

June 23, 1964

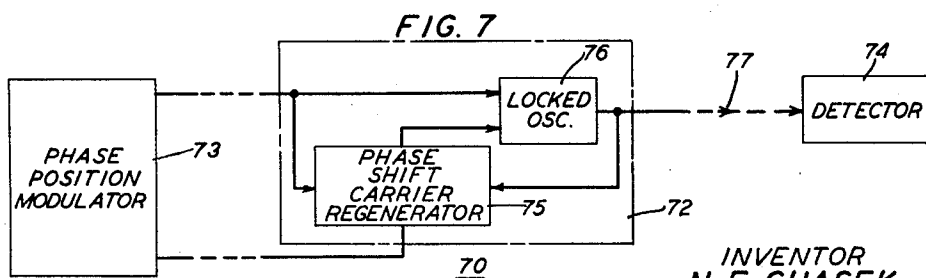
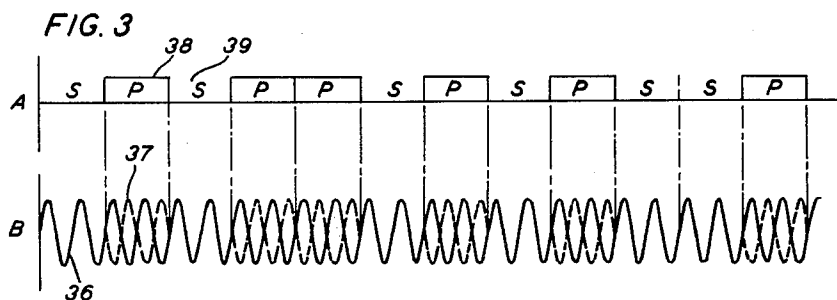
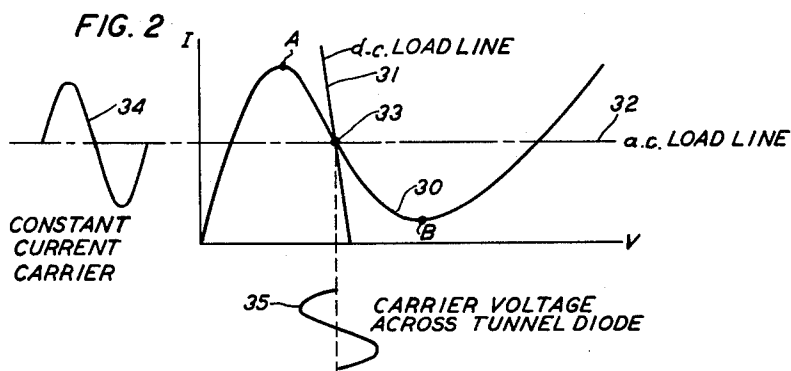
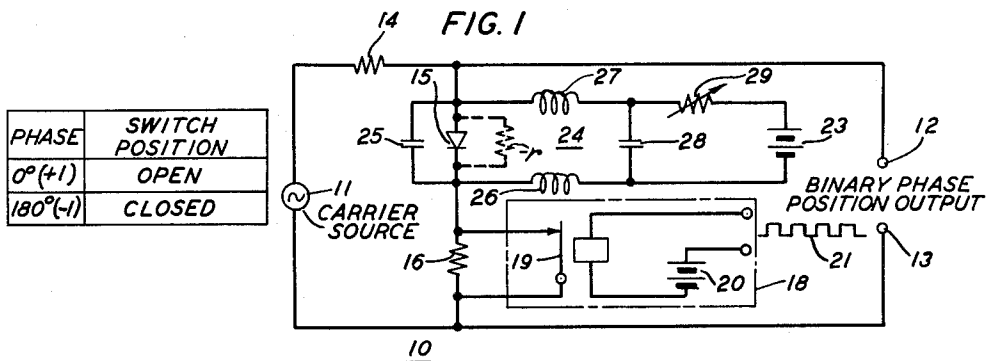
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3,138,665

