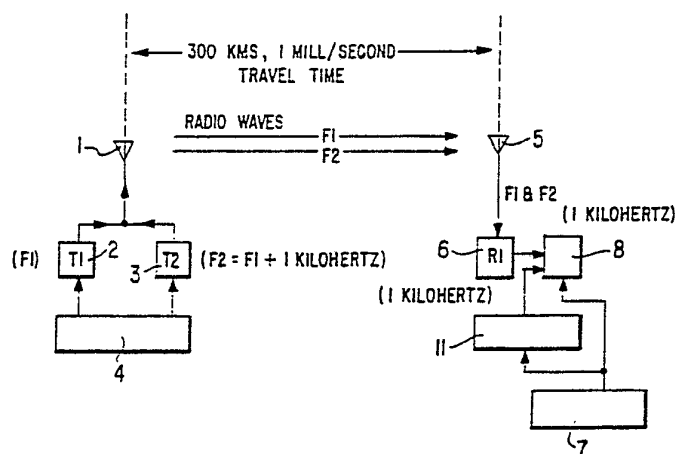




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(54) Title: CONTINUOUS WAVE CARRIER SIGNALS DISTANCE MEASURING SYSTEM AND METHOD



(57) Abstract

A radio frequency distance measuring system and method employs at least one pair of continuous wave carrier signals having a preselected frequency separation equal to a desired difference frequency. The pair of continuous wave carrier signals are generated at the transmitting station by transmitters (2, 3), in accordance with a reference signal from a frequency standard (4), and are radiated by an antenna (1) to the receiving station at the unknown point. The receiver (6) at the receiving station mixes the received pair of continuous wave carrier signals to produce a difference frequency signal which is phase compared in a phase meter (8) with a locally generated difference frequency signal from circuit (11). The phase difference is proportional to the distance from the transmitting station to the receiving station. More than one transmitting station is employed to provide position information.

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CONTINUOUS WAVE CARRIER
SIGNALS DISTANCE MEASURING SYSTEM
AND METHOD

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BACKGROUND OF THE INVENTION

1. Field Of The Invention.

The present invention relates generally to radio frequency distance and position measuring systems and methods, and more particularly to a method and apparatus for accurately determining the distance or locating the position of an unknown receiving point with respect to known transmitting point(s).

10 The present invention is of general utility in off-shore navigation and exploration, geodetic surveys, air navigation, satellite positioning, vehicle location and general surveying work as used in the construction of highways, harbors and other
15 civil engineering works.



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2. Description Of The Related Art

Many time comparison and phase comparison systems and methods have been developed, and many such systems and methods are in use, for distance
5 measuring or position locating by radio means.

While such systems and methods can be classified as employing either time comparison or phase comparison, all such systems by necessity employ highly stable frequency standards or sources. In
10 the case of time comparison systems and methods, the frequency standards are precisely calibrated so as to produce reference signals having the same frequency. The frequency standards used in phase
15 comparison systems and methods are precisely calibrated to produce reference signals having the same frequency and the same or a predetermined phase relationship.

Because the frequency standards provide the reference frame from which either the time or phase
20 comparison is performed, they must exhibit very high short term and very high long term stability in order to minimize error.

Distance is measured in time comparison and in phase comparison systems and methods by having the
25 transmitting station (at the known point) transmit a signal produced in accordance with a reference signal from its frequency standard; the transmitted signal is received at the receiving station at the unknown point. The received signal is then time or
30 phase compared with a reference signal produced by the receiving station frequency standard and the results of this comparison are used to determine the distance of the unknown point from the known point.



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Position locating in a time comparison or phase comparison systems and methods employ at least two transmitting stations at different known points.

The location of the receiving station is determined
5 by analyzing the distance information using triangulation techniques.

Conventional time comparison systems and methods intermittently transmit signals from the transmitting station(s) for reception at the receiving station.

10 The intermittent transmission of a signal from each transmitting station is precisely controlled in time in accordance with the frequency standard at that station. The receiving station produces a reference signal in accordance with its frequency standard,
15 which reference signal is also precisely controlled in time. Because the frequency standards are calibrated, the time delay introduced by the propagation of the transmitted signal to the receiving station indicates the distance between the two
20 stations. This is so because the propagation rate of radio signals, like the propagation rate of light, has been measured to a very high degree of accuracy. Thus, by multiplying the measured time delay propagation rate of radio signals, the distance can be
25 calculated.

The time delay, for example, can be determined by comparing the leading edge of the received signal with the leading edge of the reference signal generated by the frequency source at the receiving
30 station. Alternately, the trailing edge of the received signal can be compared with the trailing edge of the reference signal.

The intermittently transmitted signal can be an interrupted carrier without modulation, or can be a



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modulation signal employing any known type of modulation, such as amplitude modulation, frequency modulation, or pulse modulation. Another approach is to utilize frequency shift keying so that the

5 interruption is determined when the signal frequency changes from one selected frequency to another selected frequency. Representative of such systems is the periodic amplitude modulation timing technique shown in United States Patent Number 3,613,095

10 to Elwood. Alternate approaches are shown in United States Patent Number 3,839,719 to Elwood, United States Patent Number 3,816,832 to Elwood and United States Patent Number 3,916,410 to Elwood.

Conventional time comparison systems and methods,

15 however, do not produce sufficiently accurate distance measurement or position location. Applicants' research and experiments indicate that these deficiencies are due to several factors inherent in such systems and methods. First, it is extremely

20 difficult to determine when the transmitted signal is first received at the receiving station. Before the signal is received, the passband of the receiver includes only background noise and other interfering signals. Such noise and interfering signals often

25 erroneously trigger the zero crossing detector used to determine when the transmitted signal is first received. Second, the absence of the transmitted signal in the passband of the receiver causes the receiver to exhibit gross nonlinear responses when

30 the received signal is first passed through the passband because the equilibrium of the various stages of the receiver is suddenly shifted or changed. Both of these problems are also present in systems and methods employing frequency shift keying and



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other signal transposition methods because of the intermittent aspect of the transmitted signals.

Conventional phase comparison systems and methods, on the other hand, transmit continuously at least one signal from the transmitting station to the receiving station.

In such systems and methods which transmit a single signal from a transmitting station, the distance of the receiving station from the transmitting station is determined by comparing the phase of the received signal with the phase of a reference signal generated by the frequency standard at the receiving station. The receiving station can unambiguously determine this distance only when it is less than one wavelength away from the transmitting station (referred to herein as a sublane distance), where the length of the wavelength is determined by the frequency of the transmitted signal. When the receiving station is more than one wavelength away from the transmitting station, it is then necessary to count or determine the total number of complete wavelengths (referred to herein as the lane total) and then add this total to the sub-wavelength determination made by the phase comparison to determine the distance.

Two approaches have been employed in conventional phase comparison systems and methods to determine the total number of complete wavelengths that the receiving station is removed from the transmitting station. One approach employs using a counter or accumulator which counts or accumulates the number of complete wavelengths (lane total) as the receiving station moves more than one wavelength away from the transmitting station. Such systems



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are typically employed in off-shore environments where the receiving station is on a boat or oil drilling platform that is moved from the transmitting station to the unknown point. Another approach
5 is to employ a helicopter or airplane to fly from the transmitting station to the receiving station and count the number of complete wavelengths travelled between same.

The counter or accumulator method is unsatisfactory because any loss of the received signal will
10 cause the loss of the count or accumulated lane total. Such losses occur frequently due to many factors, such as changes in radio frequency propagation and interference. The second approach using
15 the helicopter or airplane necessarily is very expensive and sometimes impossible when extreme environmental conditions are encountered.

As is well-known, the length of a complete wavelength of a radio signal increases as the frequency of the signal decreases. For example, the
20 length of a 1.7 megahertz signal is approximately 186 meters. In comparison, the length of a 100 kilohertz signal is approximately 3.00 kilometers.

The OMEGA system in worldwide use employs a single transmitted signal having a very low frequency of approximately 1 kilohertz. While such a system has a very long wavelength (300 kilometers), it is impossible to measure distance with more than about a 3 kilometer accuracy because accurate phase
25 comparison of greater than one one-hundredth of a wavelength is difficult to achieve.

United States Patent Number 3,696,427 to Nard shows a system which attempts to produce high distance measurement accuracy using phase comparison



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while employing at least one continuously transmitted signal having a high frequency (2 megahertz).

Referring to the Nard patent system, a radio frequency signal F_A is transmitted from a first transmitting station E_a as shown in Figure 1a, and signal F_A is displaced by a frequency f_1 from a frequency reference point F . The transmitted signal F_A is generated in accordance with a stable source G_A .

10 The Nard receiver, as shown in Figure 2, located at the unknown point, receives the signal F_A and translates it down to baseband frequencies using amplifiers 2 and 4 and mixers 3 and 5 to produce a baseband frequency signal of frequency f_1 . This baseband signal of frequency f_1 is extracted using a bandpass filter 6 and is applied to a phase meter 12. A stable reference source 10 is used to generate a reference signal in synthesizer 11 having a frequency of f_1 , which reference signal being applied also to phase meter 12. Phase meter 12 compares the phase of the received f_1 signal with respect to the phase of the locally generated F_1 signal to obtain a sub-wavelength or "fine" measurement. The reason that the output of phase meter 12 provides the "fine" measurement is because the phase information inherent in the signal from the output of bandpass filter 6 is the phase information inherent in the F_A signal. Since the frequency of the F_A signal is high (for example, 2 megahertz), the phase information necessarily provides the sub-wavelength or "fine" measurement information.

