

CARRIER RECOVERY APPARATUS OF DIGITAL BROADCASTING RECEIVER USING TWO (2) PILOT SIGNALS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an apparatus and method for recover the carrier at a receiver of a digital broadcasting system, and more particularly, it relates to a carrier recovery apparatus and method capable of compensating for a frequency offset and phase offset of the carrier, which were occurred during a tuning, based on a pilot tone of a pilot included in a broadcasting signal in the process of recovering the digital broadcasting signal modulated by the vestigial sideband (VSB) modulation.

2. Description of the Prior Art

Generally, the broadcasting signal transmission system includes a vestigial sideband VSB modulation and a coded orthogonal frequency division multiplexing (COFDM) modulation. The VSB modulation transmits the broadcasting signal at a single carrier. The COFDM modulation transmits the broadcasting signal through multi-channel with division multiplexing of the broadcasting signal. The VSB modulation is the US-oriented digital broadcasting system, which is adopted in the countries like Korea and U.S.A. The COFDM modulation is Europe-oriented digital broadcasting system.

FIG. 1 is a block diagram showing a VSB receiver as an exemplary of a conventional digital broadcasting receiver. The VSB receiver includes a tuner 12, a surface acoustic wave (SAW) filter 14, an intermediate frequency (IF) amplifying unit 16, an analog-to-digital

converter (ADC) 18, an I/Q separator 20, a matched filter 22, a pilot removing unit 24, a down-sampling unit 26 and an equalizing unit 28.

The tuner 12 tunes the received digital broadcasting signal at an antenna 10 to a corresponding band according to an input tuning command. The SAW filter 14 filters the digital broadcasting signal of a tuned band into a predetermined intermediate frequency (IF) band. The intermediate frequency (IF) amplifying unit 16 amplifies the digital broadcasting signal of the intermediate frequency (IF) band output from the SAW filter 14 into intermediate frequency (IF). The ADC 18 converts the intermediate frequency (IF) amplified digital broadcasting signal into digital signal. The I/Q separator 20 separates the digital broadcasting signal into an inphase channel signal (hereinbelow called I-signal) and a quadrature signal (hereinbelow called Q-signal). The matched filter 22 filters the I and Q signals to have a sinusoidal characteristic agreed at the time of transmission. The pilot removing unit 24 removes the pilot from the filtered I and Q signals. The down-sampling unit 26 reduces the size of the pilot-removed I and Q signals according to a predetermined value. The equalizing unit 28 compensates for a distortion of the down-sampled I and Q signals, which has occurred in the transmission.

Meanwhile, the conventional VSB receiver includes a sampling compensate unit 30 for compensating for the offset occurred during the recovery of received digital broadcasting signal and a frequency/phase synchronizing unit 40. The sampling compensate unit 30 compensates for a timing distortion that has occurred during the sampling of the ADC 18. The frequency/phase synchronizing unit 40 compensates for the frequency and phase offset that has occurred during the turning of the tuner 12.

FIG. 2 is a block diagram showing the frequency/phase synchronizing unit 40 of FIG.

1 in greater detail. The frequency/phase synchronizing unit 40 includes a first low pass filter (LPF) 42, an auto frequency control low pass filter (AFC-LPF) 44, a limiter 46, a second LPF 48, a multiplier 50, an auto phase control low pass filter (APC-LPF) 52, and a voltage-controlled oscillator (VCO) 54.

The first LPF 42 filters the pilot tone of I-signal in base band. The AFC-LPF 44 calculates a frequency difference of the pilot tone for I-signal. The limiter 46 generates pulse waves corresponding to the difference of pilot tone output from the AFC-LPF 44. The second LPF 48 filters the pilot tone for Q-signal in base band. The multiplier 50 multiplies the pulse waves output from the limiter 46 by the Q-signal output from the second LPF 48. The APC-LPF 52 calculates a phase difference of the pilot tone for Q-signal. The VCO 54 provides the tuner 12 with a predetermined level of voltage, according to which the frequency difference and phase difference of the pilot tone are compensated for tuning.

The conventional digital broadcasting receiver estimates the frequency offset and phase offset for the subcarrier through the I and Q signals and compensates for the estimated offset, and supplies a predetermined level of voltage to the tuner 12 for the turning. Accordingly, the frequency offset and phase offset of the carrier, occurring during the tuning of the tuner 12, can be compensated.