PHASE POSITION MODULATOR

Filed Aug. 10, 1961

2 Sheets-Sheet 1



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PHASE POSITION MODULATOR

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FIG. 4

CODE	SWITCH POSITIONS	
	S_{18}	S_{41}
$+1 (0^\circ)$	OPEN	OPEN
0°	—	CLOSED
$-1 (180^\circ)$	CLOSED	OPEN

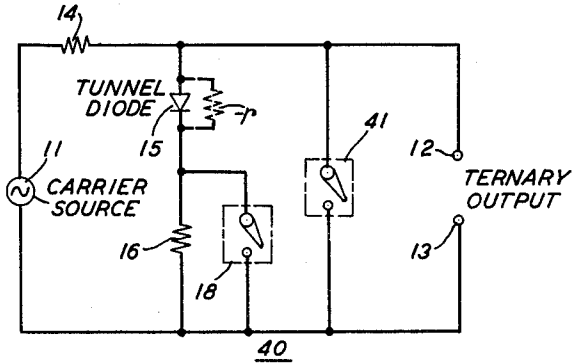


FIG. 5

PHASE	SWITCH POSITIONS	
	S_{18}	S_{53}
60°	OPEN	OPEN
180°	CLOSED	—
300°	OPEN	CLOSED

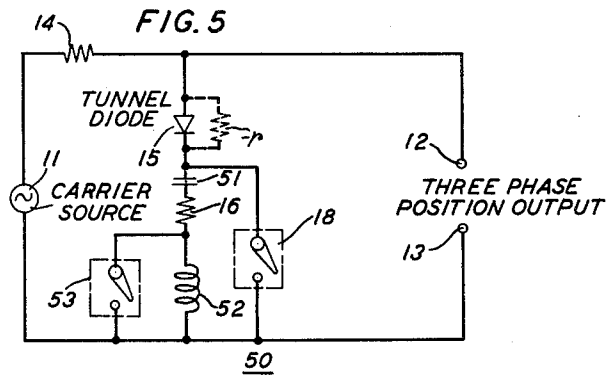
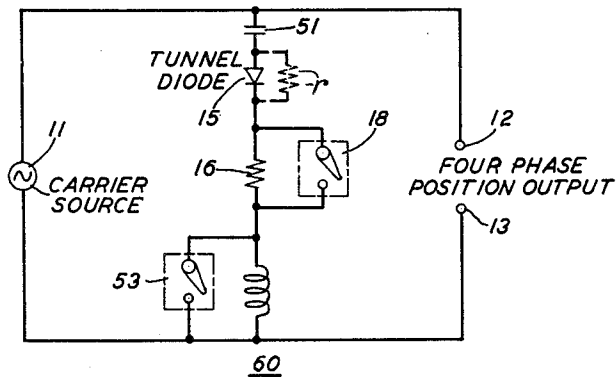


FIG. 6

PHASE	SWITCH POSITIONS	
	S_{18}	S_{53}
45°	OPEN	OPEN
135°	CLOSED	OPEN
225°	CLOSED	CLOSED
315°	OPEN	CLOSED



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3,138,665

PHASE POSITION MODULATOR

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12 Claims. (Cl. 178-66)

This invention relates to communications systems and, more particularly, to phase position modulators for use in such systems.

A primary object of the invention is to simplify the construction of phase position modulators, particularly of the type used for high speed operation. A related object is to increase the versatility of phase position modulators such that modulation codes of both n-phase positions and those comprising a combination of n-phase positions and n-amplitude positions may be produced.

As is well known, phase position modulation, often referred to as phase shift keying (PSK), has been employed for many years in the transmission of slow speed telegraph signals over wire. Microwave versions of this form of modulation have also become known as polar data transmission systems. In such systems, the signal information is generally encoded into a binary form wherein, for example, a "one" represents a pulse and a "zero" represents a space, or the absence of a pulse, in accordance with conventional pulse code nomenclature. By convention, the pulses are normally distinguished from the spaces in a phase position modulated signal by means of a carrier phase shift of, for example, 180 degrees. In another scheme, often referred to as differential phase shift keying, successive pulses shift the carrier phase back and forth between two predetermined reference phases. A combination of binary phase position and amplitude modulation permits encoding to the base three or higher with considerable precision. Primary advantages of phase position modulation over conventional on-off AM modulation are that approximately a 6 db noise advantage and over a 6 db saving in peak transmitter power are realized with no increase in radio-frequency bandwidth. For these reasons, phase position modulation is a strong competitor of other modulation systems.

