The modulator includes an oscillator generating signals, each having a different phase, and a selector receiving digital data. When the digital data received by the selector changes logic state, the selector supplies a first and second plurality of signals generated by the oscillator to first and second non-linear amplifiers, respectively. An adder then adds the output of each amplifier to generate a radio frequency output.

17 Claims, 4 Drawing Sheets
FIG. 1

REFERENCE

STATE 1

STATE 0

0° = 0 deg

θ = 180 deg

FIG. 2

Q

00

01

10

11

FIG. 3

RING OSCILLATOR

SELECTOR

RF OUT

Σ

CE1

CE2
FIG. 4A

DATA IN

FIG. 4B

FIG. 5

16 DISCRETE PHASES AROUND THE RING

TRAJECTORY OF RF OUT PHASOR

PROJECTION OF RF OUT PHASOR OVER TIME

AMPLITUDE

2A₀

t=0

t=T_bit
FIG. 6
Fig. 7

In-phase

$\theta = \pi, (-1)$

$\theta = 0, (+1)$

16 discrete phases around the ring

Trajectory of I-RF out

Re

IM

Quadrature-phase

$\Psi = 0, (+1)$

$\Psi = \pi, (-1)$

Trajectory of Q-RF out

Re

IM

All possible trajectories of RF out from adder 50

Projection of I-RF out phasor over time

Projection of Q-RF out phasor over time

Amplitude

$2A_0$

$t = 0$

$t = T_{\text{bit}}$

$0, \Psi = \pi, 0$

$0, \Psi = 0, 0$

$2A_0^{-T_{\text{bit}}}$

$2A_0$

$t = 0$

$t = T_{\text{bit}}$
METHOD AND APPARATUS FOR MODULATING DIGITAL DATA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an efficient digital transmission technique, and more particularly, a method and apparatus for modulating digital data.

2. Description of Related Art

Digital communication relies on numerous different, albeit related, forms of digital modulation such as phase shift keying (PSK), bi-phase shift keying (BPSK), quadrature phase shift keying (QPSK or 4-PSK), and quadrature amplitude modulation (QAM).

BPSK will be described with reference to FIG. 1. As shown, the magnitude of a reference carrier is constant, and to transmit either a 0 or a 1, the phase thereof is “keyed” or switched between 0° and 180°. A receiver then decides whether a 0 or a 1 was transmitted based on the phase of the received carrier, and generates the original data stream. With this simple scheme, one bit of information is transmitted at each transference so that all of proper the states appear. Constellation diagrams such as in FIG. 1 typically do not show the transition does take a finite time. But for clarity, the transitions are not shown otherwise traces connecting the two states would clutter the diagram.

FIG. 2 illustrates the constellation diagram for QPSK. As shown, four different states exist in the QPSK diagram at phase values of 45°, 135°, 225°, and 315°. As further shown, each state corresponds to a symbol representing two bits. Because the data is taken two bits at a time to form a symbol, the symbol rate is half the bit rate. As a result, QPSK requires half the bandwidth of BPSK for the same bit rate.

Transmission of the modulated signal usually requires generating an amplified modulated signal. Unfortunately, amplification can introduce distortion, which alters the bandwidth of the signal. Many multiple access communication techniques, such as time division multiple access (TDMA), require maintaining transmitted signals within a narrow frequency band to increase capacity. For this reason, linear amplifiers have generally been used to amplify modulated signals when such multiple access communication techniques are employed. Linear amplifiers, while amplifying the modulated signal, also preserve the frequency of the signal, and give a better narrow band accuracy. By narrow band, it is meant that the frequency band of the carrier signal is larger than the frequency band of the signal.

Linear amplifiers, however, consume significant power. Power becomes an issue, particularly, in wireless communication systems where the individual mobile stations are powered by a limited power source. Accordingly, techniques that advantageously lengthen the life of such power sources are highly desirable.

SUMMARY OF THE INVENTION

The method and apparatus for modulating digital data according to the present invention uses non-linear amplifiers. Non-linear amplifiers, occasionally called switching or high frequency amplifiers and commonly known (but not limited to) as classes D, E, F, G and H, faithfully reproduce the phase of a signal, but not the envelope (in contrast to linear amplifiers). Non-linear amplifiers consume significantly less power than linear amplifiers, but because of the distortion they introduce, typically do not meet narrow frequency band requirements. However, the method and apparatus for modulating digital data according to the present invention, while using non-linear amplifiers, also meets narrow frequency band requirements.

