(54) Title: COMMUNICATION SYSTEM USING LOW BANDWIDTH WIRES
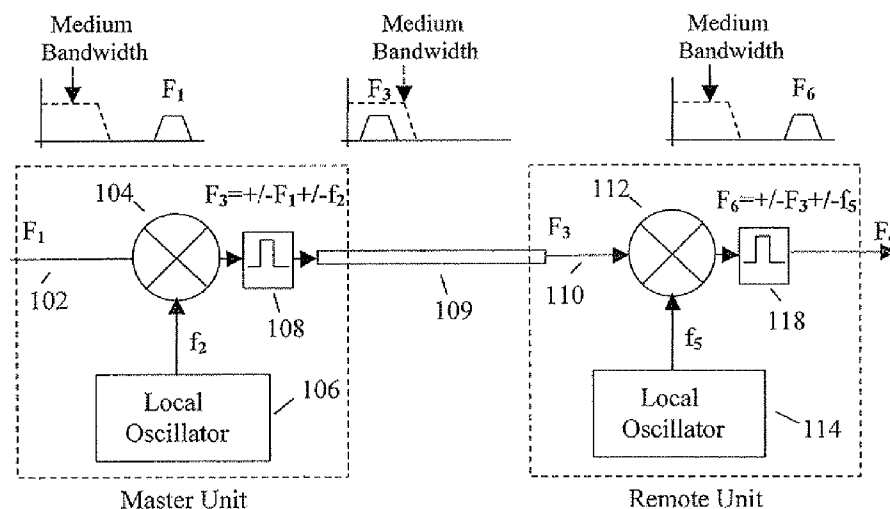
FIG. 1

(57) Abstract: A high frequency signal is down-converted into an intermediate frequency signal, transmitted over a limited band-width medium from a master unit to a remote unit and up-converted back into its original high frequency at the remote unit. The up-conversion is aided by reconstruction of a reference signal embedded at the master unit as a carrier for a management signal which is transmitted to the remote unit through the same limited bandwidth medium together with the intermediate frequency signal. The reference signal is reconstructed using a phase locked loop which includes a charge pump and is kept stable during intervals between bits and messages by a charge pump shutter.

COMMUNICATION SYSTEM USING LOW BANDWIDTH WIRES

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CROSS REFERENCE TO EXISTING APPLICATIONS

This application claims priority from U.S. Provisional Patent Application No.

10   60/960,937 filed October 22, 2007, which is incorporated herein by reference in its entirety.

FIELD AND BACKGROUND OF THE INVENTION

15   The invention relates generally to communication systems using low bandwidth wires such as telephone and Ethernet lines and more particularly to accurate reconstruction of a high frequency signal which had its frequency shifted to lower frequencies in order to enable its transmission over limited bandwidth media.

Several systems and application exist today where cellular or other high

20   frequency signals need to be propagated through copper wires such as telephone or Ethernet lines. Since the bandwidth of copper wires is limited, high frequency signals can not propagate through them without significant attenuation. Therefore a known solution is to use a system in which the original high frequency signal is converted into a lower frequency band, which can be propagated over the copper wire and

25   converted back to its original frequency band at the receiving side. Such a system is shown in FIG. 1. Frequency conversion is performed by mixing the incoming high frequency signal with a signal obtained by a local oscillator. The incoming high frequency signal at frequency band F1 is mixed by mixer **104** with the signal of a local oscillator **106** which its frequency is f2. The product of the mixer may be at a

30   frequency described by $F3 = \pm F1 \pm f2$. A filter **108** at the output of the mixer **106** determines which of the possible combinations of F3 will be selected. As an example

to be used in the following explanation, the required combination may be F3=f2-F1. The signal with this frequency is fed to the copper wire 109 and arrives through it to the remote unit which includes, among other elements a mixer 112, a local oscillator 114 and a band pass filter 118. The incoming signal at frequency band F3 is mixed at

5   mixer 112 with a signal at frequency f5 produced by local oscillator 114. According to this example, filter 118 at the output of the mixer 112 selects a frequency band F6=f5-F3. In order for F6 to be an accurate replica of F1, f5 needs to be exactly the same frequency as f2. In other words, the frequency of both local oscillators needs to be the identical.

