Oct. 29, 1963 K. E. HARDINGER ETAL 3,109,172

LOW ALTITUDE F.M. ALTIMETER

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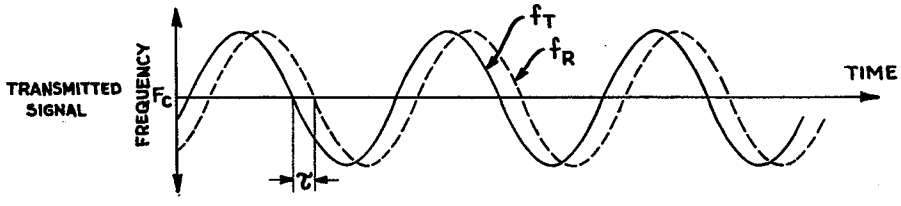


Fig. 1A

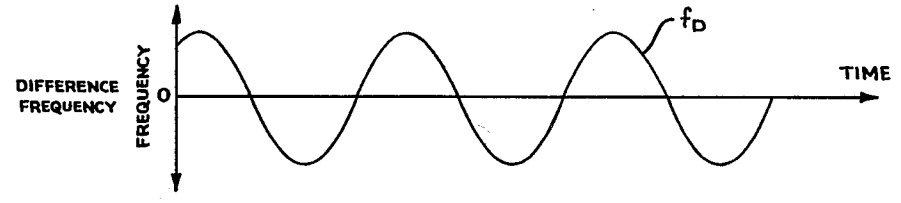


Fig. 1B

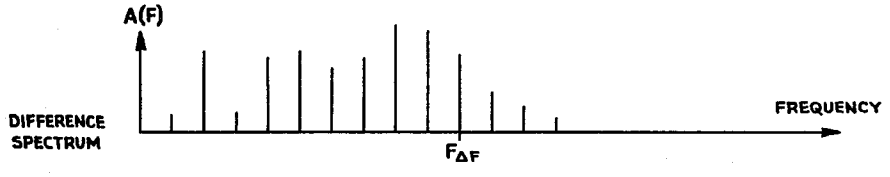


Fig. 1C

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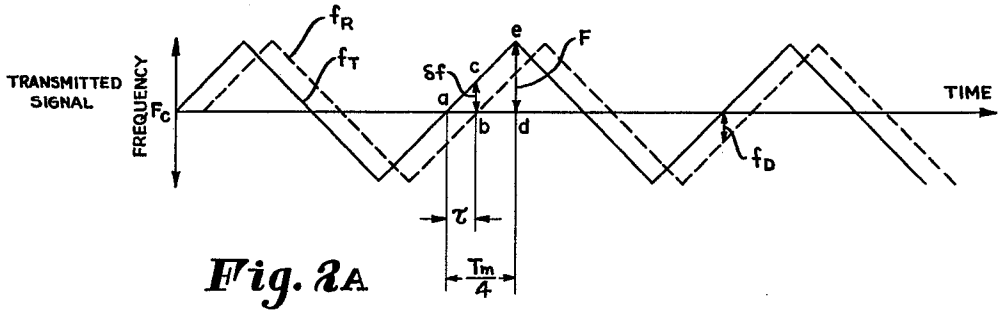


Fig. 2A

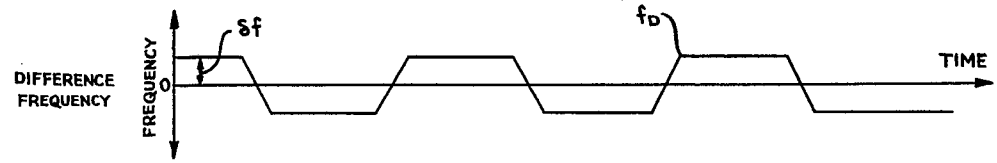


Fig. 2B

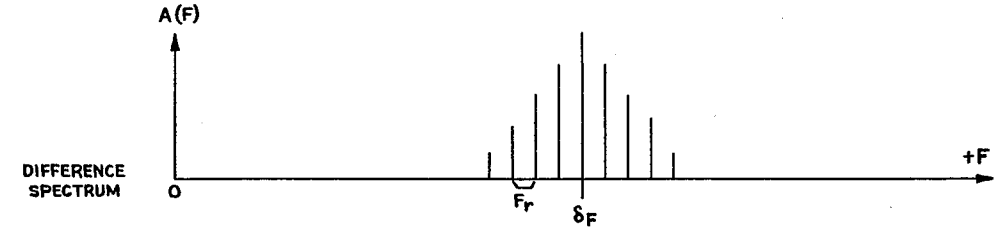


Fig. 2C

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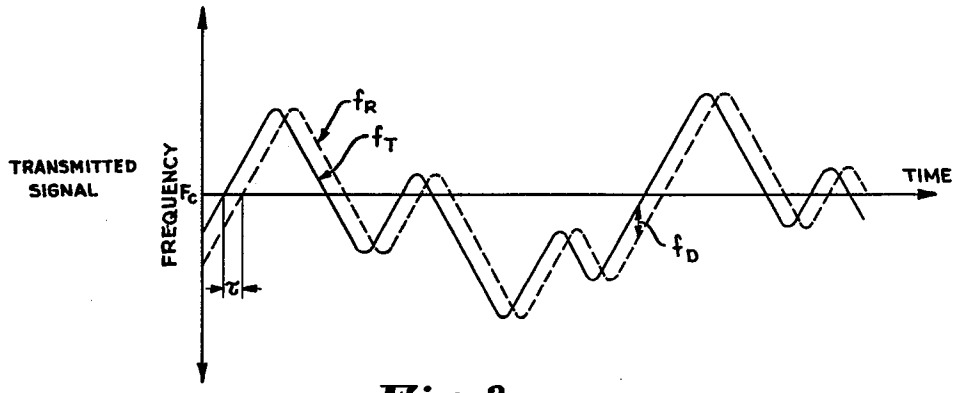