Such carrier recovery method using the conventional frequency/phase synchronizing unit 40 uses one pilot tone for each signal. Accordingly, in the even that the pilot tone is damaged, the carrier recovery quality at the conventional digital broadcasting receiver severely deteriorates. Generally, the terrestrial wave transmission channel can be modeled into channel of multipath, and in this case, the frequency response of the channel contains many nulls. Even only one of the nulls happen to exist in the same frequency band as the

pilot tone does, the pilot tone of the digital broadcasting signal is severely damaged. When this happens, the exact recovery of carrier cannot be expected.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide a carrier recovery apparatus for a digital broadcasting receiver and a method thereof, capable of recovering the carrier of the received digital broadcasting signal more reliably in consideration of the damage to the pilot tone.

Embodiments of the present invention provide a carrier recovery apparatus of a digital broadcasting receiver and a method thereof, capable of recovering the carrier even when the pilot tone is damaged.

In accordance with a first aspect of the invention, there is provided a carrier recovery apparatus of a digital broadcasting receiver for recovering an offset of a carrier generated during a tuning, by using an I-signal and a Q signal contained in a digital broadcasting signal, the carrier recovery apparatus comprising:

- a plurality of frequency offset estimating units for estimating a frequency offset of the carrier generated during the tuning of the digital broadcasting signal, by shifting a plurality of pilot tones contained in the I signal and the Q signal respectively to a base band;

- a combining unit for combining the frequency offset estimated by the plurality of frequency offset estimating units;

- a phase offset estimating unit for estimating a phase offset of the carrier for which the frequency offset is combined by the combining unit; and

- a voltage-controlled oscillating (VCO) unit for oscillating a predetermined level of voltage for compensating for the frequency offset and the phase offset and then tuning.

In accordance with a second aspect of the invention, there is provided a carrier recovery method using a carrier recovery apparatus of a digital broadcasting receiver, for recovering an offset of a carrier occurring during a tuning, by using an I-signal and a Q-signal contained in a digital broadcasting signal, the method comprising the steps of:

estimating a frequency offset of the carrier occurring during the tuning, by using a plurality of pilot tones contained in the I-signal and the Q-signal;

combining the frequency offset that is estimated according to the plurality of pilot tones;

estimating a phase offset of the carrier by using the combined value of frequency offset;

and

oscillating a predetermined level of voltage for compensating for the frequency offset and the phase offset of the carrier for tuning.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned aspects and the feature of the present invention will be more apparent by describing the preferred embodiment of the present invention by referring to the appended drawing, in which:

FIG. 1 is a block diagram of a conventional digital broadcasting receiver;

FIG. 2 is a block diagram of a frequency/phase synchronizing unit of FIG.1 in greater detail;

FIG. 3 is a block diagram of a digital broadcasting receiver and a carrier recovery apparatus according to a preferred embodiment of the present invention;

FIG. 4 is a block diagram showing the first and second frequency offset estimating units of FIG. 3 in greater detail;

FIG. 5A is a view showing the first frequency shifting unit of FIG. 4 in greater detail;

FIG. 5B is a view showing the second frequency shifting unit of FIG. 4 in greater detail;

FIG. 6 is a block diagram of the phase offset estimating unit of FIG. 3 in greater detail;

FIG. 7 is a flowchart showing a method for recovering carrier using a carrier recovery apparatus of a digital broadcasting receiver according to the preferred embodiment of the present invention;

FIG. 8 is a flowchart showing in detail the frequency offset estimating step of FIG. 7;

FIG. 9 is a flowchart showing in detail the frequency shifting step of FIG. 8; and

FIG. 10 is a flowchart showing in detail the phase offset estimating step of FIG. 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, the preferred embodiment of the present invention will be described in greater detail with reference to the accompanying drawings.

FIG. 3 is a block diagram of a carrier recovery apparatus of a digital broadcasting signal and a digital broadcasting receiver according to the present invention. The digital broadcasting receiver includes a tuner 62, a surface acoustic wave (SAW) filter 64, a intermediate frequency (IF) amplifying unit 66, an analog-to-digital converter (ADC) 68, an I/Q separator 70, a matched filter 72, a pilot removing unit 74, a down-sampling unit 76, an equalizing unit 78, a sampling compensate unit 80 and a carrier recovery apparatus 100.