In order to provide the total number of wavelengths (lane total) or "course" measurement capability, the Nard patent system requires the



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transmission of an additional signal F'_A from transmitting station A, as shown in Figure 1a. This signal F'_A has a frequency of $F' + f_1$, where F' is another reference frequency point.

5 The Nard receiver (Figure 2) receives the signal F'_A and translates it to a baseband signal of frequency f_1 using amplifiers 2', 4' and mixers 3' and 5'. The baseband signal f_1 is extracted using a baseband filter 6' and is applied to one input of a
10 phase meter 12'. The other input of a phase meter 12' is provided with the locally generated f_1 reference signal from synthesizer 11. The output of phase meter 12' also comprises "fine" measurement information because the phase information inherent
15 in f_1 is the phase information inherent in the F'_A signal (approximately 2 megahertz).

To obtain the "course" measurement, the structure and function of the Nard patent system requires that the "fine" measurement derived from signal F_A
20 and the "fine" measurement information derived from signal F'_A be subtracted in a phase subtractor 14. It is thus seen that the frequency difference between F_A and F'_A is not used, and could be used by the Nard patent apparatus to achieve "course" (lane
25 total) measurement. Rather, the structure and function of the Nard patent apparatus employs the phase data on signal F_A to obtain a first "fine" distance measurement and employs the phase data on signal F'_A to obtain a second "fine" phase measure-
30 ment, and then subtracts the two "fine" phase measurements to obtain a "course" measurement.

Another approach in conventional phase comparison systems and methods for obtaining both the sublane and lane total measurement is to have



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the transmitting station transmit a double sideband suppressed carrier signal. This signal is received by the receiving station and then supplied to a balanced mixer which mixes the two sideband signals together to produce a sum signal and a difference signal. The phase information contained in the sum frequency signal permits the sublane measurement because the complete wavelength of this high frequency signal is very short as compared to the complete wavelength of the very low difference frequency signal.

For example, assume that the carrier at the transmitting station is at 1.700,500 megahertz and that a 500 hertz audio signal is used to modulate it in a balanced modulator. Note that both the carrier signal and the audio signal are generated in accordance with the frequency standard at the transmitting station. The balance modulator produces a double sideband suppressed carrier signal having a lower sideband at 1.700,000 megahertz and an upper sideband at 1.701,000 megahertz. This double sideband suppressed carrier signal is amplified and then transmitted to the receiving station.

At the receiving station, it is received and then supplied to a balance mixer, which produces a sum frequency signal having a frequency of 3.401,000 megahertz. This sum frequency signal, for example, is then frequency divided by 2 using a divide signal generated by the frequency standard at the receiver to produce a sum frequency signal having a frequency of 1.700,500 megahertz, the frequency of the suppressed carrier of the double sideband suppressed carrier signal transmitted by the transmitting station. A complete wavelength at this "carrier"



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signal is approximately 186 meters long. By comparing this sum frequency signal with a reference signal produced by the frequency standard at the receiving station, it is possible to measure accurately the phase difference between these two signals within approximately one one-hundredth of a total wavelength--namely, ± 1.8 meters. Thus, the sublane measurement accuracy in this example is approximately ± 1.8 meters.

As has been discussed above, it is necessary also to determine the lane total when the receiving station is distanced more than one lane from the transmitting station. In conventional systems, the difference frequency signal produced by mixing the received double sideband suppressed carrier signal in a balanced modulator at the receiving station is the way in which this lane total information is determined.

In the present example, the difference frequency signal is equal to twice the frequency of the modulating audio signal. From another viewpoint, the frequency of the difference frequency signal is equal to the frequency difference between the lower sideband and the upper sideband of the double sideband suppressed carrier signal. This difference frequency signal is phase compared at the receiver with a signal of the same frequency generated in accordance with the receiver frequency source. Because the difference frequency signal has a very low frequency, it was thought that it would provide the total lane information. In the example given, the difference frequency is 1 kilohertz. A signal of such frequency has a wavelength equal to 300 kilometers. It was thus thought that the phase



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comparison using this difference frequency signal would permit the lane total to be determined.

As seen from the example, with each lane equal to approximately 186 meters and with a difference frequency of 1 kilohertz, there are approximately 1,600 lanes within a complete wavelength of the 1 kilohertz difference frequency signal. It is thus appreciated that a very high degree of phase comparison resolution must be obtainable at the receiving station in order to utilize the difference frequency signal to provide the total lane information.

Unfortunately, in conventional phase comparison systems and methods employing double sideband suppressed carrier signals, the high degree of phase resolution required to produce the total lane information using the difference frequency signal has not been attainable.

The applicants through research and experimentation have come to realize that the problems in phase comparison of the difference frequency signal is due to the use of a double sideband suppressed carrier signal.

Specifically, the double sideband suppressed carrier signal approach is deficient because of the fact that one signal is being used to modulate a carrier signal in a balance mixer to produce the double sideband suppressed carrier signal. The double sideband suppressed carrier signal can be expressed mathematically as follows:

$$(1) \quad w_{usb}t = w_c t + w_{mod}t$$

$$(2) \quad w_{lsb}t = w_c t - w_{mod}t$$



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where: w_{usb} is the frequency in radians of the upper sideband signal; w_{lsb} is the frequency in radians of the lower sideband signal; w_c is the frequency in radians of the suppressed carrier signal; and w_{mod} is the frequency in radians of the modulating signal.

Applicants have found that any amplitude variation of the modulating signal ($w_{mod}t$) results in an amplitude variation in the double sideband suppressed carrier signal. Because zero crossing detectors are employed to determine the phase difference between the received signal and the reference signal produced by the frequency standard at the receiver, the change in amplitude caused by the modulation results in a small dV/dt variation with respect to the zero crossing detectors. All existing zero crossing detectors must detect the zero crossing of a signal by detecting a very small amplitude level of the signal displaced from the zero signal state. Such zero crossing detectors cannot detect the absolute zero crossing point, but must detect this small amplitude rise or fall in the signal, which is equated to the zero amplitude crossing. Any change in amplitude caused by the modulation, however, detrimentally effects the detection of this zero crossing point. Since the phase measurements involve nanoseconds in order to achieve the desired total lane measurement capability, it is seen that any variation caused by the amplitude can easily result in an unsatisfactory error in this total lane measuring capability.

A second problem inherent in the use of a double sideband suppressed carrier signal is the phase jitter introduced by the modulation. Phase jitter is any undesired phase instability present on



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a signal that is generated in accordance with a reference source. From the equations above, it is seen that the modulating signal introduces additional phase jitter on both the upper sideband and the lower sideband signals. Experiments by the applicants have shown that the phase jitter introduced by this modulation constitutes a very substantial portion of the phase jitter present on the double sideband suppressed carrier signals. This phase jitter also prevents the desired lane total capability from being attained.

Another problem inherent in the use of a double sideband suppressed carrier signal is the frequency instability present in the modulating signal ($w_{mod}t$). The modulating signal must be generated by the frequency standard at the transmitting station in order to have the proper phase relationship with the carrier signal. Because of the very low frequency of the modulating signal (typically, 500 hertz), it is necessary to frequency divide the reference signal from the frequency standard repeatedly. It can be appreciated that any frequency instability is compounded by such divisions. Since any undesired frequency displacement affects the phase comparison, it causes a detrimental effect in the measurement accuracy as well.

The frequency spectrum exhibited by a double sideband suppressed carrier signal can be expressed mathematically as follows:

$$(3) \quad w_r t = w_c t \pm (N w_{mod}) t$$

where N is an integer equal to 1, 2, 3, 4, 5, et cetera; w_r is the frequency of the



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resultant signal spectrum in radians; w_c is the frequency of the suppressed carrier signal in radians; and w_{mod} is the frequency of the modulating signal in radians.

- 5 Solving this equation shows that there is a harmonic on either side of the upper sideband signal and on either side of the lower sideband signal displaced at intervals equal to the frequency of the modulating signal. It is extremely difficult to attenuate
10 sufficiently unwanted second, third, fourth and fifth harmonic signals associated with the double sideband suppressed carrier signal so as to be in compliance with many licensing authorities. This problem with spectral purity increases as the radio
15 frequency spectrum becomes more crowded.

Finally, the carrier of a double sideband suppressed carrier signal can only be suppressed by a certain amount. Typical carrier suppression is in the order of 50 to 60 decibels. Such carrier
20 suppression, however, results in a carrier being present in the received frequency bandwidth at a low level. This low level suppressed carrier signal can cause measurement problems, particularly with respect to the sum frequency signal used to produce
25 the sub-lane information. This is due to the fact that the suppressed carrier is mixed by the balance mixer in the receiver.

