Feb. 21, 1967 M. F. BOLSTER ETAL 3,305,682

RANGING SYSTEM

Filed July 26, 1963 3 Sheets-Sheet 1

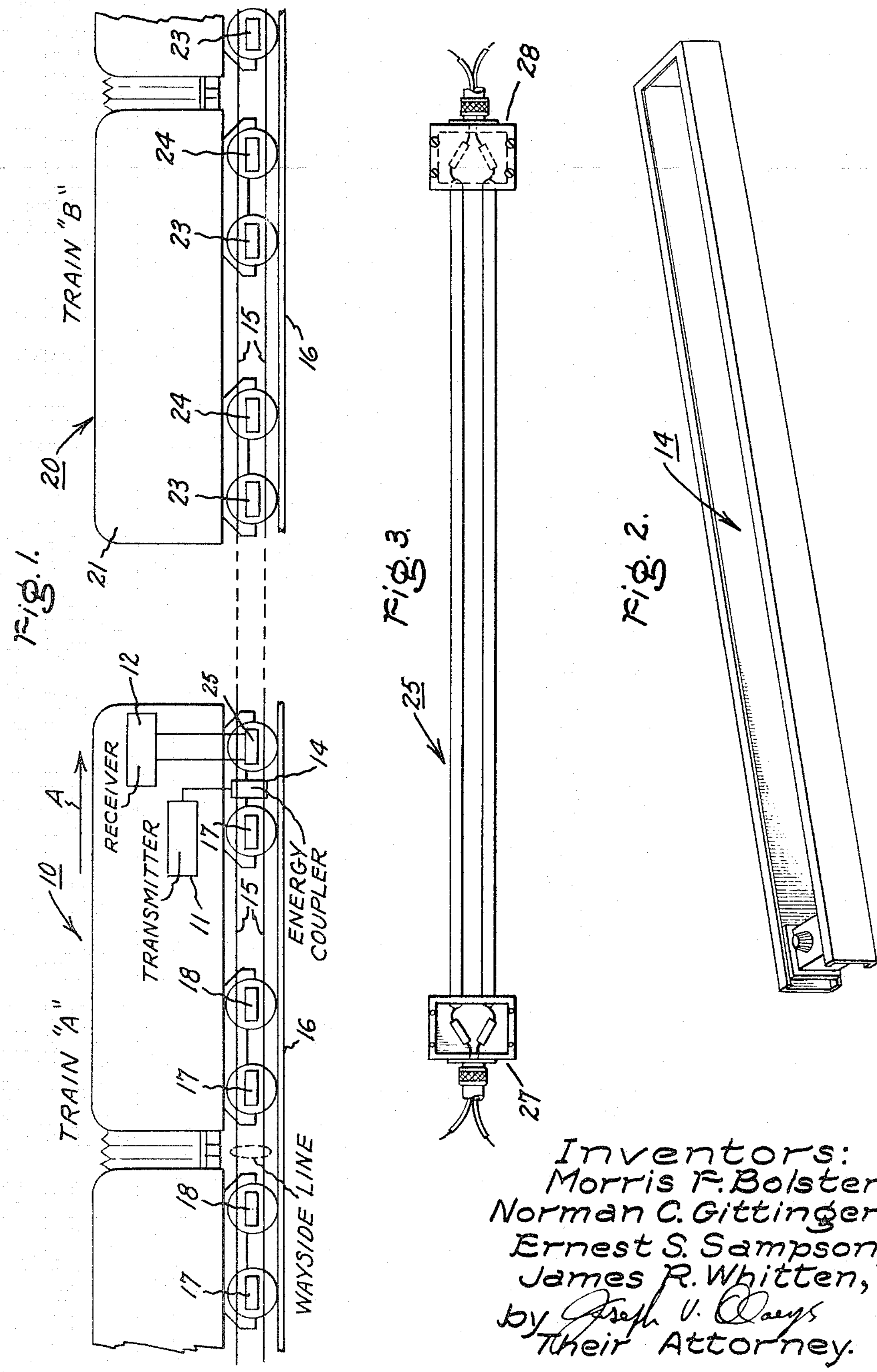