The tuner 62 tunes the received digital broadcasting signal at the antenna 60 to a corresponding band according to a tuning command. The SAW filter 64 filters the digital broadcasting signal of tuned band to a predetermined intermediate frequency (IF) band. The intermediate frequency (IF) amplifying unit 66 amplifies the digital broadcasting signal in intermediate frequency (IF) band output from the SAW filter 64 into intermediate frequency. The ADC 68 converts the intermediate frequency amplified digital broadcasting signal into digital signals. The I/Q separator 70 separates the digital broadcasting signal into I and Q signals, respectively. The matched filter 72 filters the I and Q signals to have a sinusoidal characteristic agreed at the time of transmitting. The pilot removing unit 74 removes the pilot from the filtered I and Q signals. The down-sampling unit 76 reduces the size of the pilot-removed I and Q signals. The equalizing unit 78 compensates for the distortion of the down-sampled I and Q signals that has occurred during the transmission.

The sampling compensate unit 80 compensates for the timing distortion that has occurred during the sampling of the ADC 68. The carrier recovery apparatus 100 compensates for the frequency offset and phase offset occurring during the tuning of the tuner 62, by using the pilot contained in the symbol of the digital broadcasting signal. In this embodiment, the frequency offset and the phase offset of the carrier are recovered by using the two (2) pilot tones with respect to one symbol.

As shown, the carrier recovery apparatus 100 includes a first frequency offset estimating unit 120, a second frequency offset estimating unit 140, a combining unit 160, a phase offset estimating unit 170 and a voltage-controlled oscillator (VCO) 180.

The first frequency offset estimating unit 120 estimates the frequency offset of the carrier by using the I and Q signals of the first pilot tone. The second frequency offset

estimating unit 140 estimates the frequency offset of the carrier by using the I and Q signals of second pilot tone. The combining unit 160 combines the frequency offsets respectively estimated by the first and the second frequency offset estimating units 120, 140 with respect to the carrier. The phase offset estimating unit 170 estimates the phase offset of the carrier based on the combined value of the respective frequency offsets at the combining unit 160. The VCO 180 provides the tuner 62 with a predetermined level of voltage, according to which the frequency offset and the phase offset of the carrier are compensated and tuned.

By estimating the frequency offset of the carrier based on the two pilots with respect to one symbol, and estimating the phase offset of the carrier by combining the estimated values, the error rate of carrier recovery due to the damaged pilot can be reduced.

Accordingly, the carrier can be recovered more reliably.

FIG. 4 is a block diagram showing the first and second frequency offset estimating units 120, 140 of FIG. 3 in greater detail.

The first frequency offset estimating unit 120 includes a first frequency shifting unit 121, a first low pass filter (LPF) 123, a first auto frequency control low pass filter (AFC-LPF) 125, a first limiter 127 and a first multiplier 129.

The first frequency shifting unit 121 shifts the first pilot tone of the two pilot tones in the I and Q signals output from the I/Q separator 121 in base band. The first LPF 123 filters the frequency band of the first pilot tone output from the first frequency shifting unit 121. The first AFC-LPF 125 filters the band of the first pilot tone to calculate the frequency difference of a predetermined reference signal and the first pilot tone. The first limiter 127 generates pulse waves corresponding to the frequency offset value of the carrier, based on the frequency difference calculated from the first AFC-LPF 125. The first multiplier 129 multiplies the

pulse waves generated from the first limiter 127 by the Q-signal having the first pilot tone that is filtered at the first LPF 123.

The second frequency offset estimating unit 140 includes a second LPF 143, a second AFC-LPF 145, a first limiter 147 and a first multiplier 149. The second frequency offset estimating unit 140 performs the same process as the first frequency offset estimating unit 120 does, using the second pilot tone of the two pilot tones contained in the I and Q-signals output from the I/Q separator 70.

The combining unit 160 combines the multiples from the first and second multiplying units 129, 149 to calculate the combined value of the frequency offsets of the carriers.