Fig. 3A

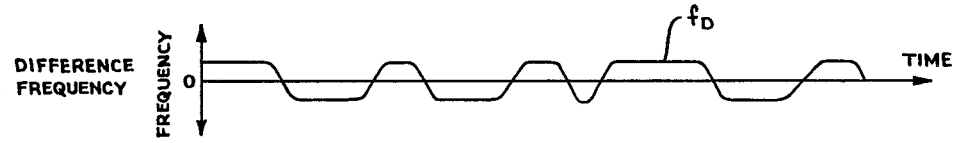


Fig. 3B

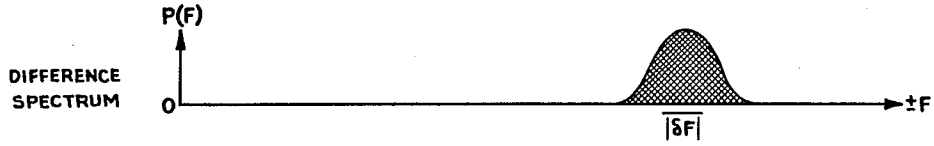


Fig. 3c

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Oct. 29, 1963 K. E. HARDINGER ETAL 3,109,172

LOW ALTITUDE F.M. ALTIMETER

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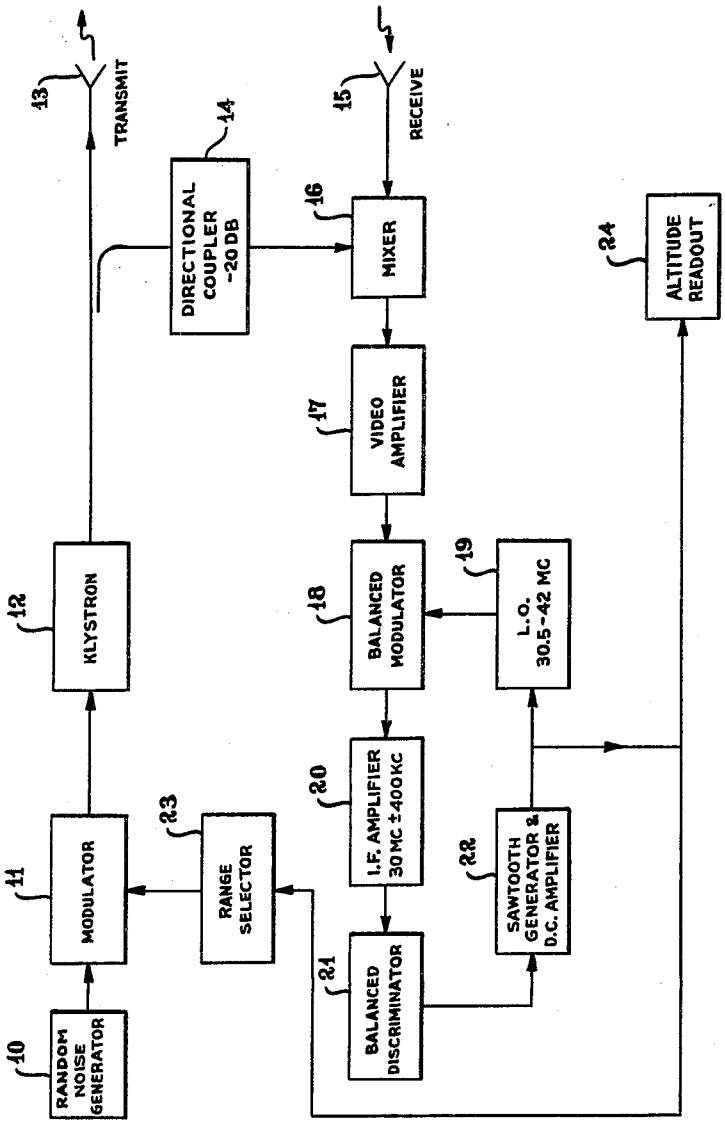


Fig. 4

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Oct. 29, 1963 K. E. HARDINGER ETAL 3,109,172

LOW ALTITUDE F.M. ALTIMETER

Filed Aug. 10, 1960 10 Sheets-Sheet 5

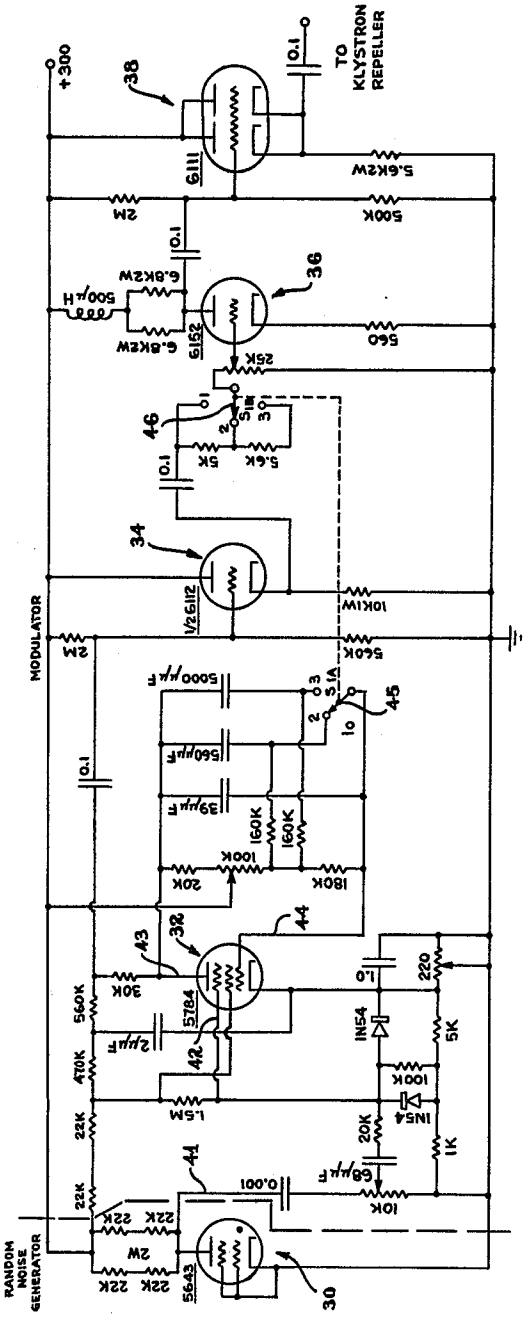


Fig. 5

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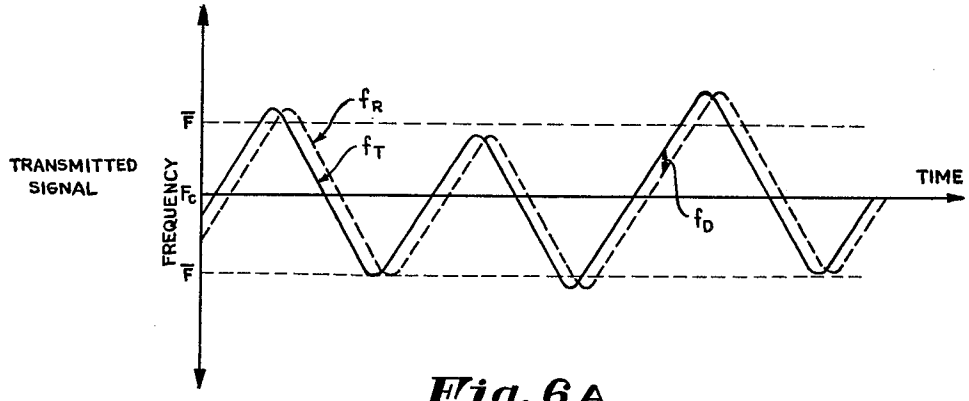