SUMMARY OF THE INVENTION

The apparatus and method of the present invention
30 tion includes one or more transmitting stations of known position. Each transmitting station radiates at least two continuous wave carrier signals, each of which is generated in accordance with the fre-



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quency standard at the transmitting station. The separation in frequency between each pair of continuous wave carrier signals from each transmitting station is an exact quantity selected to correspond to a difference frequency signal used in distance measurement. A coherent receiver means at the unknown point receives each radiated pair of continuous wave carrier signals to derive from each pair a difference frequency signal, and compares each derived difference frequency signal with a locally generated difference frequency signal (generated in accordance with a reference signal from the receiver's frequency standard) having the same frequency as the derived difference frequency signal. The phase difference between the locally generated difference frequency signal and the derived difference frequency signal is determined by a phase meter or other suitable apparatus or method step, and is subsequently displayed as a measured distance. Two or more of such distance measurements can be used to yield the position of the receiving station in reference to the known transmitting stations in accordance with the apparatus and method of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a general block diagram of an illustrative embodiment of the continuous wave carrier signal distance measurement system and method of the present invention.

Figure 2 shows in pictorial form how distance measurements from two known reference transmitter points can be determined in accordance with the present invention to locate an unknown receiver point in space.



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Figure 3 is a chart showing the relationship between the difference frequency defined by the separation of a pair of continuous wave carrier signals and the maximum distance that can be measured with such pair without ambiguity in accordance with the present invention.

Figure 4 is a schematic diagram of a simple, two frequency phase locked transmitter/exciter suitable for use in the high frequency bands that works well in the present invention.

Figure 5 is a schematic diagram of a simple coherent receiver, using no local oscillator, for use in the high frequency bands, that was designed for use in the present invention.

15 DETAILED DESCRIPTION OF
 THE PREFERRED EMBODIMENT

Broadly, the method and apparatus of the present invention transmits two or more unmodulated continuous wave carrier signals from each transmitting station. The continuous wave carrier signals are precisely displaced in frequency with respect to each other. The frequency displacement between each pair of signals is equal to the frequency of the difference frequency signal derived at the receiving station by mixing the pair of received signals using a balanced mixer. This mixing operation allows the difference frequency signal to be obtained at the receiving station in one electronic step. This difference frequency signal is then phase compared with a reference signal (of the same frequency) produced in accordance with the frequency standard at the receiving station.

The present invention is thus entirely



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different from the phase comparison apparatus and method shown in United States Patent Number 3,696,427 to Nard. As discussed above, in the Nard patent system, the phase data on the first received
5 signal is subtracted from the phase data on the second received signal to obtain the total lane information. The frequency difference between these two signals is not used in any way in the Nard patent apparatus to derive the total lane informa-
10 tion.

The present invention offers significant improvements as compared with the double sideband suppressed carrier approach described above with respect to total lane measurement. Specifically,
15 applicants have found a twentyfold increase in accuracy concerning the total lane measurement than that achievable using the conventional double sideband suppressed carrier approach.

This improvement can be better appreciated by
20 viewing the present invention from a theoretical viewpoint. For purposes of explanation, it is assumed that only a pair of unmodulated continuous wave carrier signals are being transmitted by a transmitting station. Further, the frequency dis-
25 placement between these two continuous wave carrier signals is precisely controlled and is selected so that the desired total lane capability can be obtained, as discussed below in greater detail with reference to Figure 3. It should be appreciated,
30 however, that the present invention is not limited to transmitting a pair of unmodulated continuous wave carrier signals from a single transmitting station; rather, two or more such signals can be transmitted from each transmitting station so as to



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produce more than one difference frequency signal which, for example, can be used to produce more than one total lane or "course" measurement.

Two unmodulated continuous wave carrier signals
5 precisely displaced with respect to frequency from each other can be expressed mathematically as follows:

$$(4) \quad w_{F1}t = w_{F1}t$$

$$(5) \quad w_{F2}t = w_{F2}t$$

where w_{F1} is the frequency in radians of
10 the first continuous wave carrier, and w_{F2} is the frequency in radians of the second continuous wave carrier.

Equations (4) and (5) show mathematically why the pair of unmodulated continuous wave carrier signals
15 do not exhibit any of the technical deficiencies present in the double sideband suppressed carrier approach discussed above. Specifically, there is no amplitude variation because no modulating signal is employed. Second, phase jitter is substantially
20 eliminated because there is no modulating signal. The only phase jitter that exists is that present on each of the unmodulated continuous wave carrier signals. Note, however, that this phase jitter is also present in the double sideband suppressed
25 carrier approach because a carrier signal is used to generate the upper and lower sideband signals. Third, the frequency instability introduced by the modulating signal in the double sideband suppressed carrier approach (caused by the frequency division
30 of the signal from the transmitter frequency standard to the desired modulation frequency) is eliminated again because no modulating signal is



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employed. Fourth, there is no problem with an insufficiently suppressed carrier being present in the passband of the inherent receiver because there is no carrier to be suppressed according to the method and apparatus of the present invention.

Another technical advantage achieved by the method and apparatus of the present invention is that of a spectrum having much fewer unwanted harmonic components. In the "worse" case, the present invention produces only one-half the number of harmonics that are produced in a given frequency band by the conventional double sideband suppressed carrier system. Further, the harmonics that are produced have amplitude levels which are appreciably lower than the corresponding amplitude levels of the harmonics produced by the conventional double sideband suppressed carrier approach. The "worst" case situation for the present invention occurs when the two unmodulated continuous wave carrier signals are combined using an active device prior to being provided to a single antenna at the transmitting station. Because every active device exhibits an intermodulation distortion characteristic due to nonlinearity, the combination by such a device of the two unmodulated continuous wave carrier signals results in the generation of intermodulation product signals that are displaced on either side of the carrier signals by a frequency equal to the frequency difference between the two continuous wave carrier signals. This "worst" case situation is set forth mathematically by the following equation:

$$(6) \quad w_{rt} = NW_{uct} + NW_{lct}$$



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where w_r is the frequency of the resultant frequency spectrum in radians; N is an integer greater than zero; W_{uc} is the continuous wave carrier signal in radians having the higher frequency; and W_{lc} is the continuous wave carrier signal in radians having the lower frequency.

Even in the "worst" case situation, it is possible to minimize these harmonics by the selection of a conventional active device of low cost having a low intermodulation distortion characteristic. Further, the "worst" case situation can be avoided by not combining the two unmodulated continuous wave carrier signals in the transmission process. In other words, when separate transmitter chains and antennas are used for each unmodulated continuous wave carrier signal, no wanted harmonics are produced that are closely adjacent in frequency with respect to the fundamental frequency of each signal.

Referring now to Figure 1, a distance measuring system in accordance with the present invention is shown. A first continuous wave carrier signal F_1 and a second continuous wave carrier signal F_2 are radiated from a transmitter as shown in block diagram form. The first continuous wave carrier signal F_1 is precisely displaced in frequency by an amount of 1 kilohertz from the second continuous wave carrier signal F_2 . It should be noted that the values for distances and the frequency separation of the two continuous wave carrier signals are given as an aid in understanding the structure and operation of the present invention and should not be construed as limiting factors. Any frequency separation, as shown in Figure 3, can be used and other distances than those shown can be measured.



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A frequency standard 4 of high stability, such as a MASER or molecular resonant frequency standard (hydrogen, ammonia, rubidium, et cetera) generates a reference signal of preselected phase and frequency. For example, as shown in Figure 1, the frequency of the reference signal is 1 kilohertz. A suitable form for the frequency standard 4 is that of an atomic clock such as a Hewlett Packard Model 5061-A Cesium standard.

10 A radio frequency transmitter or exciter 2 generates the first continuous wave carrier signal F_1 in accordance with the reference signal provided by the frequency standard 4. Similarly, a radio frequency transmitter or exciter 3 generates the
15 second continuous wave carrier signal F_2 in accordance with the reference signal from the frequency standard 4. It is thus seen that the first continuous wave carrier signal F_1 and the second continuous wave carrier signal F_2 have a very precisely defined phase relationship and frequency
20 relationship with respect to each other. The first continuous wave carrier signals F_1 from transmitter 2 and the second continuous wave carrier signal F_2 from the transmitter 3 are both radiated by a common
25 antenna 1 through space at the speed of light, 300,000 kilometers per second.

It should be understood that transmitters 2 and 3 can take any suitable form. One illustrative embodiment for the transmitter is the frequency
30 synthesizer exciter shown in Figure 4. The power level at the output of each of the transmitters 2, 3 can be amplified using any suitable amplifier of any class and type to produce the desired power level. Further, the output signals from the transmitters 2,



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3 do not have to be radiated by a single antenna; a separate antenna and amplifier can be employed for each continuous wave carrier signal (not shown) if desired.

5 A receiving station at an unknown point receives the propagated first continuous wave carrier signal F_1 and the second continuous wave carrier signal F_2 . In the example given in Figure 1, the receiving station is 300 kilometers from the trans-
10 mitting station. Thus, the continuous wave carrier signals F_1 and F_2 arrive at the receiving station antenna 5 one millisecond after they are transmitted from the transmitting station.