10   The method of transferring high frequency signals over low bandwidth media by frequency conversion is known in the art. However, this method requires the transfer of a reference signal between the master and the remote units in order to produce an accurate replica of the original signal at the remote side. US Patent 6,157,810 entitled "Distribution of Radio-Frequency Signals Through Low Bandwidth

15   Infrastructure" to Georges describes such a system and proposes to transfer between the master unit and the remote unit a "reference tone" in a "IF frequency", low enough to be transferred through the wires.

This approach, as used also in other systems, requires a dedicated special frequency band in the limited bandwidth of the wires and use of a relatively sharp

20   band pass filter in the remote unit in order to filter the reference tone out of the other signals. This becomes even more problematic when several frequency bands need to be transferred simultaneously through the wires.

SUMMARY OF THE INVENTION

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In order to save bandwidth and avoid the need for a dedicated frequency band for the reference signal, this invention makes use of the management signal which is transferred between a master unit and a remote unit of a communications system for control purposes and suggests a method and a system that embed a reference signal in

30   the discontinuous management signal transmitted between the master and the remote units. The reference signal is embedded into the management signal by using the

2

reference signal as the carrier of management data. The use of the management channel for transfer of the reference signal removes the need for a dedicated reference channel. This saves spectrum and reduces component count and complexity. Saving spectrum has a significant importance, since the bandwidth of the copper wires is

5   relatively low and needs to be used effectively for payload data.

The management signal is transferred through the management selected frequency band dedicated for this purpose. A phase locked loop (PLL) is used to reconstruct the reference signal in the remote units out of the management signal. Since the management signal is not continuous, there is a need for a stabilization

10   mechanism that will hold stable the reconstructed reference signal during the intervals between bits and between messages. The stabilization mechanism includes a charge pump shutter which performs this task.

In an embodiment there is provided a method for accurate reconstruction of the reference signal transmitted between a master unit having a master local oscillator and

15   a remote unit having a remote local oscillator, the master and remote units connected by a limited medium bandwidth, the reference signal transmitted over the limited medium bandwidth together with a signal which is down-converted from an original high frequency signal to an intermediate frequency signal at the master unit and up-converted back into the original high frequency signal at the remote unit, the method

20   comprising the steps of: at the master unit, embedding the reference signal as a carrier of a management signal and transmitting the management signal with the embedded reference signal over the limited bandwidth medium to the remote unit; at the remote unit, reconstructing the reference signal from the management signal and using the reconstructed reference signal for synchronizing the remote local oscillator with the

25   master local oscillator.

In an embodiment there is provided a system for reconstructing a reference signal transmitted in a communications system over a limited bandwidth medium between a master unit having a master local oscillator and a remote unit having a remote local oscillator, the system comprising a modem configured to embed the

30   reference signal at the master unit as a carrier of a management signal carrying a management data bit stream and management messages between the master unit and

the remote unit and a phase locked loop for accurately reconstructing the reference signal at the remote unit, the reconstructed reference signal used to synchronize the master and remote local oscillators.

5   BRIEF DESCRIPTION OF THE DRAWINGS

        The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

        FIG. 1 describes a prior art system for transferring high frequency signals

10   through a low bandwidth medium;

        FIG. 2 shows an embodiment of a system of the invention;

        FIG. 3 shows the form of a signal modulated by On-Off Keying (OOK) modulation;

        FIG. 4 describes in more details the phase locked loop in the system of FIG. 2;

15   FIG. 5 describes the operation of the charge pump shutter in the phase locked loop of FIG. 4.

        DETAILED DESCRIPTION OF THE INVENTION

20   A more complete understanding of the invention, as well as further features and advantages of the invention will be apparent from the following detailed description and the accompanying drawings.