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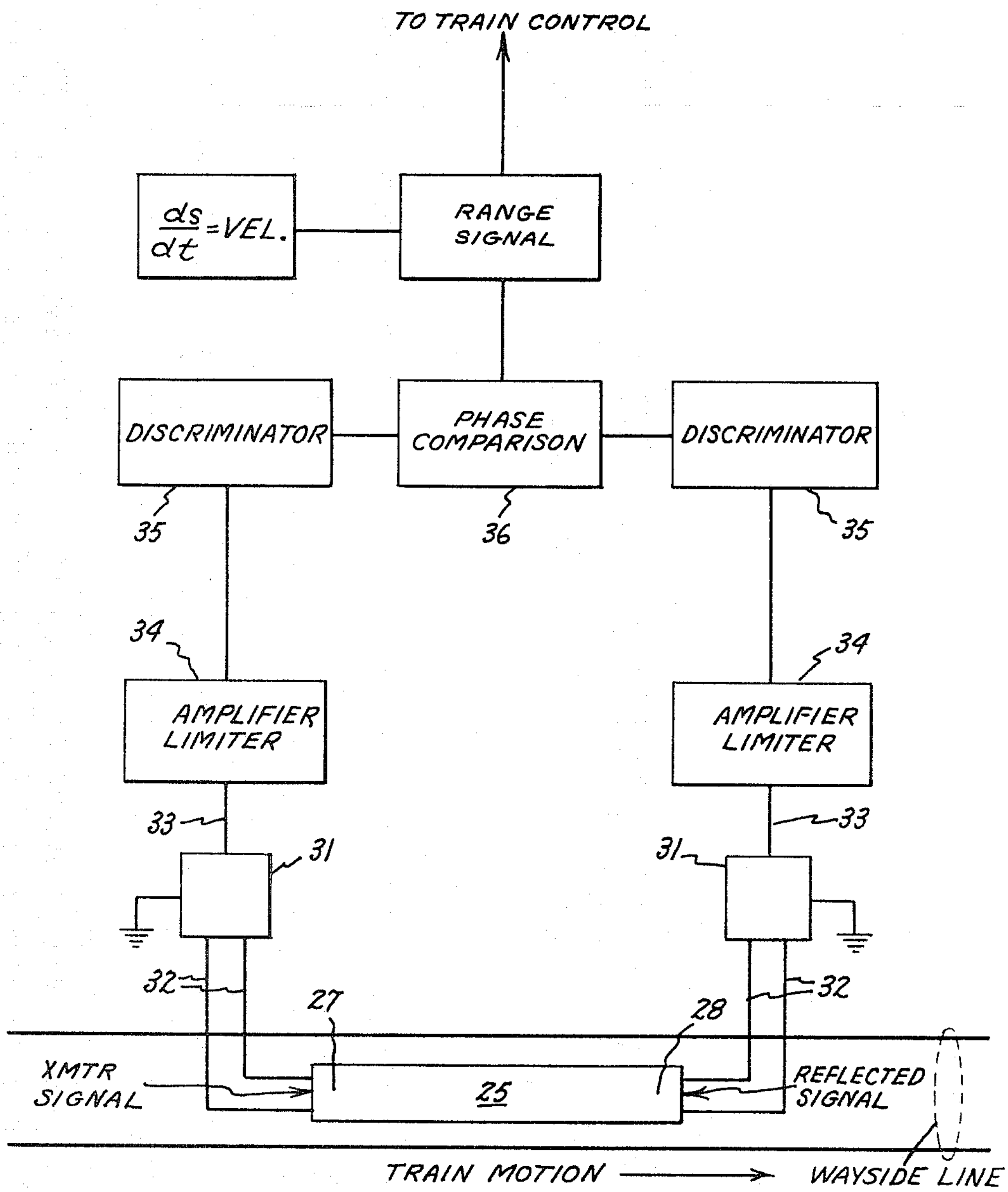
Fig. 4.