Fig. 6A

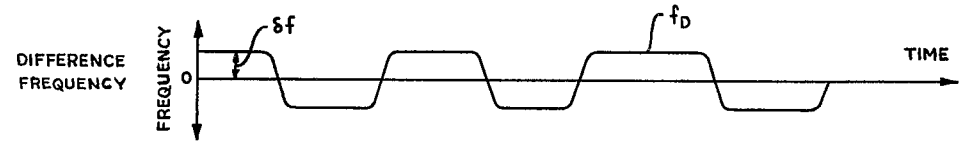


Fig. 6B

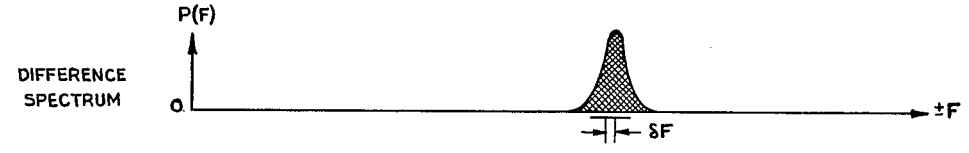


Fig. 6c

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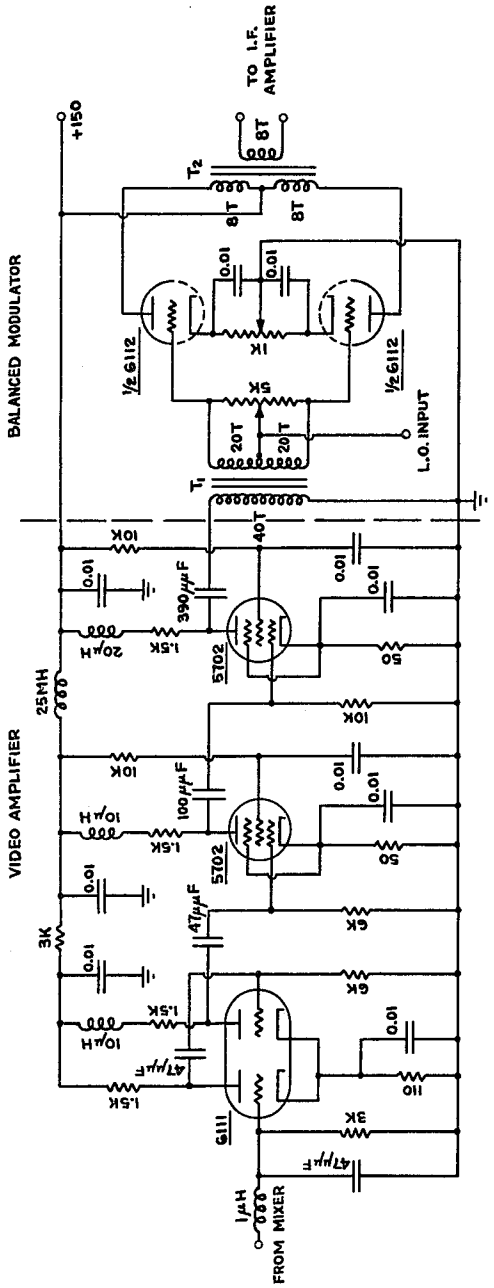


Fig. 7

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LOW ALTITUDE F.M. ALTIMETER

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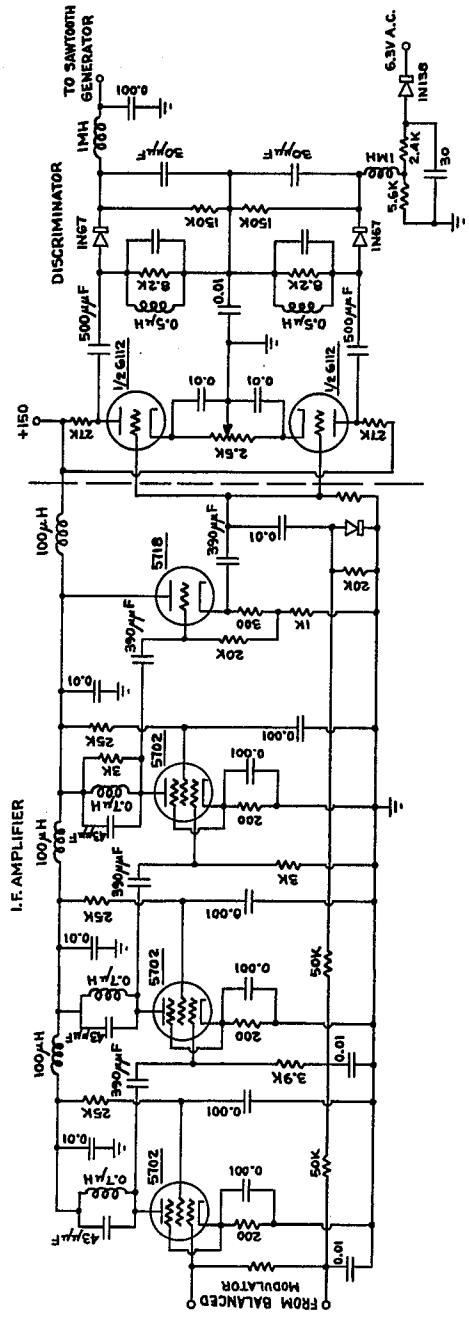