        FIG. 2 shows the block diagram of an embodiment of a system **200** of the invention, used to embed a reference signal into management signal. System **200**

25   includes a master unit **201** and a remote unit **205** coupled electrically by wiring **214**. Master unit **201** includes a mixer **202**, a duplexer **203**, a band pass filter **204**, a local oscillator **206,** a master modem **210** and a reference clock **212**, interconnected as shown. Remote unit **205** includes an input duplexer **218**, a conversion mixer **220**, a band pass filter **222**, a local oscillator **224**, a PLL **226** and a control modem **228**,

30   interconnected as shown. PLL **226** is described in more detail with reference to FIG. 4.

Master modem **210** is used at the master side for modulating the management data over the reference signal generated by reference clock **212.** That is, master modem 210 is configured and used to embed the reference signal into the management signal. The reference signal at intermediate frequency (IF) is used as a carrier for the

5   management data. The modulated management data now becomes the management signal which is transferred through duplexer **203** and wires **214** to the remote side. At the remote side, the management signal is demodulated by control modem **228** and used for controlling the remote unit. The reference signal used by modem **210** as a carrier for the management data is derived from reference clock **212.**

10   The reference signal is also provided to local oscillator **206**, used for the conversion (down-shifting) of an original high frequency signal band F1 into an intermediate frequency band F3. The resulting mixed signal can be each of the possible positive combinations of F1 and f2 described by $F3=\pm F1\pm f2$. Band pass filter **204** determines which of the possible combinations is selected. Assume

15   exemplarily that the required combination is $F3=f2-F1$. The converted signal in band F3 is combined with the management signal which uses the reference signal as a carrier at duplexer **203** and both are transferred through wiring **214** to the remote unit, where duplexer **218** separates the combined signal into its components according to their frequency band. The separated converted signal of band F3 is routed by duplexer

20   **218** to conversion mixer **220**. The separated management signal is routed to control modem **228** and to reference reconstruction unit **226**. Control modem **228** demodulates the management signal and obtains the management data. PLL **226** is used to reconstruct the reference signal from the modulated management signal. The PLL filters out the management data and leaves a filtered reference signal. This

25   filtered reference signal is fed to local oscillator **224**. Since the reference frequency of both local oscillators **206** and **224** is derived from the same source, the frequency of the two local oscillators is made identical.

Local oscillator **224** at the remote unit produces a frequency f5 based on the reference frequency arriving from PLL **226**. Mixer **220** is used for up-conversion of

30   the signals in frequency band F3 to frequency band F6. Band pass filter **222** at the output of mixer **220** selects the frequency band $F6=f5-F3$. Since the frequency of the

signal at the output of PLL **226** is identical to the frequency of the reference signal, both local oscillators **206** and **224** are synchronized on an identical reference frequency. As a result, the F6 band becomes an accurate replica of the F1 band. That is, each signal in the F1 band returns exactly to its original frequency in the F6 band.

5   The same principles may be used with multiple remote units. Furthermore, the same principles may be used where F1 represents multiple frequency bands (and consequently F3 and F6 represent multiple frequency bands).

In many applications, the management data is modulated using an On-Off-Keying modulation (OOK) scheme, shown exemplarily in FIG. 3. According to this

10   scheme, an RF signal is transmitted (ON) when a bit="1" needs to be delivered and no RF signal is transmitted (OFF) when a bit="0" needs to be delivered. The interval between RF transmissions in the same message might last up to several milliseconds. The interval between the messages might last several seconds.

FIG. 4 shows in more detail a possible implementation of the PLL **226**. In this

15   exemplary embodiment, PLL **226** includes a phase detector **406**, a charge pump **410**, a capacitor **414** and a highly stable voltage controlled crystal oscillator (VCXO) **418** interconnected as shown. Normally, a PLL can not deal with a non-continuous signal, such as the management signal. This problem is solved by the invention in the following way.