In the past, there have been various techniques employed for effecting the necessary phase shifts in phase position modulators. For example, a pair of amplifiers driven in phase, connected across a common output tank circuit and alternately triggered has been utilized to effect 180 degree phase shifts. Similarly, modified Wheatstone bridge circuits and cross-coupled diode switching matrices have also been employed to effect a desired phase shift of a radio-frequency carrier. Unfortunately, such prior art forms of phase shift modulators do not afford the simplicity and high speed capabilities desired in a high frequency, large capacity communications system. In addition, the aforementioned types of modulators do not lend themselves readily to modifications, for example, to produce modulation codes not only of n-phase positions but also of n-amplitudes. Phase position modulators capable of operating other than in a binary manner are, of course, very desirable because with them an increase in data transmission capacity for a given bandwidth is obtained without appreciable degradation in the signal to noise (S/N) ratio.

In accordance with an aspect of the present invention, the disadvantages and limitations of prior art phase position modulators are substantially alleviated by utilizing the negative resistance characteristics of a tunnel diode in a unique manner to switch the phase of a radio-frequency carrier between any given number of predetermined phase positions. In one illustrative embodiment,

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binary modulation is accomplished by means of a tunnel diode (negative resistance) and a resistor (positive resistance) connected in series across the terminals of a radio-frequency carrier source. When a fast-acting switch, such as a diode, substantially reduces the magnitude of the positive resistance in the circuit in response to alternate pulses, for example, from a PCM encoder, the radio-frequency carrier phase is shifted. If the positive resistance is reduced to zero, as by placing a short-circuit connection across it, the carrier phase is shifted by 180 degrees. Conversely, reinserting the positive resistance into the circuit effects a shift in phase of the carrier by 180 degrees.

In accordance with another aspect of the invention, the utilization of a combination of multivalued resistors, capacitors and inductors selectively connected in series with the tunnel diode enables modulation codes of n-amplitudes and n-phase positions to be produced.

The invention will be fully apprehended from the following detailed description of preferred illustrative embodiments thereof considered in connection with the appended drawings, in which:

FIG. 1 is a schematic circuit diagram of a binary phase position modulator embodying the invention;

FIG. 2 is a diagram showing the current-voltage characteristic of a tunnel diode and, in particular, the negative resistance region thereof utilized in the invention;

FIG. 3 shows several waveforms of assistance in the exposition of the invention;

FIG. 4 is a schematic circuit diagram of a phase-amplitude modulator embodying the invention;

FIG. 5 is a schematic diagram of a three phase position modulator in accordance with the invention;

FIG. 6 is a schematic diagram of a four phase position modulator in accordance with the invention; and

FIG. 7 is a block diagram of a coherent carrier regenerator and detector suitable for use in demodulating three and four phase position signal information.

Referring now more particularly to the drawings, FIG. 1 depicts a binary phase position modulator 10 comprising a radio-frequency carrier source 11 having two output terminals 12 and 13. A resistor 14 indicated between source 11 and terminal 12 represents the internal series resistance of the source 11 and the total lead resistance. A high speed switch 18, shown symbolically within the dashed line enclosure, is connected across a resistor 16 and is responsive to an appropriate form of modulating intelligence, such as pulse code information. The switch 18 may comprise any one of a number of electronic responsive types; it is shown as a simple, two-pole electro-mechanical relay 19 actuated by a current source 20 in combination with an input pulse train 21. As will become more apparent hereinafter, a high speed switching diode is particularly applicable, for example, when it is desired to convert from an on-off pulse form of modulation to a phase position form. In this case, the switching diode is simply biased to have two switching states, one representing an open or nonconducting state and the other a closed or conducting state with respect to the flow of current therethrough. Such alternate states of bias are most easily accomplished by utilizing a conventional flip-flop circuit actuated by a trigger circuit responsive to the presence and absence of pulses, such as produced by a PCM encoder. Numerous other ways to accomplish the same result are, of course, well known to those skilled in the art.

In accordance with one aspect of the invention, a negative resistance element, preferably comprising and shown as a tunnel diode 15, is connected in series with an appropriate positive resistance element, e.g. resistor 16; and the series combination is connected in shunt with the source 11.