Fig. 8

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LOW ALTITUDE F.M. ALTIMETER

Filed Aug. 10, 1960 10 Sheets-Sheet 9

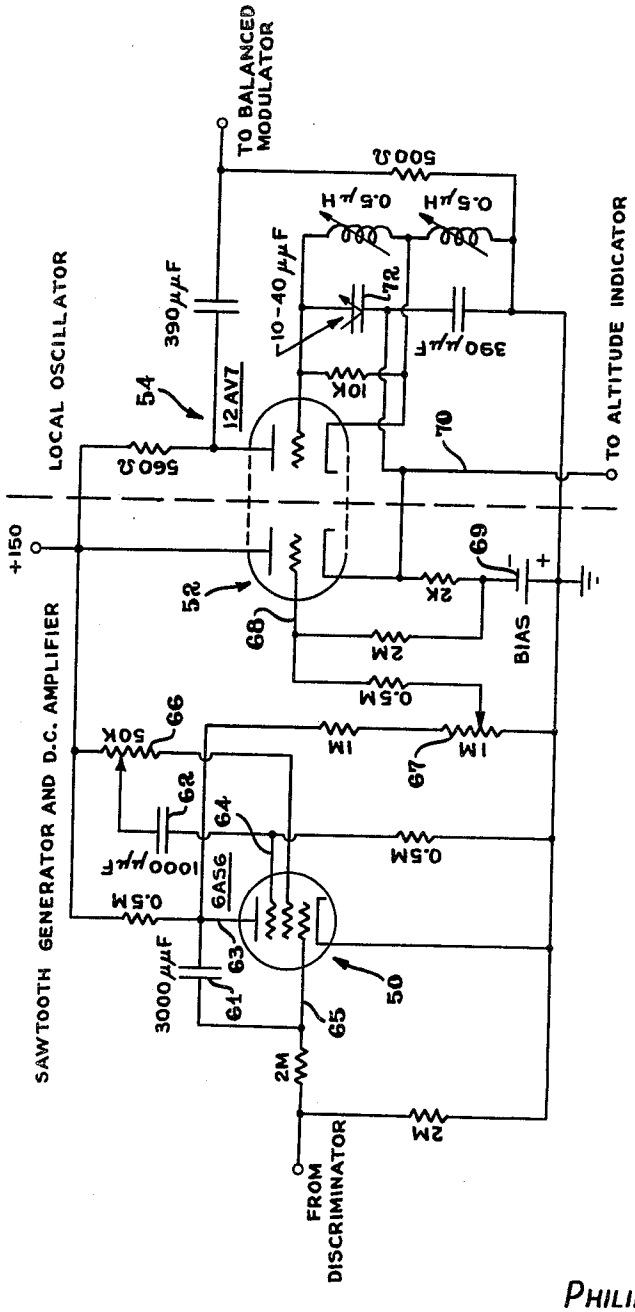


Fig. 9

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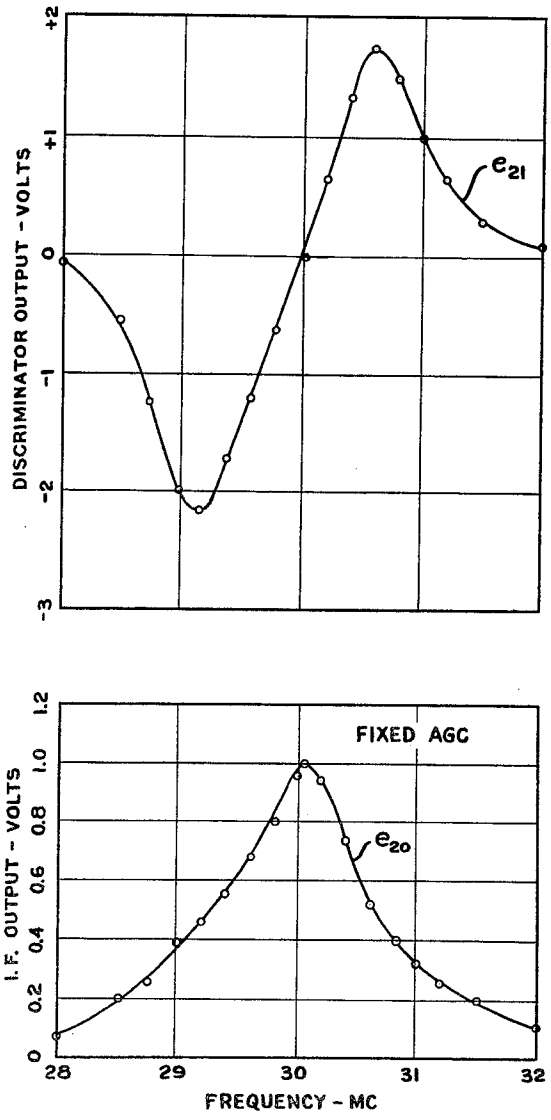


Fig. 10

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United States Patent Office 3,109,172 Patented Oct. 29, 1963

3,109,172

LOW ALTITUDE F.M. ALTIMETER

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Filed Aug. 10, 1960, Ser. No. 48,786
3 Claims. (Cl. 343—14)
(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to us of any royalty thereon.

This invention relates to continuous wave radar distance measuring systems and more particularly to frequency modulated radar altimeters.

A primary requirement for safe instrument navigation in aircraft, as well as for safe instrument landings, is an altimeter which can produce very accurate altitude information within a short response time and over a wide range of altitudes. Instrument flying becomes increasingly important as aircraft speeds are raised, as the airways become more densely populated, and as flying is extended to low visibility weather conditions. Even under visual flight regulations, the altimeter is necessary to facilitate traffic control and to place all aircraft in an immediate vicinity on a common basis.

For low altitude flight, such as takeoff and landing, a highly accurate and dependable terrain-clearance altimeter is indispensable, whether or not ground-control equipment is employed. The error of a flareout altimeter for blind landings must be less than five percent, even at low altitudes. Such an altimeter, in conjunction with a high-resolution surveillance radar, could furnish the pilot, or a computer in an automatic landing system, sufficient information to make a safe zero-visibility landing.

An object of the present invention is to provide a radar altimeter of greatly improved accuracy.

Another object of the invention is to furnish a radar altimeter in which both the range ambiguities and the "critical-distance" errors of known frequency modulated altimeters are eliminated.

A further object is to provide a frequency modulated radar altimeter which measures altitude to within five percent at all altitudes in a range from five feet to several thousand feet.

Another object of the present invention is to furnish a radar altimeter having improved sensitivity and signal-to-noise ratio.

A further object is to extend the range of a frequency modulated altimeter over which altitudes may be measured with a high degree of accuracy by maintaining a constant transmitter frequency deviation and varying the modulating frequency under control of a constant difference frequency servo system.

A feature of the invention involves the application of a random-noise signal to the frequency modulator of an altimeter transmitter to obtain a jittered triangular modulation signal. This type of modulation substantially eliminates the "critical-distance" errors and range ambiguities which would otherwise exist in the receiver, as explained in detail below.