FIG. 5A is a view showing the first frequency shifting unit 121 of FIG. 4 in greater detail, and FIG. 5B is a view showing the second frequency shifting unit 141 of FIG. 4 in greater detail. The first frequency shifting unit 121 includes a first numerically-controlled oscillator (NCO) 121a and a first complex multiplying unit 121b. The first NCO 121a calculates the frequency value for shifting the first pilot tone of I and Q signals to the base band. The first complex multiplying unit 121b complex-multiplies the I and Q signals output from the I/Q separator 70 by the frequency values calculated by the first NCO 121a to shift the first pilot tone to base band. The second frequency shifting unit 141 includes a second numerically-controlled oscillator (NCO) 141a and a second complex-multiplying unit 141b. The second NCO 141a calculates the frequency value for shifting the second pilot tones of the I and Q signals to the base band. The second complex-multiplying unit 141b complex-multiplies the I and Q signals by the frequency values that are calculated by the second NCO 141a, to shift the second pilot tone to the base band.

FIG. 6 is a block diagram showing the phase offset estimating unit 170 of FIG. 3 in

greater detail. The phase offset estimating unit 170 includes a loop filter 172 and an APC-LPF 174. The loop filter 172 filters the combined value from the combining unit 160 so that the combined value can maintain a sinusoidal pattern. The APC-LPF 174 estimates the phase offset value of the carrier by calculating the phase difference of the combined value output from the loop filter 172 and a predetermined reference signal.

The VCO 180 oscillates a predetermined level of voltage for compensating for the frequency offset combined by the combining unit 160 and the estimated phase offset estimated by the phase offset estimating unit 170, and provide the tuner 62 with the predetermined level of voltage.

According to the preferred embodiment of the present invention, the digital broadcasting receiver recovers the carriers based on the frequency offset and the phase offset of the carriers that it has estimated by using two pilots. Accordingly, the carriers can be recovered reliably even when the pilot is damaged.

FIG. 7 is a flowchart showing the method of carrier recovery using the carrier recovery apparatus of the digital broadcasting receiver according to the preferred embodiment of the present invention. First, the first frequency offset estimating unit 120 and the second frequency offset estimating unit 140 estimate the frequency offset of the carrier of the digital broadcasting signal by using the two pilots contained in the I and Q signals (step S100). The combining unit 160 combines the frequency offsets that are estimated by the first and second frequency offset estimating units 120, 140 (step S200). The phase offset estimating unit 170 calculates the phase difference between the I and Q signals and the predetermined reference signal based on the combined value of the combining unit 160, and estimates the phase offset of the carrier based on such calculated result (step S300). The VCO 180 oscillates a

predetermined level of voltage for compensating for the frequency offset of the carrier combined at the combining unit 160 and the phase offset estimated at the phase offset estimating unit 170, and provides the tuner 62 with the predetermined level of voltage (step S400).

As the carrier is recovered by the use of the two pilots to estimate the frequency offset and the phase offset, the carrier can be recovered reliably, even when the digital broadcasting signal is transmitted to a dynamic channel that changes by time.

FIG. 8 is a flowchart showing the frequency offset estimating step S100 of FIG. 7 in greater detail. First, the first and the second frequency offset estimating units 120, 140 shift the first and second pilot tones of the two pilots to the base band (step S110). The first and second LPFs 123, 143 perform the low pass filtering, by passing the first and the second pilot tones of the I and Q signals output from the first and second frequency shifting units 121, 141 to the frequency band (step S120). The first and second AFC-LPFs 125, 145 filter the bands of the first and second pilot tones passed through the first and second LPFs 123, 143, to calculate the frequency difference between the first and second pilot tones and the predetermined reference signal (step S130). The first and second limiters 127, 147 generate pulse waves corresponding to the frequency offset value of the carrier based on the frequency differences output from the first and second AFC-LPFs 125, 145, respectively (step S140). The first and second multiplying units 129, 149 multiply the Q signals containing the first and second filtered pilot tones from the first and second LPFs 123, 143, by the corresponding pulse waves generated from the first and the second limiters 127, 147 (step S150). Accordingly, the first and second multiplying units 129, 147 provides the combining unit 160 with the multiples (step S160).