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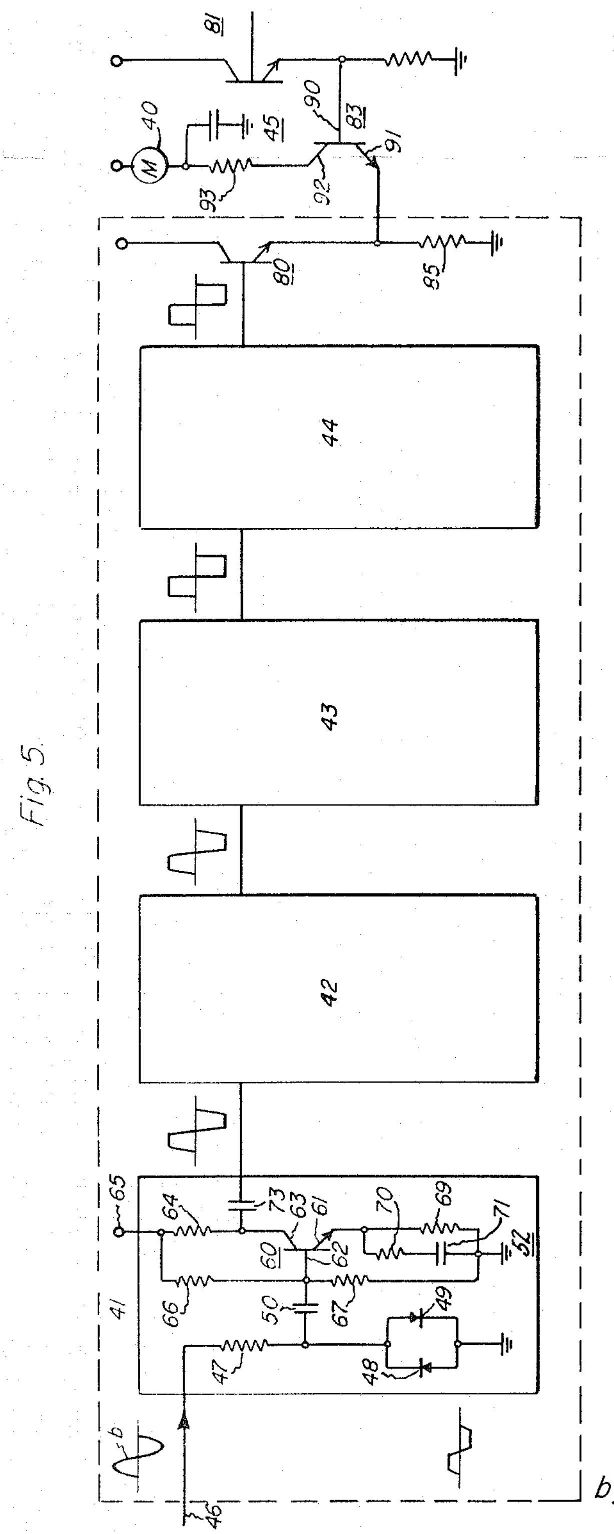

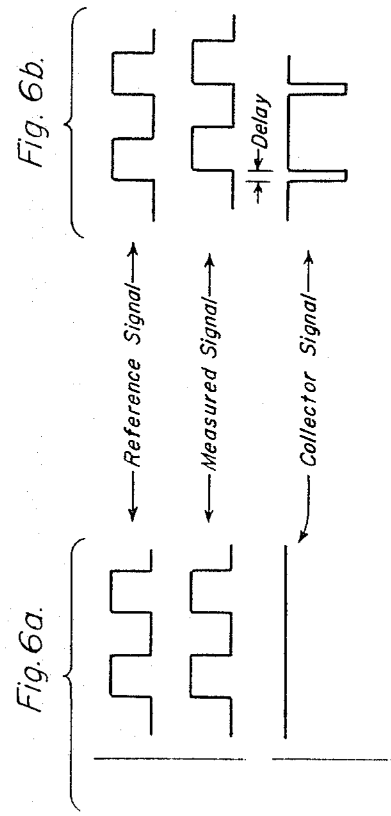

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RANGING SYSTEM

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This invention relates to a ranging system of the type utilizing guided electromagnetic energy, and more particularly to a new and improved system particularly adapted for measuring the distance between objects proceeding along a fixed route. While this invention has a wide range of applications it is especially suited for the continuous measurement of the distance between vehicles proceeding on or adjacent to a track or rail and will be particularly described in that connection.

The usual method widely employed for providing protection for vehicles, such as railway trains and the like, proceeding in the same direction on the same track has been the well known block system wherein a space interval is established between the train ahead and the train following. The most serious disadvantages of this type of protection system are the number and cost of blocks and associated equipment required to provide high traffic performance, cost of interblock wiring, and overall system inflexibility. Many attempts have been made in a prior art to provide vehicle traffic control or protection systems which would overcome at least some of the deficiencies of the block system. For example, attempts have been made to provide vehicle protection or traffic control systems employing radiation echo detection and ranging devices and the like. These systems, however, have not been entirely satisfactory particularly for transportation system involving the movement of people, due to their inability to insure absolutely safe and continuous distance measurements in the presence of ambient electrical interference, such as noise and the like, or leakage signals from other ranging vehicles elsewhere in the system both of which tended to produce inaccuracies in a distance measurement. Moreover, such prior art attempts could not provide systems which were capable of operation in a "fail safe" manner which is a requirement in a system involving the movement of people.