Another feature relates to the production of a constant difference frequency signal in the altimeter by a servomechanism control which functions so that maximum frequency deviation of the transmitter oscillator is maintained at all times, over several operating ranges of the altimeter.

A typical embodiment of the F.M. altimeter system in accordance with the present invention comprises a transmitter having a thyratron circuit operating as a diode

random-noise generator, a free running phantastron triggered by the random-noise generator to produce a jittered triangular modulating voltage, a reflex klystron frequency modulated by the phantastron modulator, and a transmitting antenna. The altimeter further comprises a receiver including a receiving antenna, a balanced microwave mixer delivering an output signal which is the difference frequency between a portion of the transmitted signal and the received reflected signal, and a wide band video amplifier. The receiver further contains a balanced modulator which mixes the difference signal from the video amplifier with a heterodyning signal generated by a variable frequency local oscillator to produce a predetermined constant difference frequency signal, a narrow bandwidth I.-F. amplifier tuned to the aforesaid constant difference frequency, a balanced F.M. discriminator which generates a D.C. output voltage proportional to the frequency variation of the heterodyned output signal of the balanced modulator from the predetermined constant difference frequency, and a phantastron acting as a combined sawtooth voltage generator and D.C. amplifier connected between the discriminator and the local oscillator, completing a servo loop which searches for the difference frequency signal from the microwave mixer containing the altitude information and "locks on" to it when the local oscillator is set to heterodyne the said difference frequency to the constant difference frequency of the I.-F. amplifier. An altitude calibrated voltmeter connected to the sawtooth generator-D.C. amplifier output provides altitude readout for the altimeter, after the servo locks on to the incoming signal. Further, a range selector responsive to the number of oscillations of the sawtooth generator alters circuit parameters in the modulator phantastron to change the modulating frequency without altering the frequency deviation of the transmitter klystron, if the reflected signal is not found in a given altitude range within a predetermined time.

The specific nature of the invention, as well as other objects, uses, and advantages thereof, will clearly appear from the following description and from the accompanying drawing, in which:

FIGS. 1A, 1B and 1C are, respectively, graphs of the frequency variations of the transmitted and received signals, the frequency variation of the beat or difference frequency signal produced by mixing the transmitted and received signals, and the frequency spectrum of the difference frequency signal of a sinusoidally modulated F.M. altimeter of known type.

FIGS. 2A, 2B and 2C are similar graphs for a triangularly modulated F.M. altimeter of the prior art.

FIGS. 3A, 3B and 3C show similar graphs for the jittered triangular modulation employed in the altimeter of the present invention.

FIG. 4 is a schematic block diagram of a system illustrating one form of this invention.

FIG. 5 is a specific wiring diagram of the random-noise generator and transmitter modulator of FIG. 4.

FIGS. 6A, 6B and 6C are graphs of certain waveforms employed in the modulator of FIG. 5 and the system of FIG. 4.

FIG. 7 is a schematic diagram of the video amplifier and the balanced modulator of FIG. 4.

FIG. 8 is a wiring diagram of the I.-F. amplifier and the balanced discriminator of FIG. 4.

FIG. 9 is a schematic wiring diagram of the sweep generator-D.C. amplifier and the local or search oscillator of the system of FIG. 4.

FIG. 10 illustrates the voltage response curves for the I.-F. amplifier and the balanced discriminator of FIG. 8.

One conventional form of radar altimeter consists basically of a frequency modulated radio transmitter, a receiver containing a mixer-detector, amplifying circuits,

and a frequency counter. In such systems, the F.M. transmitter is sinusoidally modulated with a high modulation index, as shown in FIG. 1A, and is employed both as the signal transmitter and as the local oscillator. The transmitted signal, having a frequency variation curve f_T as in FIG. 1A, is reflected from the ground and returned to the altimeter system. The received signal, whose frequency variation f_R appears in FIG. 1A, is the transmitted signal delayed by a time

$$\tau=\frac{2h}{c} \quad (1)$$

where h is the altitude and c is the velocity of light. The received signal is mixed with the local-oscillator signal, producing an instantaneous difference frequency signal f_D which is sinusoidal, as illustrated in FIG. 1B. The average magnitude of the difference frequency depends upon the time delay τ which is, in turn, proportional to altitude. The difference frequency spectrum of FIG. 1C is composed of lines spaced equally by an amount equal to the modulation frequency, starting at zero frequency. The frequency counter is arranged to count each zero crossover of the difference frequency signal voltage and average these counts over a time period long compared with the frequency of crossing, so that the average number of counts per unit time is proportional to the altitude being measured.

The frequency counter used in these altimeters registers only discrete steps, i.e., the zero crossings, and cannot count fractional zero crossings. This inability of a frequency counter, or any standard frequency discriminator, to measure the difference frequency continuously, rather than in discrete steps, gives rise to a "critical-distance" error or a "fixed" error in such altimeters. This error appears as changes in measured altitude in increments equal to the "critical-distance."

Further, since the transmitted signal is modulated by a periodic function such as f_T of FIG. 1A, it exactly repeats itself every period of the modulating signal f_T. The receiver frequency counter cannot distinguish between a signal reflected from the ground at one delay time τ corresponding to a first altitude and a delay time equal to τ plus any given number of modulation periods T_m, which corresponds to some other altitude. This periodicity of the modulating signal thus gives rise to range ambiguities.

Another type of modulation employed in F.M. radar altimeters known to the art is the linear sweep in the form of triangular or sawtooth waveforms, such as shown in FIG. 2A, the sawtooth merely being a special case of the more general triangular waveform illustrated. The instantaneous frequency difference f_D between transmitted and received signals, shown in FIG. 2B, is essentially constant with the exception of the regions near the turnaround points. The constant frequency difference δf of curve f_D of FIG. 2B contains the altitude information which can be expressed as follows. In FIG. 2A, it is seen that triangle *abc* is similar to triangle *ade*. Therefore, we have

$$\frac{\delta f}{F}=\frac{\tau}{\frac{T_m}{4}}$$

where F is the frequency deviation of the transmitted signal and T_m is the period of the modulation signal f_T. As stated above,

$$\tau=\frac{2h}{c}$$

Also,

$$T_m=\frac{1}{f_m}$$

Therefore,

$$\frac{\delta f}{F}=\frac{\frac{2h}{c}}{\frac{1}{4f_m}}=\frac{8hf_m}{c}$$

and

$$\delta f=\frac{8hf_mF}{c} \quad (2)$$

From the Equation 2 it is clear that for a given modulating signal the constant frequency difference δf, present at times other than those corresponding to turnaround points of f_T and f_R, is directly proportional to altitude h. It is to be noted that Equation 2 applies equally well in the case of the novel modulation techniques employed in the present invention and illustrated in FIGS. 3A and 6A.