For purposes of this invention, it is believed sufficient to state that because of its unique characteristics, the tunnel diode offers many advantages over conventional prior art negative resistance devices, such as the dynatron and point contact transistor in the common-emitter configuration. These include, in particular, extremely small negative time constants and very pronounced and substantially linear negative resistance regions. The latter characteristics in particular are made use of in this invention. For a detailed description of the solid state physics of the tunnelling process which gives rise to the negative resistance characteristic of these diodes, reference may be made to an article entitled "New Phenomenon in Narrow Germanium P-N Junctions," L. Esaki, Physical Review, volume 109, pages 603-604, 1958.

FIG. 2 depicts a typical current versus voltage characteristic of a tunnel diode. A direct-current load line 31 and an alternating-current load line 32 are shown mutually intersecting at a point 33 situated in the intermediate negative resistance region of the I-V curve 30. As seen in FIG. 2, the negative resistance region is quite pronounced and exists between the peak of the curve designated point A and the valley designated point B. Waveform 34 shown relative to the alternating-current load line 32, depicts the constant current carrier wave generated by source 11, and waveform 35 shown relative to a line drawn as a projection from the operating point 33 depicts the corresponding portion of the carrier wave across the tunnel diode 15.

The unique function of the tunnel diode 15 in modulator 10 will now be considered in greater detail (such function also being applicable to the other modulators to be described hereinafter). In accordance with the invention, a unique relationship exists between the operating value of tunnel diode negative resistance and the positive resistance connected in series with it. Specifically, these resistances are chosen such that when the positive resistance is selectively short-circuited, the sign only of the resistance in shunt with source 11 changes; the resistance magnitude remains substantially constant. It is this change in sign of resistance which effects the desired shift in phase of the applied carrier, such as by 180 degrees. Accordingly, with both resistance elements in the circuit, the effective value of resistance is necessarily of positive sign and results in no phase shift of an applied carrier. When the positive value of resistance is short-circuited or reduced to zero, however, the resistance magnitude in shunt with the source still remains constant but the sign changes because of the remaining negative resistance of the tunnel diode. It is thus seen that the modulator may effect a carrier phase shift of 180 degrees every time the positive resistance in series with the negative resistance is either short-circuited from or reinserted into the circuit, as in either case the effective resistance in shunt with source 11 changes sign. The necessary value of positive resistance required to accomplish a 180 degree phase shift in the modulator 10 is given by the following circuit equation:

$$r_{16} = \frac{2r_{15}(r_{14} - r_{15})}{(r_{14} - 2r_{15})}$$

where the subscripts correspond to the reference numerals of the circuit resistance elements.

That the phase of the radio-frequency carrier shifts 180 degrees whenever resistor 16 is either short-circuited from or reinserted into the circuit of modulator 10 may perhaps best be seen from the following considerations. If the output of the carrier source 11 is defined as $I_0 \sin \omega_c t$ and the net resistance across the terminals 12 and 13 is always constant, but selectively exhibits a positive or negative sign, it follows that the voltage across the carrier source terminals may be defined as

$$I_0(r_{16} - r_{15}) \sin \omega_c t$$

when resistor 16 is in the circuit (switch 18 open) and as

$$I_0[-r_{15}] \sin \omega_c t = I_0 r_{15} \sin (\omega_c t + \pi)$$

when resistor 16 is short-circuited (switch 18 closed).

As the value of negative resistance will of course depend on both the bias voltage applied to the tunnel diode and the current flowing through it, the carrier source 11 is preferably of the constant current type. The necessary bias for the tunnel diode 15 is supplied from a direct-current supply 23 through a low-pass filter 24. Filter 24 comprises, for example, a capacitor 25 shunting the tunnel diode and an L-C network including inductors 26, 27, and a capacitor 28 in shunt with the supply 23. A variable resistor 29 in series with the supply is utilized to adjust the bias of the tunnel diode to the desired value. By utilizing a carrier source of the constant current type, the capacitor 25 and inductors 26, 27 of filter 24 also serve to restrict the frequency of any possible self-oscillation of the tunnel diode 15 to the carrier frequency f_c and, hence, such oscillation will prove to be of no practical consequence.

