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PATENT SPECIFICATION

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(54) METHOD AND APPARATUS FOR AUTOMATICALLY CALIBRATING A RADIO ALTIMETER

(71) We, ROCKWELL INTERNATIONAL CORPORATION, a corporation of the State of Delaware, United States of America, P.O. Box 10462, City of Dallas, Texas 75207, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention relates to improvements in distance measuring apparatus, and, more particularly, to improvements in CWFM radio altimeter circuits, and still more particularly to a circuit for providing an auto-calibration timing signal against which a returned signal mixed with a currently transmitted signal can be compared to minimize the effects of nonlinearities in the frequency of the transmitted signal.

Typical radio altimeters transmit a signal to be reflected from the underlying terrain. The signal carries a known modulation signal, usually a frequency sweep varying in accordance with a triangular or saw-toothed waveform configuration. The frequency sweep in the prior art devices must be critically controlled to be linearly time varying or have a known average $\Delta f/\Delta t$.

The reflections from the terrain are detected by a receiver portion of the altimeter, and the frequency offset between the modulation of the received signal and the currently transmitted signal is determined. The altitude or distance between the aircraft and the terrain is then calculated from the frequency offset, which is directly proportional to the two-way time of travel of the transmitted signal. The larger the difference in frequency between the received and currently transmitted signals, the higher the altitude.

As mentioned, the slope and linearity of the frequency sweep transmitted in the prior art radio altimeter devices have to be precisely controlled for an accurate altitude measurement. If the average slope of the transmitted saw-toothed ramp were not constant, for example, then the $\Delta f/\Delta t$ measurement would not accurately reveal the proper frequency difference, resulting in erroneous measurements.

Typically, the saw-toothed linearity and slope control is achieved by using a special (and expensive) filter in the modulator stage of the transmitter, and by using extremely high quality transmitter circuits and components. This results in a larger weight and volume in the altimeter, requiring valuable space on board the particular aircraft with which it is associated.

Another provision typically incorporated into prior art altimeter devices is a calibration feedback circuit which controls the overall slope or rate of change of the frequency sweep modulated onto the transmitted signal. Thus, in addition to the weight and circuitry problems necessitated by the use of the linearity maintaining circuits mentioned, the circuitry used to control the slope of the modulation frequency must be taken into consideration, as well. Furthermore, because of the numerous variations in the transmitter components, which may result in frequency drift and the like, the prior art radio altimeters had to be necessarily frequently calibrated to ensure their continued accuracy.

According to the present invention there is provided an automatic calibration circuit for a CWFM radio altimeter, comprising means for transmitting a signal frequency modulated with a frequency sweep signal, means for detecting reflections of said transmitted signal, first mixing means for producing an altitude determining signal of frequency equal to the difference of said transmitted signal and said detected reflections, means for sampling said transmitted signal to produce a sample signal, means for delaying said sampled signal a predetermined time to produce a delayed signal, second mixing means for producing a calibration signal of frequency equal to the difference of said transmitted and delayed signals, and means for comparing the ratio of the frequencies of said altitude determining signal and said calibration signal for determining the period of said altitude determining signal.

In an embodiment of the invention there is provided an autocalibration circuit for use in a CWFM radio altimeter. The circuit includes means for transmitting a signal which has been frequency modulated with a frequency sweep signal. Reflection detecting means receives the delayed transmitted signal, and a first mixing means produces an altitude determining signal of frequency equal to the difference of the transmitted signal and the detected reflections. Means for sampling the transmitted signal produces a sample signal, and means for delaying the sample signal a predetermined time produces a delayed signal. Second mixing means produces a calibration signal of frequency equal to the difference of the transmitted and delayed signals, and means for comparing the ratio of the altitude determining signal and the calibration signal determines the period of the altitude determining signal.

In the invention, a method of automatically calibrating a CWFM radio altimeter includes the steps of developing a correction signal from a current and a delayed transmitted signal, and comparing the correction signal to a signal of frequency equal to the difference of a current and a reflected transmitted signal to produce an altitude indication.