 Antenna 5 feeds these received signals to a
15 coherent, phase stable receiver 6 that derives or detects both the sum frequency signal and the difference frequency signal. A frequency standard 7 provides a reference signal to a difference
 frequency signal circuit 11, a phase meter and
20 display 8 and the radio frequency receiver 6. The phase and frequency of the frequency standard 7 are calibrated with respect to the phase and frequency of the reference signal provided by the frequency
 standard 4 at the transmitting station. Frequency
25 standard 7 can be of the same type as employed for frequency standard 4.

 Radio frequency receiver 6 operates in a coherent fashion because all of its stages are provided with oscillator signals derived from
30 frequency standard 7. Thus, phase information is not lost during frequency translation in radio frequency receiver 6. It should be understood that any suitable receiver can be employed for receiver 6. Figure 5 shows an illustrative embodiment.



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The received continuous wave carrier signals F_1 and F_2 are provided in radio frequency receiver 6 to a balance mixer, which produces a sum frequency signal and a difference frequency signal at its 5 outputs (not shown). The sum frequency signal, for example, can be divided by 2 using a frequency divide signal derived from frequency standard 7. This divided sum frequency signal can then be phase compared with a reference signal (of the same fre- 10 quency) generated by the frequency standard 7. This phase comparison provides the sub-lane distance information because the length of a complete wavelength of a signal of this frequency typically is only several hundred meters long.

15 The difference frequency signal from the mixer stage, which in Figure 1 is denominated as the 1 kilohertz output, is supplied by receiver 6 to one input of the phase meter and display 8. A reference signal having the same frequency (1 kilohertz) 20 and having the preselected phase is provided by the difference frequency signal circuit 11 in accordance with the reference signal provided by the frequency standard 7. This locally generated difference frequency signal is applied to the second input of 25 the phase meter and display 8. The phase meter and display 8 phase compares the difference signal with this locally generated difference frequency signal so as to produce the total lane or "course" information. This total lane information is displayed by 30 the phase meter and display 8 in any suitable fashion. It should be understood that the difference frequency signal circuit 11 and the phase meter and display 8 can take any suitable form, and that additional electronic processing circuitry and/or



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software can be employed after the phase comparison step so as to produce the desired distance or position information.

5 In this way, the distance measuring system in accordance with the present invention shown in Figure 1 provides the capability of determining precisely the distance between the receiving station at the unknown point from the transmitting station at the known point.

10 In Figure 2, the system and method of the present invention is shown as a position locator or indicator by using two or more reference point transmitting stations as coordinates. Transmitting station 9 sends a pair of continuous wave carrier
15 signals to a receiving station 11 at a unknown point, which in the example shown in Figure 2 is a ship at sea. Similarly, transmitting station 10 sends a pair of continuous wave carrier signals to receiving station 11. In the example of Figure 2,
20 the frequencies of the pair of continuous wave carrier signals from transmitting station 9 are F_1 and F_2 , respectively, and the frequencies of the pair of continuous wave carrier signals from transmitting station 10 are F_3 and F_4 , respectively.

25 Knowing the two distances involved from the two transmitting stations, 9 and 10, and knowing the exact location of these transmitting stations, the receiving station 11 can determine its exact position by triangulation techniques using accurate
30 charts or computer software and hardware (not shown).

As mentioned above with respect to Figure 3, any frequency separation between each pair of continuous wave carrier signals of the present



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invention can be used. There are, however, convenient separations between pairs of signals that yield optimum results, and can be selected to fit the range requirements of a given system. Because the difference frequency component is used as a reference signal to be phase compared with a locally generated signal, an ambiguity can occur if this unit overlaps at a given distance. For example, if a 1 kilohertz separation between the continuous wave signal pair F_1 and F_2 is used, yielding a 1 kilohertz received frequency signal difference, an ambiguity will occur after 300 kilometers. This is due to the fact that the length of a signal of 1 kilohertz is approximately 300 kilometers. Thus, in the situation where the receiving station is 301 kilometers from the transmitting station and a 1 kilohertz frequency separation between the signal pair is employed, the total lane information or "course" information displayed at the receiving station will be 1 kilometer because the system will be looking at the second wavelength of the difference frequency signal.

To avoid this phenomena, the frequency separation between a pair of signals can be selected with the aid of Figure 3 in such a manner that a maximum nonambiguous range can be obtained. As an example, a frequency separation of 1 hertz between a signal pair produces a maximum nonambiguous range of 300,000 kilometers. To interpret Figure 3, read frequency separation on one side, follow the solid line to the other side and read distance in kilometers for maximum nonambiguous range in kilometers on the vertical axis.

For an optimum system in accordance with the



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present invention, the range selected (and therefore the frequency separation between pairs of signals) should be large enough to permit measurements within this range, but not so large that the accuracy or resolution of the system is impaired. For example, a worldwide navigation system may need a frequency separation of 10 hertz, equivalent to a 30,000 kilometer nonambiguous range, while a surveying, local small distance measuring system, such as used by civil engineers in road construction, could best utilize a frequency separation of 100 kilohertz for a nonambiguous range of 3 kilometers.

Figure 4 shows a schematic of a dual continuous wave carrier frequency signal transmitter or exciter that has operated well in the method and apparatus of the present invention. Transmitter 400 is a phase coherent, two signal exciter employing frequency synthesizers, a linear mixer, and amplifier stages. It is phase coherent because it is provided with oscillator signals, such as the one kilohertz reference input signal to pin 14 of integrated circuit 410, derived from the transmitter frequency standard (not shown).

Referring to Figure 4, a phase lock loop crystal controlled oscillator 4 which is part of integrated circuit 410 has a crystal 412 whose frequency is a few hertz (typically 50) higher than the desired frequency. This circuit was found to yield the best stability, both long and short term, and a lower jitter or phase noise, as compared to a free running resistance/capacitance or inductance/capacitance voltage controlled oscillator. A suitable form for integrated circuit 410 is CD4046.

The frequency and phase of the square wave



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output of the voltage controlled oscillator (pin 4) is very precisely controlled by a divide-by-N divider chain made up of integrated circuit 414, integrated circuit 416, integrated circuit 418, and integrated circuit 420. A suitable component for each of these integrated circuits is a CD4017 Decimal Divider. The carry out (CO) output of each divider is fed to the input of the next divider in the divider chain. By looking for a given number to appear in all four decimal counters, the counter may be reset in a desired 1 kilohertz multiple frequency. For example, as shown in Figure 4, the divide-by-N divider chain is preset to 1.701 megahertz by picking up one in the megahertz counter, seven in the hundreds of the kilohertz counter, 0 in the tens of kilohertz counter, and 1 in the units of kilohertz counter. The outputs from each of the four counters are fed to a four input AND gate 422. A suitable form for AND gate is a CD4081 circuit.

When the counters reach the desired preselected number, all four gate inputs go high and a short "high" pulse appears at pin 10 of AND gate 422. This reset pulse is supplied as a reset pulse to pin 15 of each of the counters so as to bring them back to a starting count of zero. Because this short reset pulse occurs at 1,000 times per second rate, the pulses are fed to the phase comparator section of the integrated circuit 410 (pin 3), where they are compared with 1 kilohertz pulses or square wave pulses applied at pin 15 from the transmitter frequency standard (not shown). The output of the integrated circuit 410 at pin 4 is a square wave, pulse and frequency locked to a one kilohertz multiple of the frequency standard (other multiples



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may be used by changing the number of counters, the divide ratio, and the frequency of the input reference signal). In the example shown, this output from integrated circuit 410 has a frequency of 1.701
5 megahertz.

In like manner, a frequency synthesizer 422 of the same construction as the frequency synthesizer just described (shown in dashed line box form) produces a square wave signal output, pulse and
10 frequency locked to a 1 kilohertz multiple of the transmitter frequency standard, and having a frequency of 1.700 megahertz.

The square wave 1.701 megahertz output signal from pin 4 of integrated circuit 410 of the synthesizer shown in detail, and the 1.700 megahertz
15 square wave output of frequency synthesizer 422 are mixed in a linear mixer in the form of a tuned radio frequency amplifier having a transistor 430. The output of this linear mixer at the collector of
20 transistor 430 is coupled via a tuned circuit having a transformer 432 and a capacitor 434 to the base of a transistor 436 of a second radio frequency amplifier. A tuned circuit coupled to the output at the collector of transistor 436 is made up of a trans-
25 former 438 and a capacitor 440. The secondary winding of transformer 438 provides a radio frequency output signal at low power levels having a signal at 1.701 megahertz and 1.700 megahertz. It should be noted that the operation of the tuned
30 circuit having transformer 432 and capacitor 434 and the tuned circuit having transformer 438 and capacitor 440 converts the square wave signals from the synthesizers to sine waves by extracting the fundamental frequency component from each square wave signal.



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While it is not shown in Figure 4, it should be understood clearly that the low power sine wave signals provided at the output of transformer 438 can be amplified to any desired power level using any suitable type of amplifying device, such as a linear amplifier or a Class C amplifier. Further, the signals from the frequency synthesizers do not have to be combined using the radio frequency amplifiers shown in Figure 4, but instead can be provided separately to separate amplifiers and antenna systems. The arrangement shown in Figure 4 is advantageous where a single antenna and amplifier is employed so as to minimize the cost of the transmitting station.