FIG. 9 is a flowchart showing the frequency shifting step S110 of FIG. 8 in greater detail. First, the first and second NCOs 121a and 141a calculate the frequency value for shifting the pilot tones of the I and Q signals to the base band (step S112). Accordingly, the first and second complex-multiplying units 121b, 141b perform the multiplication of the I and Q signals based on the multiples calculated by the first and second NCOs 121a and 141a (step S114). Accordingly, the carrier of the digital broadcasting signal is shifted.

FIG. 10 is a flowchart showing the phase offset estimating step S300 of FIG. 7 in greater detail. First, the loop filter 172 filters the combined value from the combining unit 160 so that the combined value can maintain the sinusoidal characteristic (step S320). The APC-LPF 174 calculates the phase difference between the loop-filtered combined value and the predetermined reference signal, to estimate the phase offset of the carrier (step S340).

Accordingly, the VCO 180 oscillates the predetermined level of voltage for compensating for the frequency offset from the combining unit 160 and the phase offset estimated by the phase offset estimating unit 170, and provides the tuner 62 with the predetermined level of voltage. As the frequency offset and phase offset of the carrier is estimated by using the two pilots, and such estimated offsets are considered when recovering the carrier, the carrier can be recovered reliably even when the pilot is damaged.

According to the present invention, as the frequency offset and the phase offset are estimated and recovered by using the two pilots, the carrier can be reliably recovered even when the pilot is damaged due to variation of channel environment.

Further, as the carrier is recovered by using the two pilots, the carrier and the data can be recovered more accurately.

Although the preferred embodiments of the present invention have been described, it

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will be understood by those skilled in the art that the present invention should not be limited to the described preferred embodiments, but various changes and modifications can be made within the spirit and scope of the present invention as defined by the appended claims.

CLAIMS:

1. A carrier recovery apparatus of a digital broadcasting receiver for recovering an offset of a carrier generated during a tuning, by using an I-signal and a Q signal contained in a digital broadcasting signal, the carrier recovery apparatus comprising:

a plurality of frequency offset estimating units for estimating a frequency offset of the carrier generated during the tuning of the digital broadcasting signal, by shifting a plurality of pilot tones contained in the I signal and the Q signal respectively to a base band;

a combining unit for combining the frequency offset estimated by the plurality of frequency offset estimating units;

a phase offset estimating unit for estimating a phase offset of the carrier for which the frequency offset is combined by the combining unit; and

a voltage-controlled oscillating (VCO) unit for oscillating a predetermined level of voltage for compensating for the frequency offset and the phase offset and then tuning.

2. The carrier recovery apparatus of claim 1, wherein the frequency offset estimating unit comprises:

a frequency shifting unit for shifting the plurality of pilot tones to a base band, respectively;

an auto frequency control low pass filter (AFC-LPF) for calculating a frequency difference of the plurality of pilot tones by filtering the bands of the pilot tones, respectively;

a limiter for generating a pulse wave corresponding to the frequency offset of the carrier based on the frequency difference; and

a multiplying unit for multiplying the pulse wave by the Q-signal containing the

plurality of shifted pilot tones, wherein

the combining unit calculates a combined value of the plurality of pilot tones by combining the multiples.

3. The carrier recovery apparatus of claim 2, wherein the frequency offset estimating unit further comprises a low pass filtering (LPF) unit provided between the frequency shifting unit and the AFC-LPF, for filtering the frequency band of the plurality of pilot tones output from the frequency shifting unit, whereby the multiplying unit multiplies the Q-signal filtered by the LPF by the pulse wave output from the limiter.

4. The carrier recovery apparatus of claim 3, wherein the frequency shifting unit comprises:

a numerically-controlled oscillator (NCO) for calculating a frequency value for shifting the plurality of pilot tones to the base band; and

complex-multiplying unit for shifting the plurality of pilot tones to the base band, by complex-multiplying the frequency value by the I-signal and the Q-signal.

5. The carrier recovery apparatus of claim 4, wherein the phase offset estimating unit comprises:

a loop filtering unit for filtering the combined value from the combining unit so that the combined value can maintain a smooth curve; and

an auto phase control low pass filter (APC-LPF) for estimating the phase offset of the carrier through the combined value from the loop filtering unit.