The invention will now be described by way of example only with particular reference to the accompanying drawings wherein:-

Figure 1 is a box diagram of a radio altimeter using the automatic calibration circuit and method of the present invention;

Figure 2 is a graph of the frequency versus time showing ideal transmitted and received frequency sweeps for use in altitude determination;

Figure 3 is a graph of a more realistically encountered transmitted and received frequency sweeps, showing the inaccuracies resultant therefrom in an altitude determination;

Figure 4 is a graph of the calibration frequency derived in accordance with the invention versus time;

Figure 5 is a graph of the amplitude of the mixed and limited ground return signal, with respect to time;

Figure 6 is a graph of an ideal clock signal, with respect to time, in relative scale to the ground return and calibration frequencies of Figures 4 and 5; and

Figure 7 is a detailed schematic drawing of the automatic calibration circuit of the invention, used in conjunction with a data processing system employing a direct memory access control for utilization of the data derived, which has been calibrated by the method and apparatus of the invention.

In Figures 2 to 6, the relative scales and proportions of the curves and the number of pulses shown have been exaggerated or distorted for ease of description and clarity of illustration.

The autocalibration circuit 10 of the invention is shown in Figure 1 in operative relationship with a transmitter section 11 and receiver section 12 of a CWFM radio altimeter 13. Briefly, the transmitter section 11 includes a transmitter 14 modulated by a modulator 15 to deliver a signal to an antenna 16 upon a transmission line 18. Typically, the transmitter is operated at a frequency of about 4,300 MHz, and is modulated with a triangular wave of frequency of about 100 Hz sweeping over a frequency of about 100 MHz.

The signal radiated from the antenna 16 is directed to the underlying terrain 17 or other object from which distance is desired to be measured, and reflections from the underlying terrain 17 are detected upon a receiving antenna 19. A coupling element 20 adjacent the transmission line 18 samples the transmitted signal, and the sample is mixed in a mixer 22 with the ground reflected signal received upon the antenna 19. The mixed ground return signal is amplified by a pre-amplifier 23, and mixed with an intermediate frequency and limited in an IF/limiter stage 24. The output from the IF/limiter stage 24, which is in the form of a square wave (see Figure 5, below described), is then applied to a period converter 26, which determines the period of the returned signal, from which determination the altitude can be directly derived.

If desired, a number of adjacent periods of the returned signal can be produced and listed in a memory means, such as a random access memory (RAM) 27. The data in the RAM 27 can be further processed by a computer means such as a microprocessor 28 or the like to produce digital outputs which, if desired, can be converted to analog form by a digital-to-analog (D/A) converter 30. The output of the D/A converter 30 can drive a conventional altitude display indicator 31. If desired, the digital data can be converted to a serial format in a parallel-to-serial (P/S) converter 32 to drive an indicator 34.

With the system thus constituted, the operation to produce an altitude indication is as follows, with reference particularly to

Figures 2 to 6. The transmitter modulation frequency, indicated by the saw-tooth waveform f_t (Figure 2) is transmitted from the antenna 16. The received signal, indicated by the sawtooth waveform f_r, is received on the antenna 19, but displaced in time from the transmitted signal an amount corresponding to the two-way travel time of the signal. At any given time, the difference in the frequencies of the transmitted and received signals can be observed, shown by the portion $\triangle f$, which is directly relatable to the altitude or distance over which the radio waves have traversed. In the prior art, as above indicated, in order to produce an accurate altitude indication, steps have been taken to ensure that the transmitted frequency is as linear as possible in its variations with respect to time. However, even with such linearity assuring measures, the transmitted frequency assumes a waveform which has nonlinear segments, such as shown in exaggerated form in Figure 3. Thus, the transmitted curve f_t may be rounded in a concave or convex direction, as shown. The received waveform, of course, follows a similar path, but displaced in time. However, depending upon the time in which the change in frequency between the transmitted and received waveforms is taken, different frequency measurements may be obtained, as indicated by the distances $\triangle f_1$ and $\triangle f_2$ shown. Thus, an uncertainty is introduced as to the precise altitude of the aircraft.

In order to eliminate this uncertainty, regardless of the waveform of the transmitted frequency, the autocalibration circuit 10 of the invention is presented. With reference again to Figure 1, the autocalibration circuit 10 includes a coupler 38 to sample the transmitted frequency. A delay line 39 is used to delay the sampled frequency a predetermined time, corresponding to any convenient time (or altitude) such as 100 feet. The sampled and delayed signals are mixed in a mixer 40, then amplified and limited in an amplifier and IF/limiter stage 42. The amplified and limited signal is then applied to a phaselocked loop 43 and applied as clock pulses to the period converter 26.