Figure 5 shows an illustrative schematic of a simple, coherent receiver that can be employed in the present invention. A high frequency receiver is shown, but it can be modified using different components so as to operate on other frequency bands. It should be understood that any suitable coherent receiver can be employed which can receive the continuous wave carrier signals and mix pairs of them in balance mixers so as to provide as outputs the sum frequency signal and the difference frequency signal of each mixed pair.

Turning now to Figure 5, an antenna 502 receives, for example, two continuous wave carrier signals from the ionosphere. Antenna 502 can be of any suitable type. The output from antenna 502 on a line 504 is provided to the input of an attenuator 506. Attenuator 506 can be of any suitable design. Attenuator 506 is adjusted so as to provide the received continuous wave carrier signals on a line 508 at a suitable level.



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The signals on line 508 are provided to the input of a crystal filter 510 (or other type of filter at higher frequencies) of any suitable type. The bandpass filtered output of crystal filter 510 is supplied via a line 512 to the input of a high frequency amplifier 514. Amplifier 514 can be of any suitable type, such as a CA3020 linear amplifier. Amplifier 514 linearly amplifies the received pair of continuous wave carrier signals by a selected amount (for example, 56 decibels).

The output of amplifier 514 is coupled via a transformer 516 to a resistive divider made up of resistor 518 and resistor 520. The resistive divider splits the amplified pair of received continuous wave carrier signals and provides them to the inputs (Pins 11 and 5) of a balance mixer 522. A suitable form for balance mixer 522 is a Texas Instruments TL442CN. The pair of received continuous wave carrier signals beat against each other in balance mixer 522 so as to produce a sum frequency signal (not shown) and a difference frequency signal. The difference frequency signal, present at pins 13 and 3 of balance mixer 522, is supplied via a transformer 524 to a low frequency amplifier.

In the example shown in Figure 5, the difference frequency signal is a 1 kilohertz signal. It is supplied to the low frequency amplifier via a resistor 526. The low frequency amplifier includes a low pass filter made up of inductors 528 and 530 and capacitors 532, 534 and 536. It can be appreciated that the low pass filter just described is of conventional design. The output signal of the low pass filter, which is the difference frequency



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signal minus unwanted high frequency components, is provided to the input of a low frequency amplifier having a linear amplifier 538. Amplifier 538 can be of any suitable design, such as a CA3020A. The
5 output of amplifier 538 is coupled via a transformer 540 to a phase lock loop squarer circuit.

A level meter 542 is used to display the level of the difference frequency signal. Attenuator 506 is used to keep this reading at a constant peak
10 voltage regardless of the distance between the transmitting station and the receiving station, and within the sensitivity range of the receiver. This adjustment is done to prevent changes in the received signal level from causing a phase change in
15 the receiver, and therefore introducing an error.

Though the sine wave output of the receiver could be used as a input to the phase or interval meter (not shown), it is preferable to square this sine wave for more accurate measurements. This is
20 performed by a phase lock loop squarer circuit made up of a phased lock loop voltage controlled oscillator circuit in the form of integrated circuit 546. The sine wave version of the difference frequency signal is provided to pin 14 of integrated circuit
25 546). The output signal at pins 3 and 4 of integrated circuit 546 is a square wave version of the difference frequency signal. A suitable form for integrated circuit 546 is a CD4046. Use of the phase lock loop squarer avoids zero access crossing
30 distortion errors, present in most sine wave to square wave converters using dropped level switches or comparators. A tuned circuit between pins 6 and 7 of integrated circuit 546, formed by a tunable coil 548 and a capacitor 550, is tuned to a point slightly above the frequency of the difference



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frequency signal (1 kilohertz in the example shown).

The output at pin 4 of integrated circuit 546 is a square wave signal which is phase locked to the difference frequency signal of the receiver.

5 This difference frequency signal is provided to a suitable phase meter or other device capable of comparing its phase with the phase of a reference signal having the same frequency and generated by the frequency source at the receiving station. It
10 should also be appreciated that any subsequent computation using the phase information obtained thereby can be employed and is within the scope of the present invention.

 Note that all integrated circuits used in Figures
15 4 and 5 that have a CA or CD in their part number can be obtained from the Radio Corporation of America (RCA).

 While only certain preferred embodiments are shown and described herein, it is understood that
20 many modifications are possible, particularly in the circuit design of the transmitter and receiver, and that the present invention is not limited to the specific circuits and examples disclosed, nor otherwise, except as set forth in the following claims.



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WHAT IS CLAIMED IS:

1. A transmitting station in a radio frequency distance measuring system utilized to determine the distance of an unknown point from a known point, which comprises:

(a) first means for providing a first signal of a given frequency and a given phase;

(b) second means responsive to said first signal for generating a first continuous wave carrier signal of a first frequency;

(c) third means responsive to said first signal for generating a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a selected difference frequency; and

(d) fourth means for radiating said first and second continuous wave carrier signals for reception at said unknown point for providing a difference frequency signal used in determining said distance.

2. The station as claimed in Claim 1, wherein said first means comprises an atomic clock.

3. The station as claimed in Claim 1, wherein said first means comprises a molecular resonance frequency standard.

4. The station as claimed in Claim 1, wherein said second means comprises means responsive to said first signal for frequency synthesizing said first continuous wave carrier signal.



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5. The station as claimed in Claim 4, wherein said third means comprises means responsive to said first signal for frequency synthesizing said second continuous wave carrier signal.

6. The station as claimed in Claim 1, wherein said fourth means comprises:

- (a) means for combining said first and second continuous wave carrier signals; and
- (b) antenna means for radiating said combined first and second continuous wave carrier signals.

7. The station as claimed in Claim 6, further comprising means for amplifying said first and second continuous wave carrier signals and for providing said amplified first and second continuous wave carrier signals to said antenna means.

8. The station as claimed in Claim 1, wherein said second means comprises means responsive to said first signal for frequency synthesizing said first continuous wave carrier signal, said first continuous wave carrier signal having a substantially square waveform, and

wherein said third means comprises means responsive to said first signal for frequency synthesizing said second continuous wave carrier signal, said second continuous wave carrier signal having a substantially square waveform.

9. The station as claimed in Claim 8, wherein said fourth means comprises:

- (a) means for combining said first and



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second continuous wave carrier signals;

(b) low pass filter means responsive to the combined first and second continuous wave carrier signals for passing only the fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals; and

(c) antenna means for radiating said fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals.

10. The station as claimed in Claim 9, further comprising means for amplifying said fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals and for providing same to said antenna means.

11. The station as claimed in Claim 9, wherein said means for combining comprises at least one active device.

12. A radio frequency distance measuring system for determining the distance of an unknown point from a known point, which comprises:

(a) first means for providing a first signal of a given frequency and a given phase;

(b) second means responsive to said first signal for generating a first continuous wave carrier signal of a first frequency;

(c) third means responsive to said first signal for generating a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a



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selected difference frequency;

(d) fourth means for radiating said first and second continuous wave carrier signals; and

(e) fifth means for receiving said first and second continuous wave carrier signals at said unknown point to provide a difference frequency signal used in determining said distance.

13. The system as claimed in Claim 12, wherein said first means comprises an atomic clock.

14. The system as claimed in Claim 12, wherein said first means comprises a molecular resonance frequency standard.

15. The system as claimed in Claim 12, wherein said second means comprises means responsive to said first signal for frequency synthesizing said first continuous wave carrier signals.

16. The system as claimed in Claim 12, wherein said third means comprises means responsive to said first signal for frequency synthesizing said second continuous wave carrier signal.

17. The system as claimed in Claim 12, wherein said fourth means comprises:

(a) means for combining said first and second continuous wave carrier signals; and

(b) antenna means for radiating said combined first and second continuous wave carrier signals.

18. The system as claimed in Claim 17, further



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comprising means for amplifying said first and second continuous wave carrier signals and for providing said amplified first and second continuous wave carrier signals to said antenna means.

19. The system as claimed in Claim 12, wherein said second means comprises means responsive to said first signal for frequency synthesizing said first continuous wave carrier signal, said first continuous wave carrier signal having a substantially square waveform, and

wherein said third means comprises means responsive to said first signal for frequency synthesizing said second continuous wave carrier signal, said second continuous wave carrier signal having a substantially square waveform.

20. The system as claimed in Claim 19, wherein said fourth means comprises:

(a) means for combining said first and second continuous wave carrier signals;

(b) low pass filter means responsive to the combined first and second continuous wave carrier signals for passing only the fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals; and

(c) antenna means for radiating said fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals.

21. The system as claimed in Claim 19, further comprising means for amplifying said fundamental



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sinusoidal frequency components of said combined first and second continuous wave carrier signals for providing same to said antenna means.

22. The system as claimed in Claim 20, wherein said means for combining comprises at least one active device.

23. The system as claimed in Claim 12, wherein said fifth means comprises:

(a) means for generating a second signal of said given frequency and of a predetermined phase relationship with respect to said given phase;

(b) means for mixing said received first and second continuous wave carrier signals to produce said difference frequency signal;

(c) means responsive to said second signal for supplying a third signal having said phase of said second signal and said frequency of said difference frequency signal; and

(d) means for comparing the phase difference between said difference frequency signal and said third signal.