6. The carrier recovery apparatus of claim 5, wherein the plurality of pilot tones contained in the I-signal and the Q-signal are two, and the frequency shifting unit, the LPF, the AFC-LPF, the limiter and the multiplying unit are respectively provided in two (2), correspondingly.

7. The carrier recovery apparatus of claim 6, wherein the frequency value output from the NCO is -3.57 MHz and $+3.57$ MHz, respectively.

8. The carrier recovery apparatus of claim 7, wherein the frequency difference output from the AFC-LPF is one of a positive value, a negative value and zero (0).

9. The carrier recovery apparatus of claim 8, wherein the limiter generates the pulse wave of $+1$ when the frequency difference output from the AFC-LPF is positive, generates the pulse wave of -1 when the frequency difference from the AFC-LPF is negative, and generates the pulse wave of 0 when the frequency difference from the AFC-LPF is 0 .

10. A carrier recovery method using a carrier recovery apparatus of a digital broadcasting receiver, for recovering an offset of a carrier occurring during a tuning, by using an I-signal and a Q-signal contained in a digital broadcasting signal, the method comprising the steps of:

estimating a frequency offset of the carrier occurring during the tuning, by using a plurality of pilot tones contained in the I-signal and the Q-signal;

combining the frequency offset that is estimated according to the plurality of pilot tones;

estimating a phase offset of the carrier by using the combined value of frequency offset; and

oscillating a predetermined level of voltage for compensating for the frequency offset and the phase offset of the carrier for tuning.

11. The carrier recovery method of claim 10, wherein the frequency offset estimating step comprises the steps of:

shifting the frequency of the plurality of pilot tones in a base band, respectively;

calculating a frequency difference of the plurality of pilot tones by filtering the bands of the plurality of pilot tones that are shifted to the base band;

generating a pulse wave corresponding to the frequency offset of the carrier based on the frequency difference; and

multiplying the pulse wave by the Q-signal containing the plurality of pilot tones that are shifted to the base band, wherein

the combining step calculates a combined value of the plurality of pilot tones by combining the respective multiples.

12. The carrier recovery method of claim 11, the frequency offset estimating step further comprises the low pass filtering step for filtering a narrow band where the plurality of shifted pilot tones are positioned, wherein

the multiplying step multiplies the filtered Q-signal by the pulse wave.

13. The carrier recovery method of claim 12, wherein the frequency shifting step comprises the steps of;

calculating a frequency value for shifting the plurality of pilot tones to the base band, respectively; and

performing the frequency shifting into the base band with respect to the plurality of pilot tones, by complex-multiplying the frequency value by the I-signal and the Q-signal.

14. The carrier recovery method of claim 13, wherein the phase offset estimating step comprises the steps of:

loop-filtering the combined value so that the combined value can maintain a smooth curve; and

estimating the phase offset value of the carrier based on the combined value that is loop-filtered.

15. The carrier recovery method of claim 14, wherein the plurality of pilot tones contained in the I-signal and the Q-signal are two.

16. The carrier recovery method of claim 14, wherein the frequency value output from the frequency value calculating step is -3.57 MHz and $+3.57$ MHz, respectively.

17. The carrier recovery method of claim 16, wherein the frequency difference output from the frequency difference calculating step is one of a positive value, a negative value and

zero (0).

18. The carrier recovery method of claim 17, wherein pulse wave generating step generates the pulse wave of +1 when the frequency difference output is positive, generates the pulse wave of -1 when the frequency difference is negative, and generates the pulse wave of 0 when the frequency difference is 0.

**CARRIER RECOVERY APPARATUS OF DIGITAL BROADCASTING
RECEIVER USING TWO (2) PILOT SIGNALS**

ABSTRACT

A carrier recovery apparatus of a digital broadcasting receiver. The carrier recovery apparatus has a plurality of frequency offset estimating units for estimating a frequency offset of the carrier generate during the tuning of the digital broadcasting signal, by shifting a plurality of pilot tones contained in the I signal and the Q signal respectively to a base band; a combining unit for combining the frequency offset estimated by the plurality of frequency offset estimating units; a phase offset estimating unit for estimating a phase offset of the carrier for which the frequency offset is combined by the combining unit; and a voltage-controlled oscillating (VCO) unit for oscillating a predetermined level of voltage for compensating for the frequency offset and the phase offset and then tuning.

FIG. 3