With the components of modulator 10 thus set forth, its operation as a binary phase position modulator in accordance with one illustrative application will now be described. For convenience, the switch 18 of FIG. 1 will be assumed to comprise a conventional switching diode, together with the necessary auxiliary circuitry to make it responsive to a train of input pulses from a PCM encoder, such that it either closes or opens in response to successive changes from a space to a pulse and either opens or closes in response to successive changes from a pulse to a space. Operated in this manner, the phase of the carrier wave across the output terminals 12, 13 may arbitrarily be designated to exhibit a plus one (+1) for the zero or uniform phase condition, with switch 18 open, and to exhibit a minus one (-1) corresponding to the 180 degree out-of-phase condition whenever switch 18 short-circuits resistor 16. The switching chart to the left of the modulator depicts the switching sequence for this illustrative mode of operation.

To envisage pictorially how the original waveform generated by the constant current carrier source 11 is phase position modulated, reference is made to FIGS. 3A and 3B. FIG. 3A depicts the mark-space signal information, which may represent an analog signal sampled and quantized in code form, utilized to actuate selectively switch 18. The solid line curve 36 of FIG. 3B depicts the radio-frequency carrier wave of constant current and phase, e.g. from source 11, and the dashed wave portions 37 depict the carrier wave shifted 180 degrees. The in-phase (solid line) condition is obtained with resistor 16 in the circuit and the out-of-phase (dashed line) condition is obtained with resistor 16 short-circuited from the circuit.

Considered more specifically, if it is assumed that switch 18 of FIG. 1 is originally open, then the first pulse 38 of the code train depicted in FIG. 3A will cause the switch to close, thereby removing the positive resistance (r_{16}) from the circuit. This changes the sign of the resistance in shunt with the source 11 which, in turn, effects a carrier phase shift of 180 degrees. The dashed line portion of waveform 37 shown immediately below pulse 38 in FIG. 3B depicts this condition. Similarly, the absence of a pulse or, more specifically, a space between pulses, indicated as 39 in FIG. 3A, likewise will actuate switch 18 such that it opens. This reinserts resistor 16 into the circuit, changes the sign of the effective resistance across the source and thereby shifts the carrier phase 180 degrees, i.e., back to its original phase condition represented by the solid line waveform 36 in FIG. 3B. As may be seen by the waveforms in FIGS. 3A and 3B, whenever two or more pulses occur in succession, the switching action is responsive to the presence of only the first of the pulses in the succession. In other words, the switching circuit is actuated

only when there is a change from a space to a pulse or a pulse to a space. This switching characteristic is also generally preferred in the modulators to be described hereinafter.

FIG. 4 depicts in diagrammatic form a ternary phase position modulator 40 embodying the principles of the invention. In addition to the circuit elements of modulator 40 which correspond to and are similarly identified as those of modulator 10, a second electronic switch 41 is employed. Both switches 18 and 41 are shown symbolically within the dash-lined enclosed boxes as simple, single pole mechanical switches for purposes of illustration. In practice, of course, these switches would be of the high speed electronic type, such as switching diodes. As may be seen in the chart to the left of modulator 40, a code to the base three can easily be adopted in the form of a plus one, zero and minus one. For example, a plus one may arbitrarily be assigned to indicate that both switches 18 and 41 are open, a zero to indicate that switch 41 is closed (no carrier output) and, a minus one used to indicate that switch 18 only is closed. With the negative and positive resistance values in modulator 40 chosen as described above for modulator 10, it is evident that whenever switch 18 is closed or opened, the carrier waveform is shifted 180 degrees, whereas when switch 41 is closed the radio-frequency carrier output across the terminals 12, 13 is reduced to zero. Switches 18 and 41 may be suitably actuated, for example, by converting a conventional unipolar pulse train into a bipolar pulse train characterized by code symbols of positive, negative and zero amplitudes. As such, switch 18 may be made responsive only to positive pulses and switch 41 may be made responsive only to negative pulses. Other encoding schemes to actuate these switches for ternary modulation applications will be obvious to one skilled in the art.