24. The system as claimed in Claim 23, further comprising means responsive to said phase difference for determining the distance between said known point and said unknown point.

25. The system as claimed in Claim 23, further comprising means responsive to said phase difference for indicating the distance between said known point and said unknown point.



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26. The system as claimed in Claim 23, wherein said fifth means further comprises:

(a) antenna means for providing said received first and second continuous wave carrier signals; and

(b) means for amplifying said received first and second continuous wave carrier signals to furnish said amplified, received first and second continuous wave carrier signals to said means for mixing.

27. The system as claimed in Claim 23, wherein said fifth means further comprises phase lock loop means for bandpass filtering said difference frequency signal to provide said bandpass filtered difference frequency signal to said means for comparing.

28. The system as claimed in Claim 23, wherein said means for generating a second signal comprises an atomic clock.

29. The system as claimed in Claim 23, wherein said means for generating a second signal comprises a molecular resonance frequency standard.

30. The system as claimed in Claim 23, wherein said means for mixing comprises a balanced mixer.

31. A radio frequency position measuring system for calculating the position of an unknown point from at least two known points, which comprises:



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- (a) first means for producing a first signal of a given frequency and a given phase;
- (b) second means responsive to said first signal for generating a first continuous wave carrier signal of a first frequency;
- (c) third means responsive to said first signal for generating a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a first selected difference frequency;
- (d) fourth means at said first known point for radiating said first and second continuous wave carrier signals;
- (e) fifth means for producing a second signal of said given frequency and of a predetermined phase relationship with respect to said given phase;
- (f) sixth means responsive to said second signal for generating a third continuous wave carrier signal of a third frequency;
- (g) seventh means responsive to said second signal for generating a fourth continuous wave carrier signal of a fourth frequency, displaced from said third frequency by a second selected difference frequency;
- (h) eighth means at said second known point for radiating said third and fourth continuous wave signals;
- (i) ninth means at said unknown point for receiving said first and second continuous wave carrier signals to provide a first difference frequency signal and for receiving said third and fourth continuous wave carrier signals to provide a second difference frequency signal, said first and second



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difference frequency signals used in determining the position of said unknown point with respect to said first and second known points.

32. A radio frequency distance measuring system, which comprises:

(a) transmitter means located at a known point, which includes

(i) first means for generating a first signal of a selected frequency and selected phase,

(ii) second means responsive to said first signal for producing a first continuous wave carrier signal of a first frequency,

(iii) third means responsive to said first signal for producing a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a selected difference frequency, and

(iv) fourth means for radiating said first and second continuous wave carrier signals; and

(b) means located at an unknown point, which includes:

(i) fifth means for generating a second signal of said selected frequency and of a predetermined phase relationship with respect to said selected phase,

(ii) sixth means for receiving said first continuous wave carrier signal and said second continuous wave carrier signal,

(iii) seventh means for mixing said received first and second continuous wave



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carrier signals to obtain a frequency difference signal,

(iv) eighth means for providing a reference signal in accordance with said second standard signal, and

(v) ninth means for determining the distance between said known point and said unknown point by comparing the phase difference between said reference signal and said frequency signal.

33. The system as claimed in Claim 32, wherein said first means comprises a molecular resonance frequency standard,

wherein said second means comprises a frequency synthesizer,

wherein said third means comprises a frequency synthesizer, and

wherein said seventh means comprises a balance mixer.

34. The system as claimed in Claim 32, wherein said eighth means comprises means for providing said reference signal at substantially the frequency of said frequency difference signal and at substantially the phase of said second standard signal.

35. A radio frequency distance measuring method for determining the distance between an unknown point and a known point, which comprises the steps of:

(a) producing a first signal of a given frequency and a given phase;

(b) generating in response to said first



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signal a first continuous wave carrier signal of a first frequency;

(c) generating in response to said first signal a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a selected difference frequency; and

(d) radiating said first and second continuous wave carrier signals for reception at said unknown point to provide a difference frequency signal used in determining said distance.

36. The method as claimed in Claim 35, wherein the step of generating a first continuous wave carrier signal comprises the step of frequency synthesizing said first continuous wave carrier signal in accordance with said first signal, and

wherein the step of generating a second continuous wave carrier signal comprises the step of frequency synthesizing said second continuous wave carrier signal in accordance with said first signal.

37. The method as claimed in Claim 34, wherein the step of producing a first signal comprises the step of generating said first signal using a molecular resonance frequency standard.

38. The method as claimed in Claim 35, wherein the step of radiating said first and second continuous wave carrier signals comprises the steps of:

(a) combining said first and second continuous wave carrier signals; and

(b) employing an antenna means to radiate said combined first and second continuous wave



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carrier signals.

39. The method as claimed in Claim 35, wherein the step of generating a first continuous wave carrier signal comprises the step of generating a square wave signal of said first frequency, and

wherein the step of generating a second continuous wave carrier signal comprises the step of generating a square wave signal of said second frequency.

40. The method as claimed in Claim 38, wherein the step of radiating said first and second continuous wave carrier signals comprises the steps of:

(a) combining said first and second continuous wave carrier signals;

(b) filtering said combined first and second continuous wave carrier signals for extracting the fundamental sinusoidal frequency components of said combined first and second continuous wave carrier signals; and

(c) furnishing said filtered, combined first and second continuous wave carrier signals to antenna means for radiating said signals.

41. The method as claimed in Claim 40, further comprising the steps of:

(a) amplifying said filtered, combined first and second continuous wave carrier signals; and

(b) providing said amplified, filtered and combined first and second continuous wave carrier signals to said antenna means.



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42. A radio frequency distance measuring method for determining the distance of an unknown point from a known point, which method comprises the steps of:

(a) generating a first signal of a given frequency and of a given phase;

(b) generating as a function of said first signal a first continuous wave carrier signal of a first frequency;

(c) generating as a function of said first signal a second continuous wave carrier signal of a second frequency, said second frequency displaced from said first frequency by a selected difference frequency;

(d) radiating from said known point said first and second continuous wave carrier signals;

(e) receiving at said unknown point said first and second continuous wave carrier signals; and

(f) mixing said received first and second continuous wave carrier signals for producing a difference frequency signal used in determining said distance.

43. The method as claimed in Claim 41, further comprising the steps of:

(a) generating a second signal of said given frequency and of a predetermined phase relationship with respect to said given phase; and

(b) providing a reference signal having the phase of said second signal and the frequency of said difference frequency signal.

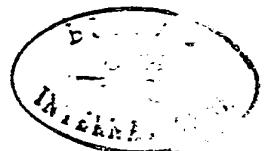
44. The method as claimed in Claim 42, wherein



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said step of mixing said received first and second continuous wave carrier signals comprises the step of balance mixing said first and second continuous wave carrier signals for producing said difference frequency signal.

45. The radio frequency distance measuring method as recited in Claim 43, further comprising the step of determining said distance in accordance with the phase difference between said reference signal and said difference frequency signal.



