digital bit stream using frequency shift keying or phase shift keying, the modulator comprising:

- 25 pattern generation means for generating a transition pattern whenever there is a transition in the digital bit stream, the transition pattern being dependent on whether the transition is from a low to a high value or from a high to a low value, and for generating a steady-state pattern corresponding to a frequency representing the instantaneous value of the digital bit stream otherwise, the output of the pattern
30 generation means being the digital bit stream modulated using frequency shift keying.

It is therefore possible to modulate a digital bit stream using FSK or PSK using digital components. This allows the circuit to have a low cost of manufacture and it is ideally suited to formation as an integrated circuit. The effects of temperature drift, pressure drift, manufacturing tolerances, component aging and other characteristic problems of analog components are reduced. The use of a transition pattern allows the transition between the two frequencies to include some intermediate frequencies, limiting the bandwidth of the transmitted signal by avoiding a step change in frequency. Furthermore, because the modulator can operate from a common clock without requiring anything more complex than a pattern generator the design can be implemented with a lower clock speed.

The modulator may have an output which is in the form of a square wave and the pattern generation means causes the half-period of the output in clock cycles to be loaded into a down-counter, the output having a constant value until the down-counter reaches zero, whereupon the value of the next half-period is loaded into the down counter and the value of the output is changed if required.

Modulation can therefore be achieved in one clock cycle reducing the power consumption, making this modulator suitable for high data rate applications. The construction of the pattern generator may also be simplified.

Optionally, the pattern generator may have an output which is in the form of a multi-level digital signal, the modulator further comprising digital to analog conversion means for converting said multi-level digital signal into an analog signal which corresponds to said digital bit stream modulated using frequency shift keying or phase shift keying.

The output of the pattern generator may then more closely resemble the desired analog wave to be transmitted.

In one advantageous configuration, the modulator may further comprise a low-pass filter for low-pass filtering said output of said pattern generation means, wherein said output is varied in duration and value such that the output from said low-pass filter is an analog signal which corresponds to said digital bit stream modulated using frequency shift keying or phase shift keying.

The output of the pattern generator may then more closely resemble the

desired analog wave to be transmitted. There is also the additional advantage that the construction of the modulator is simplified, requiring only a low-pass filter instead of a more complex digital-to-analog convertor.

According to a second aspect of the present invention there is provided a
5 method of modulating a digital bit stream using frequency shift keying or phase shift keying, the method comprising the steps of:

- (i) detecting when there is a transition in the value of the bit stream;
- (ii) generating a transition pattern whenever a transition is detected, the transition pattern being dependent on whether the transition is from a low to a high
10 value or from a high to a low value, generating a steady-state pattern corresponding to a frequency which represents the instantaneous value of said bit stream otherwise;
- (iii) outputting the pattern, the output being the digital bit stream modulated using frequency shift keying or phase shift keying.

The method may be modified to generate a square wave pattern, with step (ii)
15 further comprising the steps of:

- (ii-a) loading a count representing the half period of said pattern into a down-counter;
- (ii-b) outputting a constant value while the down-counter counts down to zero;
- 20 (iii-c) repeating steps (ii-a) and (ii-b) each time the down-counter reaches zero, and changing the constant value if required.

Optionally, the method may be modified such that said patterns generated in step (ii) have the form of a multi-level digital signal, and said step (ii) further comprises the step of: converting said multi-level digital signal into an analog signal
25 before said step of outputting.

Advantageously, the method may be modified such that said patterns generated in step (ii) are varied in duration and value, and said step (ii) further comprises the step of: low-pass filtering said patterns before said step of outputting to generate an analog signal.

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A preferred embodiment of the invention will now be described, by way of

example only, with reference to the accompanying diagrams in which:

Figure 1 is a schematic of a FSK modulator according to an embodiment of the present invention; and

5 Figure 2 is a schematic of the detailed construction of a square wave pattern generator used in the embodiment.

Like parts are denoted in the various figures by like references.

10 The construction of an FM modulator in accordance with an embodiment of the present invention is shown in Figure 1. It is known that modulation of a digital bit stream using a conventional analog FM modulator will result in a signal that switches between two defined frequencies. The present invention dispenses with conventional analog modulation components to implement a FSK modulator which can be
15 constructed cheaply and easily from digital components.

 The data to be transmitted is represented as a single serial bit stream which forms the input to the modulator. In this embodiment the bit stream first passes through a coder 2, which applies coding to reduce the dc content of the signal to as close to zero as possible. This is done through a non-return-to-zero (NRZ) code. The
20 coder 2 is optional, however, and may be omitted if not required.

 The bit stream now forms the input to a square wave pattern generator 4. This generates a predetermined output pattern corresponding to the value of the input bit stream at a given point in time. When the input is a "1" value the pattern generator 4 outputs a steady-state pattern corresponding to a square wave of a first frequency.
25 When the input is a "0" the pattern generator 4 outputs a steady-state pattern corresponding to a square wave of a second frequency. It was noted above that abrupt changes in the frequency will give harmonics which increase the bandwidth required for transmission. For this reason when the pattern generator 4 detects a one-to-zero (high to low) transition or zero-to-one (low to high) transition it instead outputs a
30 transition pattern designed to reduce the harmonics instead of simply switching from one frequency to another. The transition pattern is different for each type of transition

since in one case the frequency will need to be increased and in the other case the frequency will need to be reduced.