It is an object of this invention therefore to provide a new and improved ranging system which substantially overcomes one or more of the prior art disadvantages and is both more flexible and less expensive for use in association with high performance transportation systems than any system heretofore known.

It is another object of this invention to provide a new and improved ranging system for vehicles proceeding on, or adjacent to, the same track or rail and having a mode of operation which assures that any failure therein will be in a direction to produce a zero distance indication between vehicles thereby providing for "fail safe" operation.

It is a further object of this invention to provide a new and improved ranging system which provides true and continuous distance indications between vehicles proceeding on, or adjacent to the same track or rail and which is capable of very sharply distinguishing between true and spurious signals such as signals from other ranging vehicles.

It is a still further object of this invention to provide a new and improved guided electromagnetic energy ranging system employing transmitted and reflected wave comparison which provides for the automatic compensation for any differences or deficiences associated with the transmission line coupling means.

Briefly stated, in accordance with one aspect of this invention, a continuous carrier modulated wave is caused to be propagated in one direction only along a transmission line and arranged, as by a reflecting device associated with the transmission line at a location remote in the direction of propagation from the wave source, for causing the wave to be reflected toward the source. Means are provided for simultaneously and continuously extracting first and second signals from the transmitted and reflected wave energies respectively. Means are further provided for phase comparing the first and second signals to obtain a continuous signal representative of the distance between the signal extracting means and the wave reflecting means. This signal may then be employed in any desired utilization means.

In a more specific aspect of this invention, for example, the reflective element may be associated with a vehicle ahead and a signal extracting device and signal phase comparing means may be associated with the vehicle behind so that a continuous signal may be provided representative of the distance between the two vehicles at all times.

The novel features believed characteristic of this invention are set forth with particularity in the appended claims. Our invention itself however together with further objects and advantages thereof may best be understood by reference to the following description taking in conjunction with the accompanying drawing in which:

FIGURE 1 is a schematic diagram illustrating one embodiment of the system of this invention for providing a continuous measurement of the distance between two trains proceeding in the same direction along the same track.

FIGURE 2 is a diagrammatic illustration of a suitable inductive energy coupling means.

FIGURE 3 is a detailed illustration of the signal extracting means.

FIGURE 4 is a block diagram illustrating the signal extracting and phase comparing portion of the system and their relationship to the transmission line including the manner in which the transmitted and reflected wave signals are phase compared.

FIGURE 5 is a schematic circuit diagram of a novel phase comparison circuit in accordance with another aspect of this invention.

FIGURES 6*a* and 6*b* are waveforms useful in explaining URE 5.

In FIGURE 1 a train, generally designated at **10**, carries a transmitting means **11** and a receiving means **12**. Transmitting means **11** includes means for generating a continuous carrier signal and means for modulating the carrier to produce a continuous carrier modulated signal. The continuous carrier signal may be either amplitude, phase or frequency modulated. Since frequency modulation provides a system having a capability of more sharply discriminating between true and spurious signals as well as between true signals and noise, a frequency modulated transmitter means is preferred for use in the system of this invention. To this end, any suitable frequency modulated transmitter, preferably crystal controlled, may be utilized to produce the desired continuous carrier modulated signal.

An energy coupling device 14, shown in more detail in FIGURE 2 which is preferably an inductive coupling device, is carried by train 10 and arranged for coupling the continuous carrier modulated signal from transmitting means 11 to transmission line 15 which is disposed parallel with the track 16 on which train 10 runs. For example, the line 15 may be a parallel two conductor transmission line as illustrated or any other suitable transmission line for guiding the continuous carrier modulated wave. Preferably, transmission line 15 is placed on the wayside to avoid the adverse effects of dirt, snow, ice and other contaminents. Further line 15 may be constructed in either the vertical or horizontal plane or any other plane. The energy coupling device 14 carried by train 10 is then suitably positioned so as to move near the transmission line 15 but not be in contact therewith. Thus the continuous carrier modulated signal is coupled from transmitter means 11 to transmission line 15 in a well known manner. Although an inductive coupling device is preferred, a suitable capacitive coupling device of the type known in the art may also be employed.