The operation of the autocalibration circuit 10 of the invention can be seen from the graphs of Figures 4 to 6. Specifically, Figure 4 shows the change in frequency with respect to time of the calibration signal produced by the mixed calibration delay signal and the sampled transmitted signal. Any nonlinearities in the signal are reflected in a change in frequency of this calibration signal. Thus, as shown, the calibration signal may increase in frequency with respct to time. (It should be noted that although the $\triangle f_{CAL}$ is shown having a time increase in frequency, other nonlinear variations may be seen depending upon the particular nonlinear variations of the transmitted frequency.)

The returned signal difference, as shown in Figure 5, will also exhibit a nonlinear time varying function, since it is derived from the transmitted signal having the precise nonlinearities detected by the autocalibration circuit 10. Thus, for instance, at a particular altitude, the frequency of the output of the phase-locked loop 43 may be four times the frequency of the signal produced at the output of the limiter stage 24. This can be seen in a comparison of Figures 4 and 5. Thus, as noted, each comparison of the period of the returned frequency and the calibration frequency has the same ratio, i.e., 4, even though the actual time of the return frequency period may be increasing or decreasing. If the returned frequency were to be compared, for instance, to a standard nonvarying clock frequency, illustrated in Figure 6, the ratio would change from, for example, a period of 4 to a period of .5 (using the arbitrary curves of the drawing).

It can therefore be seen that by utilizing the sampled and delayed actual transmitted signal as a calibrating signal, the effects of the nonlinearities of the transmitted frequencies are cancelled.

The autocalibration circuit of the invention is shown in detail in Figure 7, used in conjunction with a microprocessing and direct memory access data acquisition and controlling system. The mixed return signal is amplified in the amplifier 23, mixed with an intermediate frequency and limited in the IF/limiter stage 24 to be applied to clock a D-type flip-flop 50 to a set state. The output Q of the D flip-flop 50 is connected to one input of a NAND gate 51, to enable the calibration pulses derived as below described to pass through the NAND gate 51 to the clock terminal of a counter 52.

The output from the IF/limiter 24 is additionally applied to the clock input terminal of a second counter 54 to produce an output after a predetermined number of mixed return signal periods has been received. Such number of periods may conveniently be one, ten, sixteen, a hundred, or any conveniently handleable number.

The mixed calibration signal, after being amplified and limited in the amplifier and IF/limiter state 42 is applied to a "signal in" terminal of a phase-locked loop circuit 43. The particular phase-locked loop circuit illustrated is of the RCA type CD4046, although it will be apparent that any equivalent type circuit can be equally advantageously employed. The VCO output of the phase-locked loop 43 is connected to a clock terminal of the counter 62, and an output derived, for instance upon the Q_4 output terminal, is connected to the Q_{11} input of the phase-locked loop. With the phase-locked loop 43 and counter 62 thus configured, the output frequency upon the VCO output terminal can be adjusted to be 16 times the frequency of the mixed calibration signal derived from the amplifier and IF/limiter 42. The VCO output is applied to another terminal of the NAND gate 51 to be gated thereby to the clock input of the counter 52.

Thus, in operation, when a pulse is detected of the mixed return signal, the flip-flop 50 changes to a "set" state, to enable the NAND gate 51 to pass the output from the phase-locked loop 43. The mixed calibration signal, multiplied by the output frequency control provided by the counter 62 is then counted by the counter 54 until the counter 54 reaches the preselected count. At that time, the Q_N output terminal of the counter 54 changes state, signaling the termination of the desired period to a direct memory access (DMA) control 64. The DMA control 64 then latches the count presented at the various output terminals Q_1-Q_N of the counter 52 into a microprocessor peripheral interface circuit 65. Additionally, the DMA control 64 resets the flip-flop 50, and the counters 52 and 54 so that an additional subsequent period count can be made. It should be noted that at this point, the data produced by the counter 52 latched into the interface circuit 65 is representative of a predetermined number of periods (for instance one, ten, a hundred, etc.) which can be directly used for producing an output altitude signal to the digital-to-analog (D/A) converter 30 or the parallel to serial (P/S) converter 32 to provide an altitude indication upon indicator 31 or 34, respectively.