An advantage of the ternary modulator 40 over the binary phase position modulator 10 is that approximately a 60 percent decrease in bandwidth is realized for the same signal transmission capacity. This is obtained, however, at the expense of approximately a 6 db decrease in threshold value, i.e., the point at which the modulator cannot detect whether the symbols of an input ternary code train identify accurately the original code conditions of zero, plus one or minus one amplitude.

FIG. 5 depicts in diagrammatic form a three phase position modulator 50 embodying the principles of the invention. In addition to the circuit elements corresponding to those of modulator 40 and similarly identified, modulator 50 further includes a capacitor 51 and an inductor 52, serially connected with the tunnel diode 15 and the resistor 16 in shunt with source 11. This arrangement permits the transformation of signal information, for example, from a three-level unipolar or a bipolar encoder, into a three phase position code wherein carrier amplitude remains substantially constant and only carrier phase is selectively changed. For example, the values of circuit resistance and reactance may be so chosen that the train of input pulses will actuate the switches 18 and 53 in a manner to establish the carrier at any one of three symmetrically oriented phase positions 120 degrees apart. To obtain such phase shifts at 60, 180 and 300 degrees with the switching sequence illustrated in the chart associated with FIG. 5, for example, the impedances of the reactive circuit elements can be derived from the following equations:

$$\left| \frac{r_{15}}{r_{14}-r_{15}} \right| = \left| \frac{r_{16}-r_{15} \pm jX}{r_{14}-r_{15}+r_{16} \pm jX} \right|$$

where jX represents the effective reactance in the circuit. By arbitrarily designating $\theta_1 = +60^\circ$ and $\theta_2 = -60^\circ$,

$$\theta_1 = \tan^{-1} \frac{X_1 - X_2}{r_{14} - r_{15} + r_{16}}$$

and

$$\theta_2 = \tan^{-1} \frac{-X_2}{r_{14} - r_{15} + r_{16}}$$

where X_1 and X_2 represent the inductive and capacitive reactances of modulator 50, respectively. A virtue of modulator 50 in a complete communications system is that it has approximately a 1 db net advantage, in terms of threshold, over the binary phase position modulator of FIG. 1, and about a 5 db net advantage over the ternary modulator of FIG. 4. This follows from the fact that in a three phase position system a peak signal to peak noise voltage ratio of approximately 1.15 is required to introduce errors into the system at the receiver. This can be shown to be about 1.2 db poorer than the value of threshold for a binary phase position modulator. However, for the same information rate, the bandwidth is reduced by about 60 percent as in the case with the ternary modulator of FIG. 4. As this reduction in bandwidth results in a 2 plus db advantage over the binary system, the net advantage of the three phase position system is seen to be approximately 1 db.

FIG. 6 depicts in diagrammatic form a four phase position modulator 60 embodying the principles of the invention. The basic structural difference of modulator 60 from modulator 50 is the connection of switch 18 across only the positive resistor 16. This change is required so that the respective switches may be made selectively and independently responsive to different code symbols of the input signal information. In other words, switch 18 when closed cannot over-ride switch 53 as in modulator 50 since the carrier, in the four phase position case, is periodically modulated in phase quadrature with the 0-180 degree phase positions. By suitably choosing the values of resistance and reactance across the phase shift network, phase shifts of 45, 135, 215 and 315 degrees, for example, can easily be obtained by selectively actuating switches 18 and 53. The chart associated with modulator 60 in FIG. 6 depicts one illustrative switching sequence for producing a four phase position modulated signal when the circuit parameters are chosen to effect a 45 degree reference phase position with both switches 18 and 53 open. Other than in requiring an input pulse code train characterized by four rather than three discrete code symbols to actuate the switches, the operation of modulator 60 is essentially identical to that of modulator 50 described above.

From the foregoing description of the illustrative embodiments, it becomes apparent that modulation codes of n -phase positions as well as n -amplitudes can be readily obtained. For example, additional switches may be used to add or remove positive resistors, capacitors, and inductors from the circuit. These elements may be connected as required, in series or parallel (or in combinations of series and parallel), with the negative resistance device 15. Moreover, while the various modulators have been described in terms of operation with a radio-frequency carrier of constant amplitude as shown in FIG. 3B, it is to be understood that the carrier may be converted to a raised cosine waveform by well known techniques. As such, the desired phase shifts of the carrier wave may be effected at times when the amplitude of the carrier wave is reduced to zero. This may be advantageous in certain applications to prevent or minimize any undesired transient effects that could possibly occur with each phase reversal of the carrier.