With triangular F.M. modulation, the energy of the difference frequency signal f_D of FIG. 2B is concentrated in a narrow band of frequencies. The center frequency of the band or the average difference frequency is proportional to the distance to the ground. The spectrum of the difference frequency signal is depicted in FIG. 2C. This spectrum is easier to detect than that of the sinusoidally modulated types of FIG. 1C and does not require as much receiver bandwidth, resulting in better sensitivity. However, altimeters utilizing the periodic triangular modulation as discussed above still contain range ambiguities and "critical-distance" errors which are inherent in periodic systems which determine the difference frequency by measuring zero crossovers.

In the altimeter system in accordance with the present invention, a random-noise signal is applied to a triangular modulation signal to eliminate these sources of error. The modulating waveform becomes a triangular wave having a random period and amplitude, as seen in FIG. 3A, but having constant slopes for any given range of altitudes. To measure altitudes in several ranges, the altimeter of the invention incrementally changes the aforementioned slopes in successive time intervals by changing the modulating signal's period while maintaining the frequency deviation constant, as explained more fully below. The resulting instantaneous difference frequency f_D of FIG. 3B is still constant, except in the turnaround regions. The spectrum, shown in FIG. 3C, is concentrated at a frequency proportional to the distance from the ground, with randomly spaced lines as shown in FIG. 3C instead of the discrete lines of FIG. 2C. The periodicity of the modulation signal which is obtained by the application of random noise to the F.M. modulator eliminates all range ambiguities, as the latter are based on periodic repetition of the modulating waveform. Also, since the period of the modulation signal f_T of FIG. 3A is random, the number of whole cycles of the difference frequency f_D of FIG. 3B in each modulation cycle is also random. Therefore, the average number of whole cycles of f_D does not change in discrete steps as the altitude being detected varies. Consequently, there are no "critical-distance" errors in the altimeter of this invention.

Referring to FIG. 4 which shows the altimeter system of this invention, block **10** represents a random-noise generator whose output voltage is coupled to an input of a frequency modulator **11**. The modulator **11** generates an output voltage whose waveform corresponds to the curve f_T of FIG. 6A. The signal f_T from modulator **11** is then applied to the repeller of a conventional reflex klystron oscillator **12**, having a linear frequency-voltage characteristic, which generates a frequency modulated transmitting signal. This signal is radiated by transmitting antenna **13** connected to the output of klystron **12**.

Noise generator **10** and modulator **11** are shown in greater detail in FIG. 5. Therein it is seen that a thyratron **30** is arranged to function as a diode random-noise

generator. The modulator 11 consists of a screen-coupled phantastron oscillator 32 which is free running. The voltage at plate 43 of phantastron 32 falls quite linearly after a triggering voltage is applied to its suppressor grid 42 and then rises exponentially as soon as the plate voltage at 43 "bottoms," as is well known in the art. The output from thyratron 30 on lead 41 is R-C coupled to suppressor grid 42 to supply the required triggering voltage. By using only the initial part of the exponential rise of the plate voltage at 43 in phantastron 32, the magnitudes of the slopes of the rise and fall may be made equal. The noise voltage on lead 41 randomly varies the amplitude at which phantastron 32 reverses the direction of its sweep, thus generating the desired modulating waveform at 43, as illustrated in FIG. 6A by curve f_T. Since the slopes remain constant and the amplitude at the turnaround is random, the period is random. The waveform f_T of FIG. 6A generated by modulator 11 is similar to that of FIG. 3A except that the randomness of the amplitude is substantially reduced due to the characteristics of the phantastron 32. The negative peaks are practically constant due to the "bottoming" of the plate 43 while the positive peaks vary slightly as determined by the output of noise generator 30. However, these variations are chosen to be relatively small and result in an average frequency deviation $\overline{F}$ in FIG. 6A which is constant, as previously stated. The positive peak variations are still sufficient to give the jittered modulation effect which eliminates "critical-distance" errors as has been fully explained.

The output of phantastron oscillator 32 from plate 43 is R-C coupled to the control grid of a cathode follower amplifier 34 whose output is connected through switch 46 to the input of a triode amplifier stage 36. Amplifier 36 has a wide band response due to the plate circuit inductor which improves its high frequency response. A final dual triode cathode follower 38 provides a low output impedance for modulator 11 and its output is coupled to the repeller of klystron 12. Further, a switch 45 in the feedback loop of phantastron 32, which is ganged with switch 46, selects one of three separate sets of resistor-condenser components to control the time constant of the feedback loop. This allows controlled variation of the nominal time period T_m of modulation signal f_T of FIG. 6A and thus selection of three different constant slopes of the modulation function corresponding to three altitude ranges in which the altimeter can operate. The setting of switches 45 and 46 is controlled by a range selector 23 which is described in more detail subsequently.

Referring again to FIG. 4, the received signal reflected from the ground is detected by a receiving antenna 15 and applied as one input to a conventional balanced microwave mixer 16. A directional coupler attenuator 14 is connected to the output of klystron 12 and feeds a part of the transmitted signal directly to mixer 16 as an R.-F. local oscillator signal. The mixer 16 produces an output signal whose frequency is the mean magnitude of the instantaneous difference frequency between the transmitted and received signals, as illustrated in FIG. 6B. The balanced mixer should have an amplitude modulation rejection of approximately 20 db. The difference frequency signal from mixer 16, is amplified by a wideband video amplifier 17 which has a voltage gain of 600 and a bandwidth between half-power points extending from 500 kc. to 12 mc. The amplifier 17 is of known construction, the details of which are fully illustrated in FIG. 7.

The receiver section of the altimeter shown in FIG. 4 further contains a servomechanism consisting of a modulator 18, an amplifier 20, a frequency discriminator 21, combined sawtooth voltage generator and D.C. amplifier 22 and a variable frequency search oscillator 19 connected in a closed loop as shown.