The modulator includes an oscillator generating signals, each having a different phase. A selector, in the modulator, sends a first plurality of these signals to a first non-linear amplifier when the digital data received by the selector changes logic state (e.g., goes from 0 to 1 or from -1 to 1), and also sends a second plurality of the signals to a second non-linear amplifier when the digital data changes logic state. The outputs of the first and second non-linear amplifiers are summed to generate a radio frequency output that does not suffer from distortion typically introduced by non-linear amplifiers.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given below and the accompanying drawings which are given by way of illustration only, wherein like reference numerals designate corresponding parts in the various drawings, and wherein:

FIG. 1 illustrates the reference carrier, keyed reference carrier and constellation diagram for bi-phase shift keying;

FIG. 2 illustrates the constellation diagram for quadrature phase shift keying;

FIG. 3 illustrates a modulator according to the present invention for performing BPSK modulation;

FIGS. 4A-4B illustrate the digital data received and the RF output of the modulator illustrated in FIG. 3;

FIG. 5 illustrates the differently phased signals generated by the oscillator in the modulator of FIG. 3 and the RF output phasor trajectory;

FIG. 6 illustrates a modulator according to the present invention for performing QPSK modulation; and

FIG. 7 illustrates the differently phased signals generated by the oscillator in the modulator of FIG. 6 and the phasor trajectories of the output from the in-phase modulator circuit, the output from the quadrature-phase modulator circuit, and the RF output.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 3 illustrates a modulator according to the present invention for performing BPSK modulation. As shown, a ring oscillator 10 includes first-Nth inverters 12-1 to 12-N connected in series, and the output of the Nth inverter 12-N is connected to the input of the first inverter 12-1. The first-Nth inverters 12-1 to 12-N resonate so that the output of each first-Nth inverter 12-1 to 12-N is a differently phased signal.

A selector 14 receives the digital data for modulation and the output from the ring oscillator 10. Based on the digital data, the selector 14 selectively applies the output from the
The ring oscillator 10 to a first non-linear power amplifier 16 and a second non-linear power amplifier 18. An adder 20 sums the output of the first and second non-linear power amplifiers 16 and 18 to generate the modulated signal at radio frequency RF for transmission.

The operation of the modulator illustrated in FIG. 1 will now be described in detail with reference to FIGS. 4A-5. The ring oscillator 10 generates multiple differently phased signals. One embodiment of these differently phased signals is illustrated in FIG. 5. FIG. 5 illustrates a coordinate plane with the horizontal axis as the real axis and the vertical axis as the imaginary axis. As represented by inner circle 30, each of the differently phased signals have the same magnitude 10.

As demonstrated above, modulators according to the present invention provide the low power consumption benefits of using non-linear amplifiers and satisfy the narrow frequency band requirements typically demanding the use of linear amplifiers.

[Diagram Illustration]
b) receiving digital data;
c) applying said first and second plurality of differently phased signals to first and second non-linear amplifiers, respectively, when said received digital data changes state; and
d) summing output from said first and second non-linear amplifiers.

2. The method of claim 1, wherein said first plurality of differing amounts are incrementally different from said first reference phase signal by a same negative increment, and said second plurality of differing amounts are incrementally different from said first reference phase signal by positive increment equal in magnitude to said negative increment.

3. The method of claim 2, wherein said first reference phase signal and said second reference phase signal differ in phase by 180 degrees.

4. The method of claim 3, wherein said step c) applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

5. The method of claim 2, wherein said step c) applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

6. The method of claim 1, wherein said first reference phase signal and said second reference phase signal differ in phase by 180 degrees.

7. The method of claim 6, wherein said step c) applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

8. The method of claim 1, wherein said step c) applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

9. An apparatus for modulating digital data, comprising:
a first non-linear amplifier;
a second non-linear amplifier;
an oscillating circuit generating first and second plurality of differently phased signals, wherein said first and second plurality of differently phased signals both include first and second reference phase signals, said first plurality of differently phased signals differ from said first reference phase signal to said second reference phase signal by a respective first plurality of differing amounts, said second plurality of differently phased signals differ from said first reference phase signal to said second reference phase signal by a respective second plurality of differing amounts, and a selecting circuit receiving digital data, and applying said first and second plurality of differently phased signals to said first and second non-linear amplifiers, respectively, when said received digital data changes state; and
an adder adding output from said first and second non-linear amplifiers.

10. The apparatus of claim 9, wherein said first plurality of differing amounts are incrementally different from said first reference phase signal by a same negative increment, and said second plurality of differing amounts are incrementally different from said first reference phase signal by positive increment equal in magnitude to said negative increment.

11. The apparatus of claim 10, wherein said first reference phase signal and said second reference phase signal differ in phase by 180 degrees.

12. The apparatus of claim 11, wherein said selecting circuit applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

13. The apparatus of claim 10, wherein said selecting circuit applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

14. The apparatus of claim 9, wherein said selecting circuit applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

15. The apparatus of claim 14, wherein said selecting circuit applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

16. The apparatus of claim 9, wherein said selecting circuit applies said first and second plurality of differently phased signals from said first reference phase signal to said second reference phase signal when said received digital data transitions from a first state to a second state, and applies said first and second plurality of differently phased signals from said second reference phase signal to said first reference phase signal when said received digital data transitions from said second state to said first state.

17. The apparatus of claim 9, wherein said oscillating circuit is a ring oscillator.