20   When the management signal transmits bit="1", an RF signal at the frequency of the reference signal appears at the input of phase detector **406**. The PLL is then locked to this frequency and the VCXO is driven by the voltage on capacitor **414** controlled by charge pump **410** to generate a signal with the same frequency as the frequency of the signal at the input signal of the PLL. The lock time of the PLL is

25   designed to be much shorter than the period of a bit. In the PLL embodiment implemented given here as an example, the period of one bit is about 50 microseconds and therefore the lock time was designed to be about 10 microseconds.

In continuous operation, the charge pump controls the frequency of the VCXO by adjusting the voltage on capacitor **414**. When the voltage on the capacitor needs to

30   be increased, charge pump **410** injects small current bursts into the capacitor (a "charge" adjustment). When the voltage on the capacitor needs be lowered, charge

pump **410** sinks small current bursts from the capacitor (a "pump" adjustment). These adjustments are required to compensate for the drift in the frequency of the VCXO. During the intervals between bits or between messages of the management signal, no reference signal appears at the input of phase detector **406** and therefore the PLL

5   might lose its lock and the VCXO might be pulled out of the frequency of the reference signal. In order to avoid such situation, a charge pump shutter **408** is used. The charge pump shutter maintains the frequency of the \VCXO stable in the intervals between the bits and the messages. Charge pump shutter **408** senses the incoming management signal at the output of duplexer **218.** When it identifies that a signal

10   appears at the input of the phase detector **406**, it allows the charge pump to change the voltage on capacitor **414.** When no signal appears in the input of phase detector **406,** the charge pump shutter shuts off the charge pump and therefore the voltage on capacitor **414** remains constant, thus the frequency of the VCXO **418** remains stable until the signal appears again at the input of the phase detector. The VCXO used for

15   this PLL embodiment has non- significant drift during the interval between messages. According to the implementation described here, the maximum interval between messages is up to ten seconds where the VCXO used for this implementation drifts during this period by less then one part of ten million.

       The charge pump shutter must shut the charge pump <u>before</u> the disappearance

20   of the signal at the input of the PLL, otherwise the PLL might lose its lock and the VCXO might be pulled out of the frequency of the reference signal. Therefore, it is not possible to rely on an energy detector which responds after the disappearance of the signal and an alternative approach is proposed here. According to this approach, shown in FIG. 5, the charge pump shutter synchronizes with the data stream of the

25   control signal which appears at the output of control modem **228.** A short time before the arrival of a new bit, the charge pump shutter shuts off the charge pump and checks whether a signal exists at the next bit. If a signal exists, then the charge pump shutter opens the charge pump, thus allowing normal operation. If no signal exists at the next bit, the charge pump shutter keeps the charge pump shut. The charge pump shutter can

30   be implemented in software, hardware or a combination of software and hardware. In

software, it can be implemented using the existing microprocessor of the system and a hardware control port that shuts off the charge pump when required.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made. What has been described above is merely illustrative of the application of the principles of the present invention. Those skilled in the art can implement other arrangements and methods without departing from the spirit and scope of the present invention.

CLAIMS

1.   A method for accurate reconstruction of a reference signal transmitted in a communications system between a master unit having a master local oscillator and a remote unit having a remote local oscillator, the master and remote units connected by a limited medium bandwidth, the reference signal transmitted over the limited medium bandwidth together with a signal which is down-converted from an original high frequency signal to an intermediate frequency signal at the master unit and up-converted back into the original high frequency signal at the remote unit, the method comprising the steps of:

a)   at the master unit, embedding the reference signal as a carrier of a management signal;

b)   transmitting the management signal with the embedded reference signal over the limited bandwidth medium to the remote unit; and

c)   at the remote unit, reconstructing the reference signal from the management signal.

2.   The method of claim 1, further comprising the step of:

d)   using the reconstructed reference signal for synchronizing the remote local oscillator with the master local oscillator.