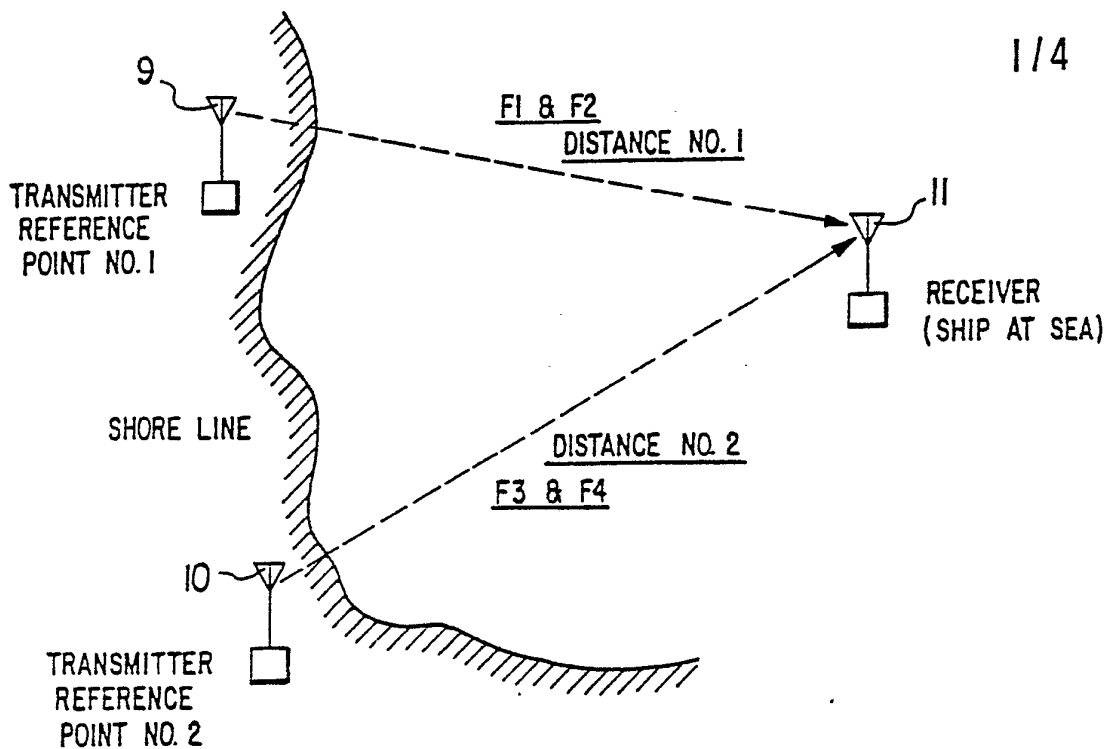


FIG. 2

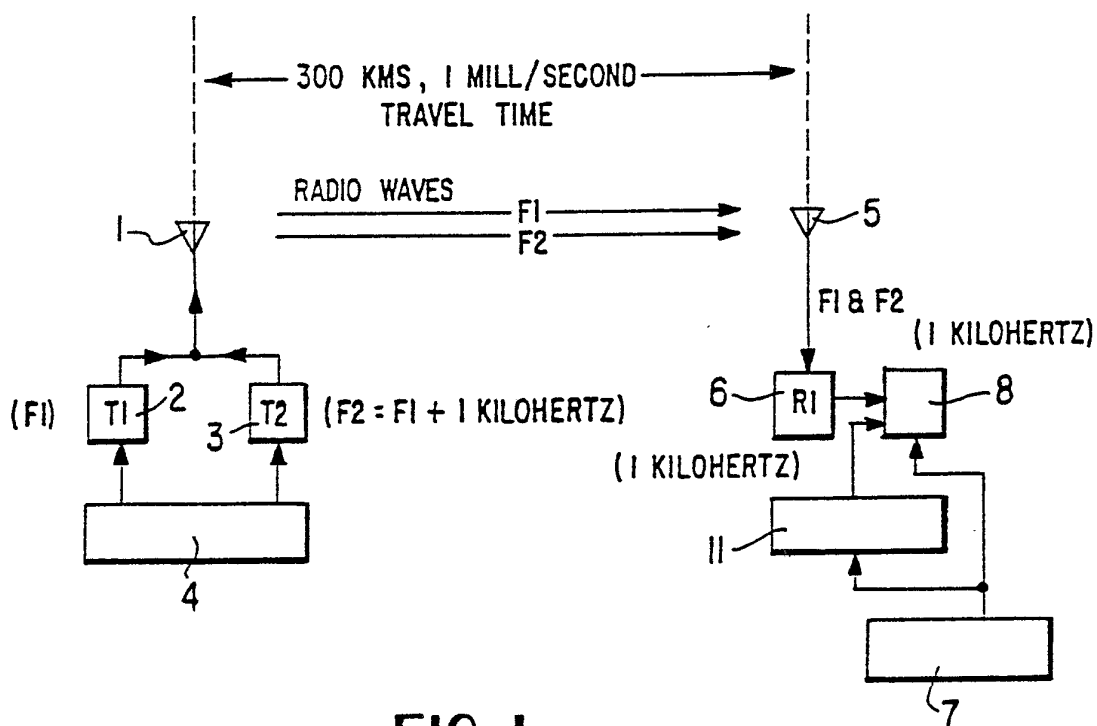


FIG. 1

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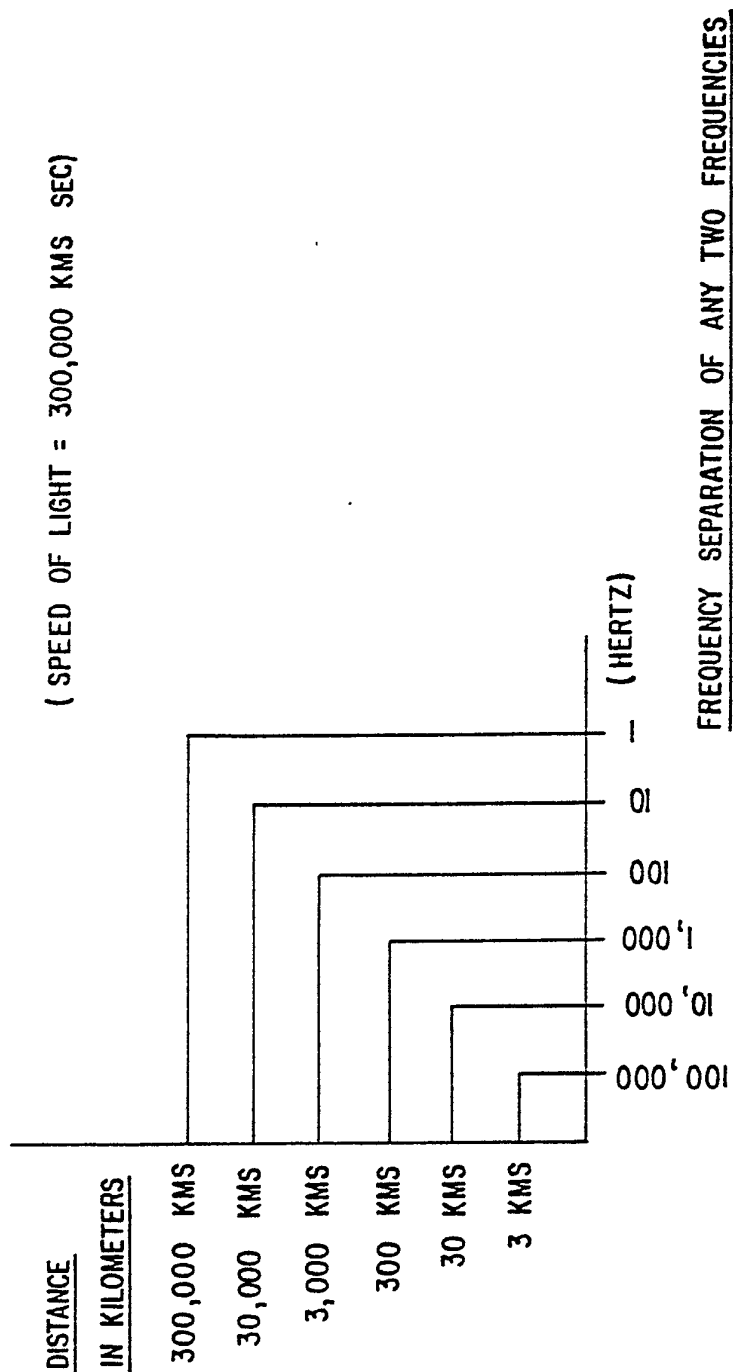


FIG. 3

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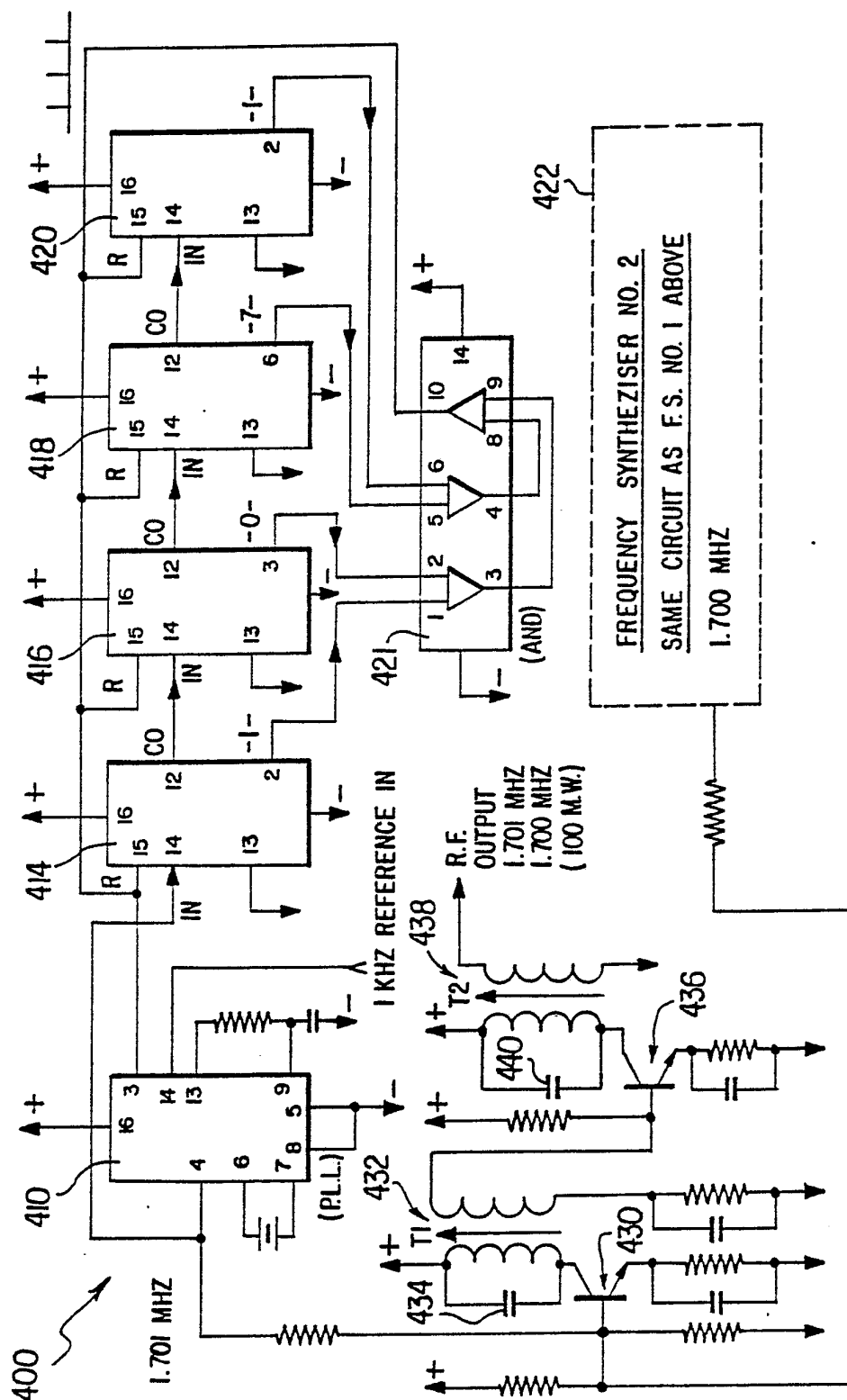