An energy reflecting device 17 is associated with coupling device 14 and is also carried by train 10 so as to move with the train, near but not necessarily in contact with, transmission line 15. For example, if the transmission line is constructed in the horizontal plane the coupling and reflecting devices 14 and 17 respectively move with the train 10 so as to be positioned above the transmission line 15. Similarly, if the transmission line is constructed in the vertical plane the various devices carried by the trains would move so as to be positioned near the two parallel conductors. Preferably, the energy absorbing device 18 is similarly carried by train 10 so that energy not reflected by device 17 is absorbed in device 18 thereby more positively assuring propagation of the wave in transmission line 15 in one direction only. For example, in FIGURE 1 the direction of wave propagation is in the direction of train travel as shown by the arrow (A). To still more positively ensure that such propagation will be in only one direction we provide additional reflecting and absorbing devices. Conveniently, for a two car unit as shown in FIGURE 1 such additional reflecting and absorbing devices may be disposed at both the front and rear portions of the second car of the pair.

Preceding the train 10 in FIGURE 1 there is illustrated a similar train 20 only the second or rear car 21 of which has been shown. Train 20 is equipped in a manner similar to that described in detail with respect to train 10. Thus, the reflecting device 23 and absorbing device 24 on train 20 corresponds to the reflecting and absorbing devices 17 and 18 respectively, on the rear of the second car of train 10. The wave propagated from the coupling device 14 associated with transmitting means 11, therefore, is reflected back toward the source by the reflecting device 23 at the rear of train 20. More specifically, this transmitted wave is reflected back toward the source by the reflecting device 23 on the rear car of train 20. Again the additional reflecting and absorbing devices assure that the transmitted wave will be reflected and/or absorbed to such an extent that any spurious signal of appreciable magnitude is prevented from appearing on the transmission line 15 at any point ahead of the train 20. In addition to the absorbing devices 18 and 24, the energy coupling device 14 and reflecting device 17 also absorb energy thereby preventing multiple reflections of the wave on transmission line 15.

A signal extracting means 25 which may be a suitable transmission line directional coupler, the details of which are shown more specifically in FIGURE 3, is also carried by both the trains 10 and 20 respectively so as to move with the trains near but not necessarily in contact with transmission line 15. For example, a signal extracting means 25 is carried by trains 10 and 20 in the manner similar to the coupling, reflecting and absorbing devices 14, 17 and 18 and the related devices on the preceding vehicles.

In further accord with this invention, therefore, signal extracting means 25 provides means for automatically compensating for any differences or deficiencies in the coupling of the continuous carrier modulated signal to the transmission line 15 which might tend to give an inaccurate distance measurement between the trains 10 and 20. (In addition, due to the amount of leakage provided at signal extracting means 25, failure of the signal reflecting means of the preceding vehicle, for example, causes a signal to be extracted from the signal extracting means having the same phase as the transmitted wave so as to give an indication of zero distance thereby providing for "fail safe" type of operation.)

Signal extracting means 25 extracts continuously at the same location on the transmission line 15 a first and second signal associated respectively with the transmitted and reflected wave energies. To this end, signal extracting means 25 is arranged to simultaneously extract a first signal at the end of 27 thereof from the transmitted wave energy and a second signal at the end of 28 thereof from the reflected wave energy. These two signals are then compared in phase and a continuous signal is derived representative of the distance between the signal extracting means and the reflecting device 23 on the rear of the train 20.

Although in the foregoing description the reflecting and absorbing devices have been described as being disposed on a preceding vehicle, it will be understood that additional reflecting and absorbing devices may be provided at appropriate locations along the transmission line. For example, such devices may be provided at a station where it is desired to derive a distance signal continuously as the station is approached.

Although the theoretical electrical spacing between the energy coupling device 14 and the reflecting and absorbing devices 17, 18, 23 and 24, and so on should ideally be 0, ½, 1, 1½, etc. wavelength of the carrier signal, due to the distributed constants of the devices themselves, the spacings therebetween should generally be provided less than about ⅛ wavelength of the carrier signal. Although no particular spacing is required between the coupling means associated with transmitting means 11 and the signal extracting means 25 associated with the receiver 12, the coupling device 14 should ordinarily be placed sufficiently remote from the signal extracting means 25 so as to insure that there will be very little direct coupling between transmitter means 11 and the receiver means 12 which would destroy the protective effect and self compensating characteristics provided by the extraction of the first and second signals associated respectively with the transmitted and reflected wave energies from the same line location.