3.   The method of claim 1, wherein the step of reconstructing the reference signal from the management signal includes using a phase locked loop (PLL).

4.   The method of claim 1, wherein the PLL includes a phased detector, a charge pump, a voltage controlled crystal oscillator and a capacitor.

5.   The method of claim 3, wherein the management signal includes a management data bit stream and wherein the step of reconstructing the reference signal from the management signal further includes using a charge pump shutter coupled to the PLL and

synchronized with the management data bit stream to keep the reconstructed reference signal stable.

6.   The method of claim 1, wherein step of embedding the reference signal as a carrier of a management signal includes forming the management signal by modulating management data using an On-Off Keying modulation scheme.

7.   The method of claim 5, wherein the using a charge pump shutter coupled to the PLL and synchronized with the management data bit stream to keep the reconstructed reference signal stable includes using the charge pump shutter to shut off the charge pump at least during intervals between transmissions of the management signal.

8.   A system for reconstructing a reference signal transmitted in a communications system over a limited bandwidth medium between a master unit having a master local oscillator and a remote unit having a remote local oscillator, the system comprising:
a)   a master modem configured to embed the reference signal at the master unit as a carrier of a management signal carrying a management data bit stream and management messages between the master unit and the remote unit; and
b)   a phase locked loop (PLL) for accurately reconstructing the reference signal at the remote unit, the reconstructed reference signal used to synchronize the master and remote local oscillators.

9.   The system of claim 8, further comprising a charge pump shutter for keeping the reconstructed reference signal stable during intervals between the management data bits and management messages.

10.   The system of claim 8, wherein the PLL includes a charge pump, a voltage controlled crystal oscillator and a capacitor configured to reconstruct the reference signal.

11.   The system of claim 9, wherein the charge pump shutter is synchronized with the management data bits.

12.   The system of claim 10, wherein the PLL has a lock time designed to be significantly faster by a factor of at least two than the period of a management data bit.