The difference frequency signal f_D containing the altitude information from video amplifier 17 is applied as one input to the balanced modulator 18. The modulator 18 is preferably of the carrier suppressed type with push-pull output, which is well known to the art. It is shown in detail in the FIG. 7 schematic. The other input to balanced modulator 18 is supplied by a search oscillator 19 which acts as a local heterodyne oscillator to apply a heterodyning signal to modulator 18. The local oscillator or search oscillator 19 is of the variable frequency type, and its operating frequency is controlled by circuit 22 in a manner to be explained below. The output signal from balanced modulator 18 is coupled to an I.-F. amplifier 20 of very narrow bandwidth. The frequency response of amplifier 20 is centered at 30 mc. and has a bandwidth of 800 kc. between its half-power points, as shown in curve e_{20} of FIG. 10. The I.-F. amplifier 20 is of conventional design, preferably incorporating automatic volume control in order to maintain linear operation over a wide range of signal amplitudes. One particular example of a suitable I.-F. amplifier is illustrated in FIG. 8.

The frequency of local oscillator 19 is varied or swept from 42 mc. to 30.5 mc. under control of a 30 c.p.s. sawtooth voltage from circuit 22. The difference frequency signal from amplifier 17 is thus mixed or heterodyned with the swept output of search oscillator 19 and translated to a higher frequency region. The local oscillator 19 is connected to the "carrier" input of the balanced modulator 18, as seen in FIG. 7, and the video amplifier signal is applied to the modulating voltage input of 18 so that the search oscillator signal is suppressed after mixing. Assuming that the altimeter picks up a signal reflected from the ground at a distance proportional to a particular difference frequency δf, then the output of balanced modulator 18 is a signal whose frequency spectrum, such as shown in FIG. 6C, sweeps from (42 mc. $-\delta f$) down to 30 mc., the center frequency of the I.-F. amplifier. It will be seen subsequently that when this modulator output signal on its downward sweep is amplified at the upper end of the I.-F. amplifier response, the servo loop functions to "lock" the frequency of the local oscillator 19 at the frequency required to heterodyne the δf signal to 30 mc., the I.-F. frequency. Thus the need for very wideband response in the receiver of the altimeter to accommodate wide variations of δf corresponding to a wide altitude range is eliminated. This is an important advantage, since the attainment of wide range for the altimeter while employing narrow bandwidth amplifier circuits results in improved receiver sensitivity. The receiver's sensitivity is inversely related to its bandwidth. Also, the conversion to a high frequency region by the superheterodyne circuits 18, 19 and 20 largely removes microphonic interferences and Doppler type error signals which occur in a low frequency range and will not be passed by I.-F. amplifier 20.

The constant difference frequency output of I.-F. amplifier 20, which exists when local oscillator 19 is set to a frequency f_{SO} such that $f_{SO}=30$ mc.$+\delta f$, is applied as an input to a balanced frequency discriminator 21. The particular circuit configuration of discriminator 21 is shown in FIG. 8. The discriminator 21 is arranged to weight the spectral energy of the signal from I.-F. amplifier 20 on each side of the 30 mc. center frequency, and produces an output signal with an amplitude and polarity which is proportional to the imbalance of the energies on the two sides of the center frequency. The curve e_{21} of FIG. 10 illustrates the required discriminator characteristic. The discriminator 21 functions to generate an "error" voltage which is proportional to the frequency displacement of the signal output of I.-F. amplifier 20 from the predetermined constant difference signal which is the I.-F. center frequency. This "error" voltage output from discriminator 21 is connected to the control grid 65 of a circuit 22 which operates as a combined sawtooth voltage generator and D.C. amplifier as will now be explained with reference to FIG. 9.

The circuit **22** of FIG. 4 is arranged to function as a sawtooth voltage generator during the time intervals when the voltage at control grid **65** of phantastron **50** of FIG. 9 is greater or more positive than a predetermined negative magnitude and further to function as a D.C. amplifier at other times when control grid **65** is more negative than the said predetermined magnitude. The voltage at grid **65** at any given time is determined by the output of balanced discriminator **21**, since it is connected to the input of circuit **22**. The circuit **22** as shown in FIG. 9 comprises a phantastron circuit **50** coupled to a cathode follower output stage **52**. When the voltage at **65** is positive or of a small negative magnitude, stage **50** is effectively a screen-coupled phantastron relaxation oscillator generating a 30 cycle sawtooth voltage at plate **63** which is coupled by potentiometer **67** to control grid **68** of cathode follower **52**. The cathode follower output appears at terminal **70**. The sawtooth oscillations of phantastron **50** at terminal **70** are applied to capacitor **72** in the circuit of triode oscillator **54** of FIG. 9, the "search" oscillator or local oscillator **19** of FIG. 4. Triode **54** and its associated circuit components form a conventional Hartley oscillator. Capacitor **72** is a voltage sensitive capacitor or "Varicap," whose capacitance is determined by the voltage applied to it. When a varying voltage is applied to capacitor **72** to vary its capacitance, the frequency of oscillation of oscillator **54** will be controllably varied, as will be apparent to those skilled in the art. Thus the sawtooth voltage at terminal **70** of circuit **22** varies the bias voltage across capacitor **72** applied by bias source **69** to drive the "search" oscillator **19** over its 40 mc.–30.5 mc. sweep. This completes the "search and lock" servo loop.

The sweeping local oscillator **19** performs a "search" function in the altimeter, such that at some point during its sweep the difference between its frequency and the signal from amplifier **17** mixed with it in modulator **18** is equal to the tuned frequency of I.-F. amplifier **20**. Then, $f_{SO}-\delta f=P$, the operating frequency of the I.-F. amplifier, here 30 mc. As local oscillator **19**, decreasing in frequency during its sweep, approaches f_{SO}, the output signal of modulator **18** also decreases in frequency towards frequency P. The spectrum of this output signal is amplified by the upper end of I.-F. amplifier **20**, and a negative swing of the output voltage of discriminator **21** occurs upon detecting the amplified signal. The discriminator output voltage becomes sufficiently negative to cause "search" oscillator **19** to cease sweeping and remain at frequency f_{SO}.

This "locking" action occurs because when the discriminator voltage applied to control grid **65** of phantastron **50** becomes sufficiently negative as just mentioned, the gain of the phantastron tube is reduced to a level below that required to sustain the relaxation oscillations producing the sawtooth voltage. The loop gain of the stage becomes so low that feedback through capacitor **61** has no effect. At this point, however, the signal at grid **65** is not at cutoff so stage **50** acts as a D.C. amplifier. Its constant output voltage at **70** maintains the frequency of local oscillator **19** constant at f_{SO}. The servo loop is "locked onto" the signal δf from video amplifier **17** and subsequently tracks it.