One convenient manner by which the two signals extracted from transmission line 15 by the signal extracting means 25 are phase compared to produce the signal representative of the distance between the trains 10 and 20 is shown in block diagram form in FIGURE 4. As shown, the signals extracted respectively from the ends 27 and 28 of signal extracting means 25 from the transmitted and reflected wave energies respectively are applied to a matching device 31 of any suitable type to provide conversion and matching from the line 32 to the unbalanced line 33. The signals are then applied to amplifiers and limiters 34, demodulated in discriminators 35 and the demodulated signals phase compared by the phase comparison means 36. The amplifiers and limiters 34 may be of any suitable type well known in the art as long as they are alike and stable in phase. Similarly, the discriminators 35 may be of any suitable type such as for example, a Foster-Seely type discriminator.

The phase comparison circuit may be any known type but is preferably a transistorized circuit such as that shown schematically in FIGURE 5.

The novel phase comparing means shown in FIGURE 5 provides a distance signal which is proportional to the phase difference between two fast rise time square waves. This is illustrated in FIGURES 6*a* and 6*b* wherein the two fast rise time square waves are identified as "reference signal" and "measured signal" respectively. Thus, in FIGURE 6*a* there is no phase difference between the two signals with the result that no output signal is produced from the phase comparison circuit thereby indicating a "zero" distance. In FIGURE 6*b*, on the other hand, there is a phase difference between the two signals, that is, there is a delay in the measured signal with respect to the reference signal, with the result that an output pulse is produced having a time duration which is equal to the phase difference between the reference and measured signals as illustrated. For simplicity this distance signal is schematically indicated by the meter **40** the indication of which represents the distance. Since the signals extracted by the signal extracting means **25**, however, are sine waves, means are provided for successively limiting and amplifying the demodulated first and second signals to derive therefrom the desired fast rise time square waves. To this end a number of limiter-amplifier stages indicated generally are **41**, **42**, **43** and **44** are provided for converting the signal extracted from the reflected energy in the transmission line to the desired fast rise time square wave to be applied to the phase comparing circuit **45**. Similar means (not shown) are provided for converting the signal extracted from the transmitted wave energy in the line **15** to the other, of reference, fast rise time square wave to be applied to the phase comparing circuit **45**.

The limiting and amplyfing stages **41**, **42**, **43** and **44** are similar in circuitry, function and mode of operation so that only the circuitry and operation of the limiter amplifier stage **41** will be described.

The signal from the reflected energy end **28** of signal extracting means **25** is demodulated and applied to the input terminal **46** of the limiter-amplifier stage **41**. This is shown as the sine wave indicated by the reference letter (*b*). Clipping may be provided by a conventional clipping circuit arrangement including the resistance **47** and the back-to-back diodes **48** and **49**. Preferably to assure that diodes **48** and **49** are carefully matched with respect to the clipping voltage and the temperature and maintained at the same temperature so that the resulting roughly square wave will have the same zero crossings as the original sine wave input signal, a matched diode pair, such as GE–MP2, manufactured and sold by the General Electric Company may be employed. This clipped signal is then coupled by capacitance **50** to the linear amplifier section designated generally at **52**, to increase the amplitude of the roughly square wave input signal to a high value (usually in the range of about 20 to 30 volts r.m.s.). In this way the rise time of the resulting square wave can be made short.

The linear amplifier section **52** includes a transistor **60** having an emitter electrode **61**, a base electrode **62** and a collector electrode **63**. Suitable supply voltage is provided for collector **63** through a suitable resistance **64** from a voltage source (not shown) to which the terminal **65** may be connected. Bias resistors **66** and **67** are connected respectively from the base electrode **62** to collector electrode **63** and from base electrode **62** to ground potential. The emitter electrode **61** is connected to ground potential through a suitable bias resistance **69**. A resistance **70** and capacitance **71** in series combination shunts resistance **69** to set the gain at a desired value.

The output and the linear amplifier section **52** is coupled through a suitable capacitance **73** to the next limiter-amplifier stage **42**. The output of limiter-amplifier stage **42** being similarly coupled to stage **43** whose output is coupled to the stage **44** to provide a final fast rise time square wave for application to the phase comparing means **45**.