FIG. 4

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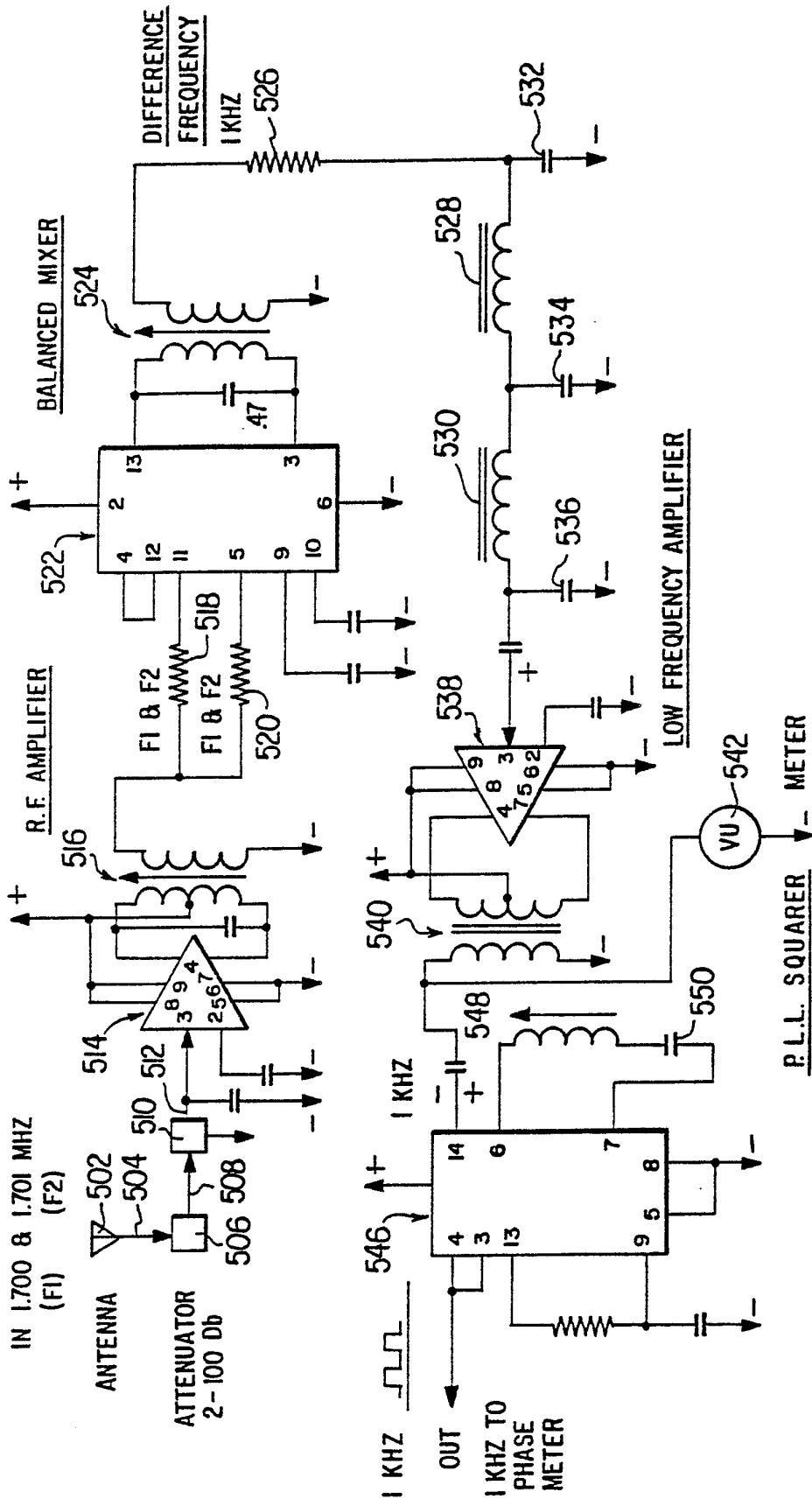


FIG. 5

SUBSTITUTE SHEET



INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 81/01058

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ³ According to International Patent Classification (IPC) or to both National Classification and IPC INT. CL. ³ G01S 5/06 U.S. CL. 343/112D																	
II. FIELDS SEARCHED Minimum Documentation Searched ⁴ <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 20%; border: 1px solid black; padding: 5px;">Classification System</th> <th style="border: 1px solid black; padding: 5px;">Classification Symbols</th> </tr> <tr> <td style="border: 1px solid black; text-align: center; padding: 10px;">U.S.</td> <td style="border: 1px solid black; text-align: center; padding: 10px;">343/112D</td> </tr> </table> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁵			Classification System	Classification Symbols	U.S.	343/112D											
Classification System	Classification Symbols																
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III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴ <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 10%; border: 1px solid black; padding: 5px;">Category ⁶</th> <th style="width: 60%; border: 1px solid black; padding: 5px;">Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷</th> <th style="width: 30%; border: 1px solid black; padding: 5px;">Relevant to Claim No. ¹⁸</th> </tr> <tr> <td style="border: 1px solid black; text-align: center; vertical-align: top; padding: 5px;">A</td> <td style="border: 1px solid black; vertical-align: top; padding: 5px;">US, A 2,947,985 PUBLISHED 02 AUGUST 1960 COOLEY</td> <td style="border: 1px solid black; text-align: center; vertical-align: top; padding: 5px;">1-45</td> </tr> <tr> <td style="border: 1px solid black; text-align: center; vertical-align: top; padding: 5px;">A</td> <td style="border: 1px solid black; vertical-align: top; padding: 5px;">US, A 3,366,957 PUBLISHED 30 JANUARY 1968 LODE</td> <td style="border: 1px solid black;"></td> </tr> <tr> <td style="border: 1px solid black; text-align: center; vertical-align: top; padding: 5px;">A</td> <td style="border: 1px solid black; vertical-align: top; padding: 5px;">US, A 3,696,427 PUBLISHED 03 OCTOBER 1972 NARD</td> <td style="border: 1px solid black;"></td> </tr> <tr> <td style="border: 1px solid black; text-align: center; vertical-align: top; padding: 5px;">A</td> <td style="border: 1px solid black; vertical-align: top; padding: 5px;">US A 3,755,816 PUBLISHED 28 AUGUST 1973 KRATZER</td> <td style="border: 1px solid black;"></td> </tr> </table>			Category ⁶	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸	A	US, A 2,947,985 PUBLISHED 02 AUGUST 1960 COOLEY	1-45	A	US, A 3,366,957 PUBLISHED 30 JANUARY 1968 LODE		A	US, A 3,696,427 PUBLISHED 03 OCTOBER 1972 NARD		A	US A 3,755,816 PUBLISHED 28 AUGUST 1973 KRATZER	
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A	US A 3,755,816 PUBLISHED 28 AUGUST 1973 KRATZER																
¹⁵ Special categories of cited documents: "A" document defining the general state of the art "E" earlier document but published on or after the international filing date "L" document cited for special reason other than those referred to in the other categories "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but on or after the priority date claimed "T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention "X" document of particular relevance																	
IV. CERTIFICATION <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border: 1px solid black; padding: 5px;"> Date of the Actual Completion of the International Search ² 26 OCTOBER 1981 </td> <td style="width: 50%; border: 1px solid black; padding: 5px;"> Date of Mailing of this International Search Report ² 04 NOV 1981 </td> </tr> <tr> <td style="border: 1px solid black; padding: 5px;"> International Searching Authority ¹ ISA/US </td> <td style="border: 1px solid black; padding: 5px;"> Signature of Authorized Officer ¹⁰ THEODORE H. TUBBESING </td> </tr> </table>			Date of the Actual Completion of the International Search ² 26 OCTOBER 1981	Date of Mailing of this International Search Report ² 04 NOV 1981	International Searching Authority ¹ ISA/US	Signature of Authorized Officer ¹⁰ THEODORE H. TUBBESING											
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