The construction of the square wave pattern generator is shown in Figure 2. An output square wave signal is generated by loading the time for a half period of the square wave, expressed as a number of cycles of the clock 24, from the pattern generator 18 into the auto-reload down counter 20. Simultaneously the value of the square wave (ie "1" or "0") is loaded into the phase adjuster 22. The phase adjuster 22 outputs a voltage corresponding to this value, for example +5V or -5V. When the auto-reload down counter 20 reaches zero, the phase adjust circuit 22 loads the next value of the square wave and the auto-reload down counter 20 loads the value of the next half period from the pattern generator. Thus, the circuit can generate a wave with any frequency up to the clock frequency, under the control of the pattern generator 18. The output frequencies and transition sequences may be chosen as desired to suit the application. They may be stored permanently, for example in a ROM section, or may be determined dynamically each time a bit stream is modulated.

Referring again to Figure 1, the signal now passes through a digital wave shaper 6. At this stage the signal is a square wave modulated ready for transmission. However, the sharp steps of the square wave contain many odd harmonics. These increase the bandwidth required for the transmitted signal and reduce transmission efficiency. The digital wave shaper 6 shapes the signal to remove the sharp steps and give a signal that can be transmitted in a smaller bandwidth.

The wave shaped digital signal is then converted into an analog signal by the DAC 8. The analog filter 10 filters this signal to remove the "stair steps" in the signal introduced by the DAC 8, reducing the bandwidth required for transmission of the signal still further.

Although this embodiment has described the use of a digital wave shaper 6 and a DAC 8 to shape the signal to improve transmission efficiency, these components are optional. If they are not used the analog filter 10 acts to smooth the sharp steps present in the square wave signal, reducing the bandwidth required for transmission.

Finally, the signal is up-converted 12 to the transmission frequency, for example 100Mhz. The up-converted signal is then amplified by the amplifier 14 and transmitted from the antenna 16.

In a second embodiment (not illustrated) of the present invention, the square
5 wave pattern generator 4 of the first embodiment may be substituted with a multi-level pattern generator which can output shaped waves directly, eliminating the need for a digital wave shaper 6. The multi-level pattern generator generates a digital signal which has more levels than the binary "1" and "0" of a square wave. This signal is converted into an analog signal by the DAC. The construction and operation
10 of the second embodiment is otherwise identical to the first embodiment.

In a third embodiment (not illustrated) of the present invention the square wave pattern generator is replaced with a pattern generator which varies the duration and value of its output, in a method similar to pulse width modulation. The output from the pattern generator is then passed directly to the low pass filter. The output
15 from the low pass filter is the analog signal required. This enables both the digital wave shaper 6 and the DAC 8 of the first embodiment to be omitted, and has better performance than simply passing a square wave of the correct frequency through a low-pass filter. The construction and operation of the third embodiment is otherwise identical to the first embodiment.

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Whilst a radio communication system has been described above, the person skilled in the art will appreciate that the present invention may be applied to any communication system using FSK modulation, for example a modem. The skilled person will understand that the above described modulator may be applied to a PSK
25 system with appropriate changes to the pattern generator.

Whilst embodiments of the invention have been described above, it will be appreciated that this description does not limit the scope of the invention, which is defined in the appended claims.

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CLAIMS

1. A modulator for modulating a digital bit stream using frequency shift keying or phase shift keying, the modulator comprising:
 - 5 pattern generation means for generating a transition pattern whenever there is a transition in said digital bit stream, said transition pattern being dependent on whether said transition is from a low to a high value or from a high to a low value, and for generating a steady-state pattern corresponding to a frequency representing the instantaneous value of said digital bit stream otherwise, the output of said pattern
 - 10 generation means being the digital bit stream modulated using frequency shift keying or phase shift keying.
2. A modulator according to claim 1 wherein the output of said pattern generation means is in the form of a square wave and said pattern generation means causes the
- 15 half-period of said output in clock cycles to be loaded into a down-counter, said output having a constant value until said down-counter reaches zero, whereupon the value of the next half-period is loaded into the down counter and the value of said output is changed if required.
- 20 3. A modulator according to claim 1 wherein the output of said pattern generation means is in the form of a multi-level digital signal, the modulator further comprising digital to analog conversion means for converting said multi-level digital signal into an analog signal which corresponds to said digital bit stream modulated using frequency shift keying or phase shift keying.
- 25 4. A modulator according to claim 1 further comprising a low-pass filter for low-pass filtering said output of said pattern generation means, wherein said output is varied in duration and value such that the output from said low-pass filter is an analog signal which corresponds to said digital bit stream modulated using frequency shift keying
- 30 or phase shift keying.

5. A modulator according to any preceding claim formed as an integrated circuit.

6. A modem incorporating a modulator according to any preceding claim.

5 7. A method of modulating a digital bit stream using frequency shift keying or phase shift keying, the method comprising the steps of:

(i) detecting when there is a transition in the value of said bit stream;

(ii) generating a transition pattern whenever said transition is detected, said transition pattern being dependent on whether said transition is from a low to a high value or from a high to a low value, generating a steady-state pattern corresponding to a frequency which represents the instantaneous value of said bit stream otherwise;

(iii) outputting said pattern, said output being said digital bit stream modulated using frequency shift keying or phase shift keying.

15 8. A method according to claim 7 wherein said patterns generated in step (ii) have the form of a square wave, said square wave being expressed in terms of the half-period during which its value is constant, and said step (ii) further comprises the steps of:

(ii-a) loading a count representing the half period of said pattern into a down-counter;

20 (ii-b) outputting a constant value while the down-counter counts down to zero;

(iii-c) repeating steps (ii-a) and (ii-b) each time the down-counter reaches zero, and changing said constant value if required.

25 9. A method according to claim 7 wherein said patterns generated in step (ii) have the form of a multi-level digital signal, and said step (ii) further comprises the step of:

converting said multi-level digital signal into an analog signal before said step of outputting.

30 10. A method according to claim 7 wherein said patterns generated in step (ii) are varied in duration and value, and said step (ii) further comprises the step of:

low-pass filtering said patterns before said step of outputting to generate an analog signal.