It may, nevertheless, be desirable to accumulate a number of such period indicating data. Consequently, the random access memory (RAM) circuit 27 is supplied, into which the data produced at the interface circuit 65 can be successively written by the DMA control 64. The micropocessor system 28 together with an associated preprogrammed read only memory (ROM) 66 can then access the RAM 27 to perform the predefined processing procedures to the data therein. Such processing procedures may, for example, include detection and rejection of contaminated data, averaging a number of period indicating data, and so forth. The microprocessor system can then produce outputs to the digital-to-analog and parallel-to-serial converters 30 and 32 via an input-output device 67.

WHAT WE CLAIM IS:-

1. An automatic calibration circuit for a CWFM radio altimeter, comprising:

means for transmitting a signal frequency modulated with a frequency sweep signal,

means for detecting reflections of said transmitted signal,

first mixing means for producing an altitude determining signal of frequency equal to the difference of said transmitted signal and said detected reflections,

means for sampling said transmitted signal to produce a sample signal,

means for delaying said sampled signal a predetermined time to produce a delayed signal,

second mixing means for producing a calibration signal of frequency equal to the difference of said transmitted and delayed signals,

and means for comparing the ratio of the frequencies of said altitude determining signal and said calibration signal for determining the period of said altitude determining signal.

2. An automatic calibration circuit as claimed in claim 1 wherein said comparing means comprises means for counting a number of cycles of said calibration signal between a predetermined number of cycles of said altitude determining signal to produce an altitude indicating signal.

3. An automatic calibration circuit as claimed in claim 2 further comprising means for accumulating a predetermined number of sequential altitude indicating signals, and for averaging said accumulated signals to produce an average altitude indicating signal.

4. An automatic calibration circuit for a CWFM radio altimeter substantially as hereinbefore described and as shown in the accompanying drawings.

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1589047 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