13.   The system of claim 9, wherein the charge pump shutter is implemented in hardware.

14.   The system of claim 9, wherein the charge pump shutter is implemented in software.

15.   The system of claim 9, wherein the charge pump shutter is implemented in a combination of hardware and software.
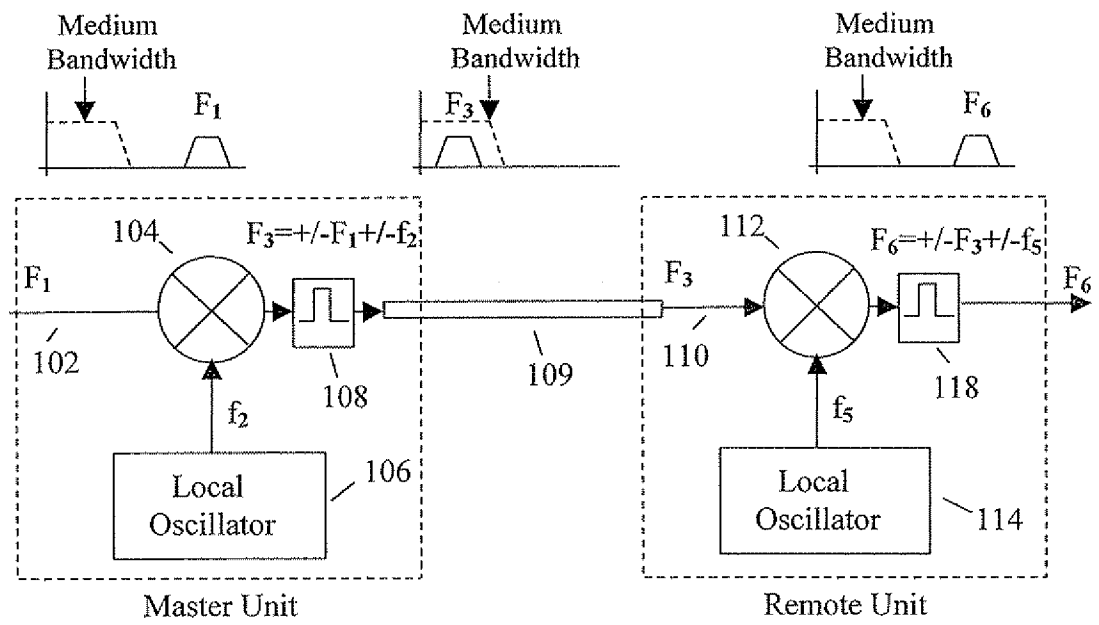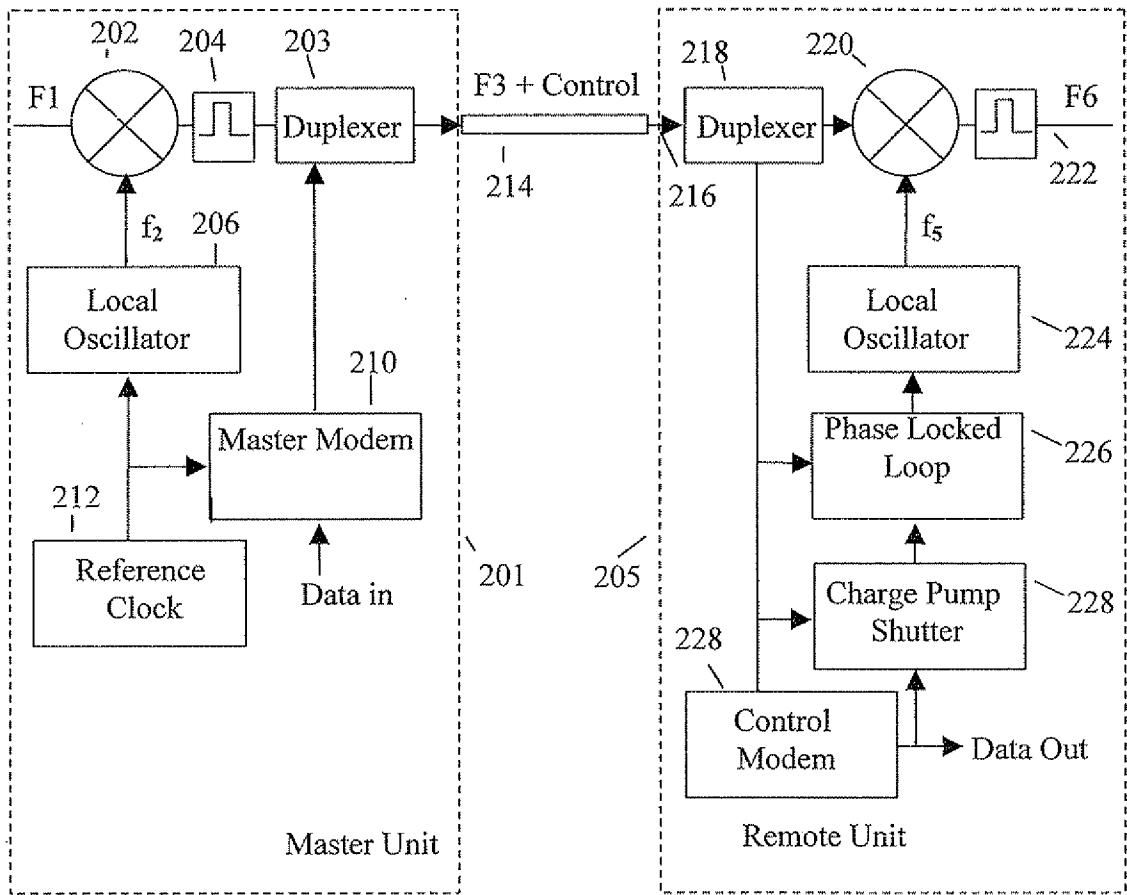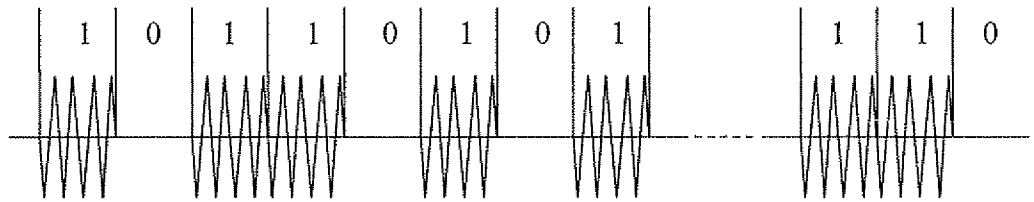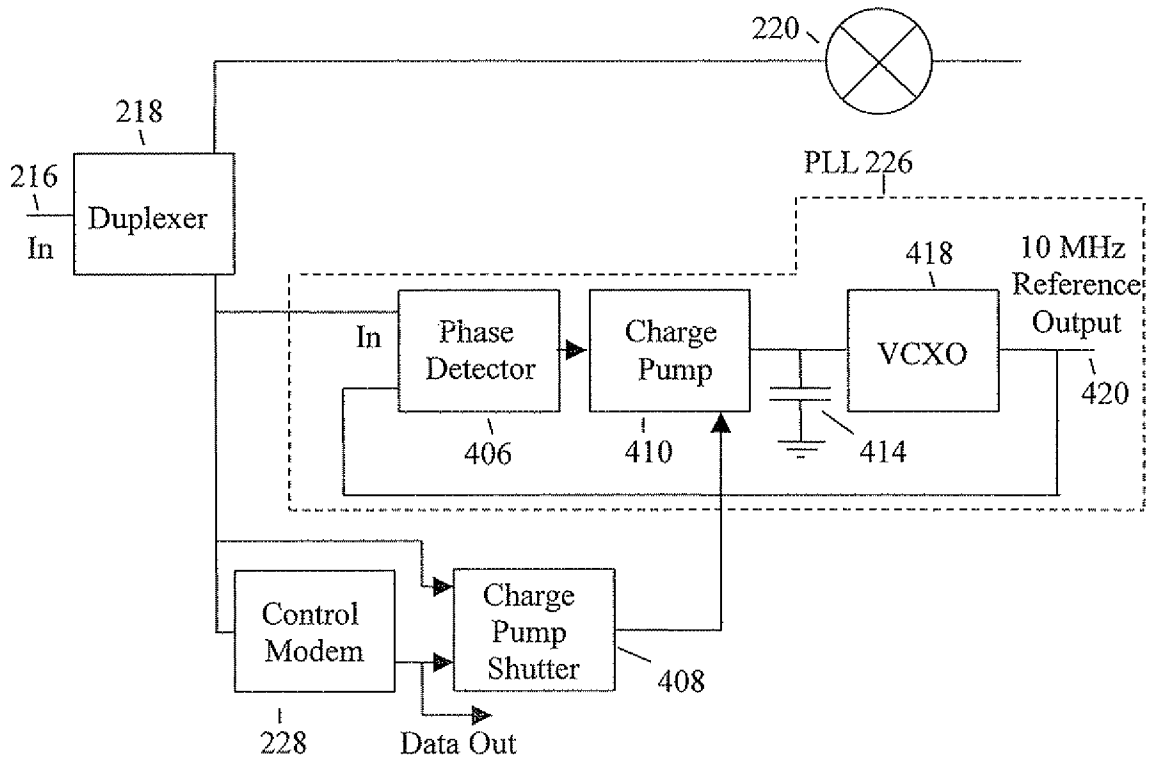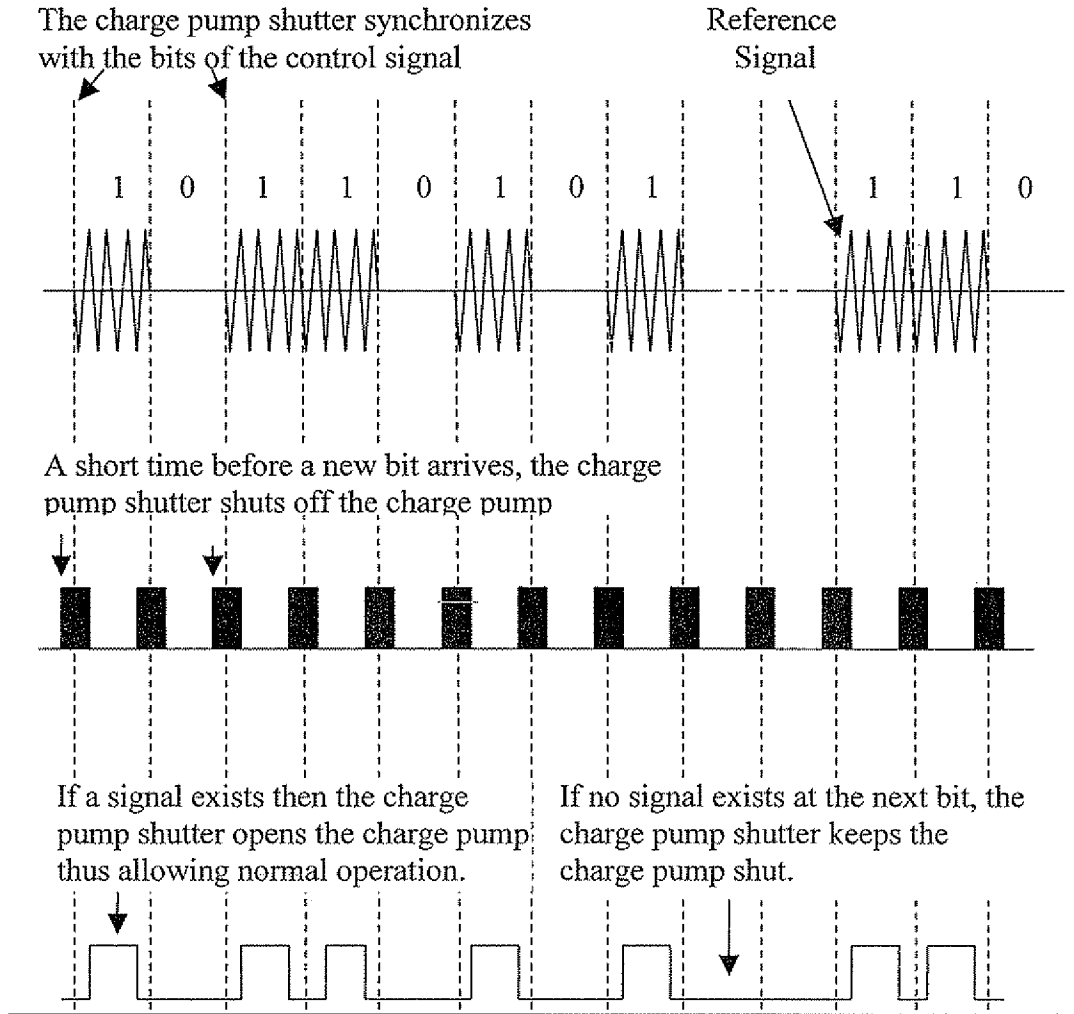
FIG. 1

Prior Art

200

FIG. 2

FIG. 3

FIG. 4

The charge pump shutter synchronizes
with the bits of the control signal

Reference
Signal

1   0   1   1   0   1   0   1   1   1   0

A short time before a new bit arrives, the charge
pump shutter shuts off the charge pump

If a signal exists then the charge
pump shutter opens the charge pump
thus allowing normal operation.

If no signal exists at the next bit, the
charge pump shutter keeps the
charge pump shut.

FIG. 5