While conventional binary or phase shift keying receiver apparatus may be used to demodulate binary encoded information, more refined apparatus is required to demodulate information coded to the base three or higher. For example, unique apparatus must be provided to prevent "wobble" in the reference phase of the regenerated carrier caused by varying phase quadrature components. In addition, detector apparatus is required in the three phase position case to ascertain in which of the phase sectors the

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signal vector is located with respect to the reference sector so that the original signal information may be reconstructed for utilization.

In my copending application, Serial No. 130,610, filed concurrently with this application, unique carrier regenerator and detector apparatus are disclosed for the demodulation of both binary and higher base phase position codes.

By way of illustration, FIG. 7 depicts, in block diagram form, a circuit 70 for the demodulation of three or four phase position coded signal information comprising a coherent carrier regenerator network 72 and a phase detector 74 each of the type described in my aforementioned copending application. The detector may include a phase vector sensor and a pulse regenerator. The incoming three or four phase position signal information received from a modulator 73, which may be of the type depicted in either FIG. 5 or 6, described above, depending on the number of phase positions, is applied to carrier regenerator network 72 and, more specifically, to a phase shift network 75 and a locked oscillator 76. The network 75 includes a phase shift circuit similar to that employed in the particular one of modulators 50 and 60 employed at the transmitting end of the system. The periodic phase differences that occur between the reference phase at the output of the locked oscillator 76 and the phase of the received signal are detected and transformed into two distinct control pulses. These control pulses in turn actuate suitable switching circuits in the phase shift network 75 in order to remove from or restore to the phase shift network predetermined values of resistance and reactance in much the same manner as described above for the three and four phase position modulators. Such switching action effects selective, predetermined in-phase and quadrature phase shift inversions of the receiving signal which, in turn, produces a time-varying resistance function exhibiting frequency components peculiarly related to the signal and carrier frequencies. Specifically, the product of the frequency components established by the time-varying resistance function and the sideband frequency components of the received signal produce a strong coherent carrier of the proper phase which keeps locked oscillator 76 in precise phase and frequency with the original carrier.

In the four phase position case, the in-phase and quadrature components of the received signal at the output 77 of the locked oscillator are separately applied to conventional homodyne detectors for demodulating the signal information in much the same way as for ordinary binary signals. A portion of the regenerated carrier must be shifted 90 degrees, however, to demodulate the phase quadrature components of the received signal information.

In the three phase position case, the output of the locked oscillator is applied to the detector 74. This circuit is designed to ascertain in which of the phase sectors the signal vector (representative of an original pulse or space) is located with respect to the reference sector so that the original signal information may be accurately reconstructed for utilization. A more detailed description of the phase position demodulator of FIG. 7 and the manner in which it functions may be found in my aforementioned copending application.

It is to be understood that the specific embodiments described herein are merely illustrative of the general principles of the instant invention. For example, the switching means utilized in the modulator circuits may be made responsive to a train of input pulses in a manner whereby only successive pulses shift the carrier a predetermined number of degrees, the spaces causing no phase shift in the modulation process. In such a system, the decision process at the receiver depends upon the previously transmitted signal for the phase reference, resulting in adjacent bit dependence with respect to error probability. Detracting from the advantages of this form of phase position modulation, however, is the tendency

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for errors due to noise to occur in pairs. Numerous other structural arrangements and modifications similarly may be devised in the light of this disclosure by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A modulator for converting pulse encoded information into phase position encoded information comprising a negative resistance element and a positive resistance element connected in series across the terminals of a source of a radio-frequency carrier, and means responsive to a given code character of said pulse code information connected across one of said resistance elements for selectively altering the resistance thereof such that the phase of said carrier is shifted from one predetermined phase condition to a second predetermined phase condition.

2. A modulator in accordance with claim 1 wherein said negative resistance element comprises a tunnel diode and wherein said means connected across one of said resistance elements comprises a signal responsive switching element connected across said positive resistance element.

3. A modulator in accordance with claim 1 further comprising switching means positioned across the terminals of said carrier source and means for selectively operating said last-mentioned switching means in response to a different code character of said pulse code information for providing a ternary phase position coded signal modulated output.