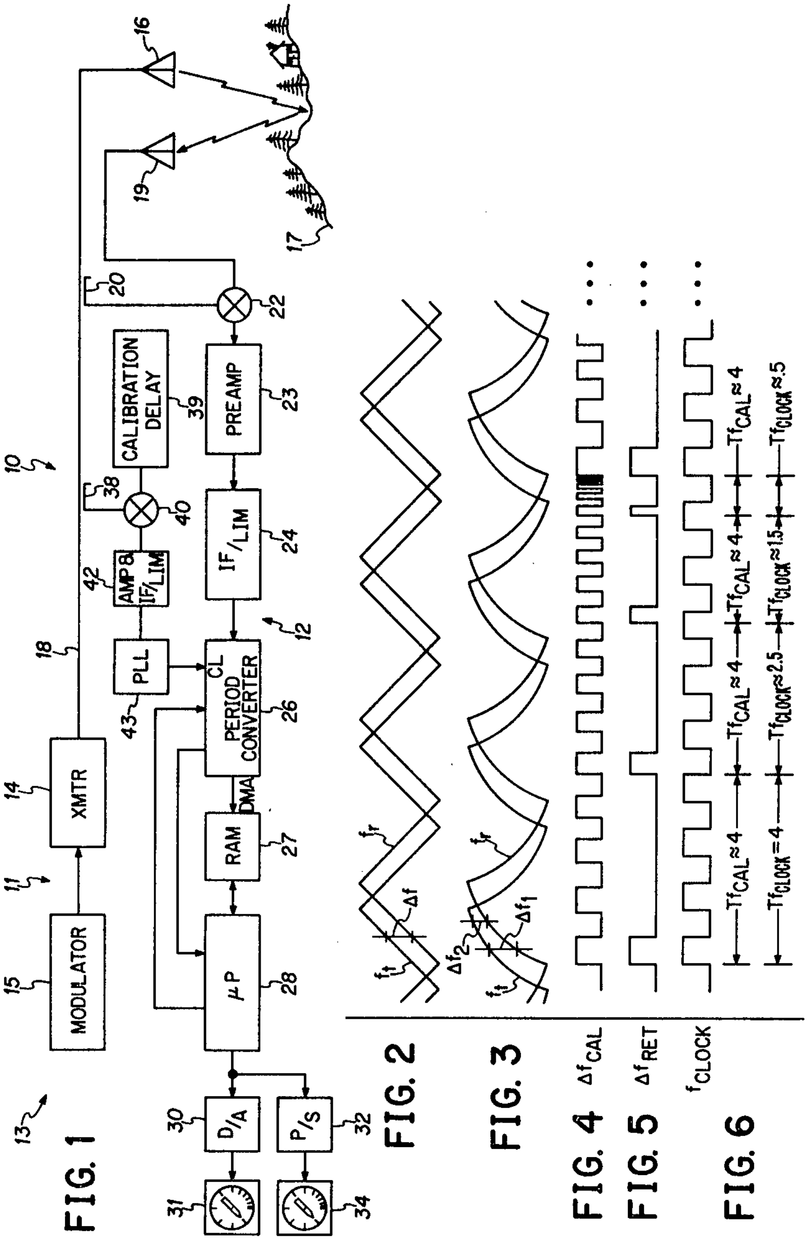
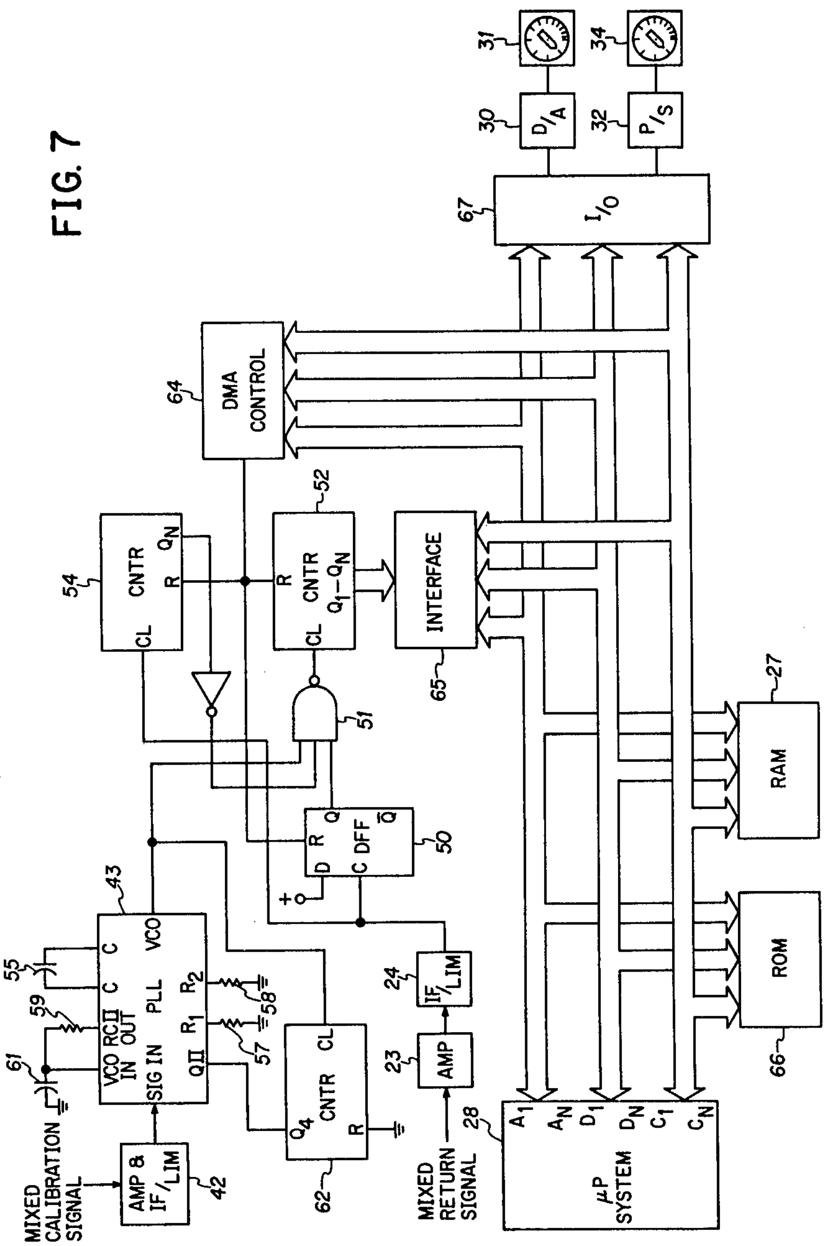


FIG. 7


MIXED CALIBRATION SIGNAL
AMP & IF/LIM
42
61
59
55
VCO IN
RCII OUT
C
C
SIG IN
PLL
VCO
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R1
R2
57
58
43
CNTR
Q4
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