The frequency of "search" oscillator **19** is controlled by the voltage of the sawtooth generator **22**. When a reflected signal has been picked up by the receiver and the servo loop has "locked onto" this signal, the voltage at terminal **70** of circuit **22** is a measure of the altitude. This D.C. voltage is applied to an altitude readout voltmeter **24** connected to terminal **70** and calibrated to indicate altitude. However, when no signal has been acquired by the altimeter and consequently the voltage at **70** is a 30 c.p.s. sawtooth, a neon light also connected to terminal **70** (not shown) is energized to indicate that the system is not "locked" on a target, but is in a searching mode. These latter functions could also be employed in

suitable form in conjunction with any type of computer or rate-of-descent meter desired in a particular application.

Also connected to terminal **70** of sawtooth generator **22** is a range selector device **23** whose output is coupled back to modulator **11** of the transmitter circuits. The range selector can be of any suitable form adapted to count a predetermined number of cycles of the sawtooth voltage generated by phantastron **50** during the "searching" mode of the altimeter and then produce an output signal suitable to rotate the movable members of switches **45** and **46** in modulator **11** to a new position. For example, range selector **23** could take the form of a predetermined counter actuated by individual "pulses," or cycles, of the sawtooth voltage at terminal **70** and a stepping relay connected to the above-mentioned counter's output to rotate the movable arms of switches **45** and **46** to their next successive positions. As described above with regard to modulator **11**, such actuation of switches **45** and **46** will select a different resistor-condenser combination in the feedback loop of phantastron oscillator **32** to alter the nominal or average time period T_m of the modulation signal f_T of FIG. 6A while still maintaining the frequency deviation $\overline{F}$ of the klystron **12** substantially constant. The above arrangement permits selection of three distinct modulation waveform frequencies corresponding to three separate altitude ranges. This can be seen from Equation 2,

$$\delta f=\frac{8hf_mF}{c}$$

i.e., the difference frequency from mixer **16** varies in direct proportion to altitude h for a given modulation waveform which has a constant F and a constant f_m. The range selector **23** causes successive incremental changes in the f_m of the modulation waveform of FIG. 6A without altering $\overline{F}$ which means that in the above Equation 2, any signal δf of a given frequency now corresponds to a new value of h, i.e., the altitude range being measured is changed.

When the altimeter is first turned on, modulator **11** generates a triangular wave of random period but nevertheless having an average frequency

$$f_m=\frac{1}{T_m}$$

(see FIG. 6A), and f_m corresponds to one particular range of altitudes, for examples, 5 to 100 feet. The servo loop under control of the sawtooth generator **22** searches for a received signal indicating the altitude is within this range. Should the altitude be much higher than 100 feet, so that no return signal is obtained within the proper frequency range to pass I.-F. amplifier **20** after the superheterodyne action of components **18** and **19**, the sawtooth voltage at terminal **70** actuates the predetermined counter of the range selector **23**. Modulator **11** is thereby switched to a different average modulating frequency f_m, that is, a lower average modulating frequency. The sawtooth generator **22** again causes search oscillator **19** to make the predetermined number of searches for a signal return within the new altitude range before actuating switches **45** and **46** of modulator **11**. This process of sweeping within the three altitude ranges repeats in sequence until a target is acquired, whereupon the sawtooth voltage is no longer generated because of the "locking" action of the servo loop and no further switching of the modulator altitude range occurs. The servomechanism tracks the received target signal and the correct altitude is indicated by the altitude readout **24**.

It will be apparent that the embodiment shown is only exemplary and that various modifications can be made in construction and arrangement within the scope of the invention as defined in the appended claims.

We claim as our invention:

1. An improved radar altimeter comprising in com-

bination: a transmitting signal source, means for generating a randomly jittered triangular modulating signal, said generating means including control means for maintaining the maximum and minimum values of said modulating signal within predetermined mutually exclusive ranges, means for frequency modulating said transmitting source with said triangular modulating signal to produce an F.M. transmitted signal, receiver means for mixing said transmitted signal with a received signal reflected from the ground, and a servomechanism connected to said receiver mixer means, said servomechanism including a balanced modulator, a variable frequency local oscillator, an I.-F. amplifier, an F.M. discriminator, and a combined sawtooth generator-D.C. amplifier connected together in a closed loop, altitude readout means connected to an input of said local oscillator, and range selecting means connected to said sawtooth generator for varying in discrete steps the average frequency of said triangular modulating signal.

2. An improved altimeter having no range ambiguities or critical-distance errors comprising an oscillator, a modulator for generating a triangular frequency modulating signal, a random noise generator connected to said modulator to randomly vary a predetermined parameter of said modulating signal, means connecting said modulator to said oscillator to frequency modulate said oscillator in accordance with said modulating signal, a transmitting antenna connected to the output of said oscillator, and receiving means comprising a mixer for producing a difference frequency from the output of said frequency modulated oscillator and a received signal which has been radiated by said transmitting antenna and reflected from the ground, frequency responsive means responsive to the output of said mixer for producing a voltage proportional to said difference frequency, and altitude indicating means responsive to said voltage.

3. In a frequency modulated radar altimeter, a random noise source, a klystron oscillator, means for frequency modulating said klystron oscillator, means connecting said random noise source to said modulating means for randomly varying the period of the frequency modulation, a transmitting antenna connected to said klystron oscillator, a receiving antenna, a balanced microwave mixer connected to said receiving antenna, attenuation means coupled between said klystron oscillator and said mixer to apply a portion of the transmitted signal directly to said mixer, so that said mixer produces a difference frequency between said transmitted signal and a received signal reflected from the ground which is proportional to altitude, wide-band amplifying means connected to said mixer, a balanced modulator having two inputs, said amplifying means connected to one of said modulator inputs, a variable frequency local oscillator connected to the other of said modulator inputs, a narrow bandwidth I.-F. amplifier coupled to the output of said modulator, a balanced F.M. discriminator connected to said I.-F. amplifier, means for generating a sawtooth voltage when the output signal of said discriminator is zero and for amplifying the output signal of said discriminator when it exceeds a predetermined negative magnitude, means connected to said last-mentioned means for varying the frequency of said local oscillator in response to said sawtooth voltage and for locking the frequency of said local oscillator when the output signal of said discriminator exceeds said predetermined negative magnitude, altitude indicating means connected to said discriminator output signal amplifying means, and range selecting means connected between said sawtooth voltage generating means and said frequency modulating means for incrementally changing the average modulating frequency of said modulating means to measure altitudes in a plurality of discrete ranges.

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