4. A modulator for converting signal information previously encoded in pulse code form into a phase-position carrier wave form wherein the original pulses and spacing intervals of said code are respectively characterized by at least first and second predetermined time-phase positions of the carrier wave, comprising a source of a radio-frequency carrier means for shifting the phase of said carrier wave selectively between said first and second predetermined phase positions, said means including a two-terminal semiconductor element biased in its negative resistance region and a positive resistance element connected in series across the terminals of said source, a first high speed switch connected across said positive resistance element responsive to a first identifiable code character of said pulse code information, the presence of said first code character being sufficient to close said switch, thereby to alter the magnitude of said positive resistance element.

5. A modulator according to claim 4 which includes means for shifting the phase of said carrier wave selectively by a predetermined number of degrees from one of said first and second phase positions, said means including an inductor and a capacitor serially connected with said two-terminal semiconductor element and said positive resistance element across the terminals of said source, a second high speed switch connected across said inductor responsive to a second identifiable code character of said pulse code information, the presence of said second code character being sufficient to close said second switch thereby to alter the inductance of said inductor.

6. A modulator in accordance with claim 5 which includes a third high speed switch responsive to externally applied code signals connected across the series combination of said positive resistance element, said capacitor, and said inductor, the presence of a code signal being sufficient to close said third switch thereby to alter the magnitude of the resistance and reactance of said series combination.

7. Apparatus for converting signal information previously encoded in pulse-code form into phase-position form comprising a two-terminal negative resistance semiconductor element, a positive resistance element, an inductor, and a capacitor connected in series across the terminals of a source of a radio-frequency carrier, first switching means connected across the series combination of said positive resistance element, said capacitor, and

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said inductor responsive to identifiable code characters of said pulse code signal information, second switching means connected across said inductor only responsive to different identifiable code characters of said pulse code signal information, and means for selectively actuating said first and said second switching means whereby the sign of the total resistance shunting said source is reversed and the magnitude of the inductance of said inductor is altered thereby to shift the phase of said carrier wave successively between at least three distinct predetermined phase positions.

8. Apparatus for shifting the phase of a radio-frequency carrier from one predetermined phase position to a second comprising a source of carrier signals, a negative resistance element which exhibits a preselected absolute value of resistance, a positive resistance element which exhibits substantially the same preselected absolute value of resistance connected in series across the terminals of said carrier source, and means responsive to a first code signal for altering the resistance of one of said resistance elements whereby the magnitude of resistance remaining in shunt with said source is substantially constant but the sign thereof is changed.

9. Apparatus in accordance with claim 8 wherein said negative resistance element comprises a tunnel diode biased in its negative resistance region and wherein said means for altering the resistance of one of said resistance elements comprises switching means responsive to said code signals for altering the resistance of said positive resistance element.

10. Apparatus in accordance with claim 8 further comprising a capacitor and an inductor serially connected with said negative and positive resistance elements in shunt with said source, second means responsive to a second code signal for altering the reactance of said series combination of said inductor and said capacitor thereby to shift the phase of said carrier a predetermined number

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of degrees with respect to said first and said second predetermined phase conditions.

11. Apparatus in accordance with claim 10 wherein said first and said second means for altering the resistance and reactance respectively of said serially connected impedances comprise first and second two-state signal actuated switches, said first switch being connected across the positive resistance element and said second switch being connected across said inductor.

12. A modulator for converting signal information previously encoded in pulse code modulation form into phase position form comprising in series relation a tunnel diode, a positive resistance element, an inductor and a capacitor connected in shunt across the terminals of a radio-frequency carrier source, means for biasing said tunnel diode in its negative resistance region, first means for selectively short-circuiting said positive resistance element, capacitor and inductor in response to a first identifiable character of said pulse information thereby to shift the phase of said carrier wave from a first predetermined phase condition to a second predetermined phase condition and second means for selectively short-circuiting the inductance of said inductor in response to a second identifiable character of said pulse information thereby to shift the phase of said signal information selectively a predetermined number of degrees from one of said first and second phase conditions of said carrier wave, respectively, to at least a third predetermined phase condition.

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