As described in the foregoing, therefore, the first squaring circuit is followed by a linear A.C. coupled transistor amplifier to raise the waveform to a very high voltage. To accomplish this, high collector supply voltage is supplied to the transistor **60**. As long as the amplifier stage is linear, temperature variation will affect the gain thereof but will not affect the zero crossings.

The phase comparing circuit **45** provides a reading on the meter **40** which is proportional to the phase difference between the two fast rise time square waves applied to it. Since the two square waves have been derived from the demodulated first and second signals extracted by signal extracting means **25** from the transmitted and reflected wave energy respectively, the indication on meter **40** represents the distance between the signal extracting means **25** and its nearest reflecting device **23**.

The two square waves are applied to two transistor emitter-follower circuits designated generally at **80** and **81**. Emitter follower circuits **80** and **81** are both biased so that the negative half cycle of the output wave is at zero potential with respect to ground. To reduce reaction from the phase comparing transistor **83**, the emitter-follower circuits **80** and **81** are arranged to feed a low load resistance **85**.

The emitter-follower **81** associated with the demodulated signal from the transmitted wave energy is direct current coupled to the base electrode **90** of the phase comparing transistor **83** and the demodulated signal associated with the reflected wave energy is connected to the emitter electrode **91** thereof. The collector **92** is connected to a stable source in voltage (not shown) through a current limiting resistance **93**. The meter **40** indicates the average collector current in transistor **83** and hence indicates the distance signal.

As will be understood by those skilled in the art this distance signal may be suitably differentiated to provide a velocity signal which may also be indicated on a meter or applied to some other utilization means.

In operation, the comparator transistor **83** does not conduct unless the base electrode **90** is positive with respect to the emitter electrode **91**. This should be set at about 0.8 volt for example. If both square waves are in phase this will never occur.

If the measured signal is delayed in phase from the reference signal, the base electrode **90** of the transistor **83** will go positive before the emitter electrode **91** thereof. The square wave input amplitude applied to the base is sufficient to turn the transistor **83** completely on, therefore, the collector voltage will drop to a fixed low value at the instant the base electrode **90** goes positive.

When the emitter electrode **91** goes positive a short time later, the transistor **83** will stop conducting. The collector signal, therefore, will be a negative pulse with length equal to the time delay of the measured signal with respect to the reference signal. As the amplitude of this pulse is constant regardless of its length, the average collector current is proportional to the time delay in a linear manner. The meter **40** may be inserted here to measure phase delay from nearly zero (limited by rise time of square waves) to 180°.

To assure positive fail safe operation of the ranging system of this invention the leakage of signal from one end to the other of signal extracting means **25** should be at least 10 db lower than the lowest reflected signal. In this way for example, failure of the reflecting means resulting in no reflected signal at the signal extracting means **25** will assure a signal from the transmitter wave energy at both ends thereof. Since these signals are in phase the derived range signal will be zero and the system "fail safe."

Preferably, to achieve many practical advantages with respect to transmission line, bandwidth considerations, less criticality in spacing between coupling, reflecting, absorbing and signal extracting means and the transmission line and many others, the carrier signal should be in the range of about 1 to 200 megacycles. For best practical and operative considerations for use with railway systems we prefer a range of about 20 to 100 megacycles.

To more positively and completely insure against the interference from separate vehicles on a common route, the different vehicles may each be assigned a different modulation frequency. In this way added isolation is provided between separate ranging equipments.

Although the system has been described with respect to the transmitter means disposed on the vehicles it will be understood that for some applications it may be desirable to locate the transmitter means at a fixed point on the transmission line and propagate a wave unidirectionally towards a vehicle located or proceeding between a signal reflecting means and the transmitter means. In such an application a range indication will be provided in the vehicle of the range between the vehicle and the signal reflecting means.

Having shown a preferred embodiment of a new ranging system for measuring distance between objects proceeding along a fixed route in accordance with the present invention, it is believed obvious that other modifications and variations of the invention are possible in the light of the above teachings. It is, therefore, to be understood that changes may be made in the particular embodiments of the invention described which are within the full intended scope of the invention as defined by the appended claims.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A ranging system comprising: A transmission line; means for generating a continuous carrier signal; means for modulating said carrier to produce a continuous carrier modulated signal; energy coupling means disposed proximate said transmission line and at a first location thereof for coupling said continuous carrier modulated signal to said transmission line; means including an energy absorbing device proximate said transmission line for assuring propagation of wave energy therein in one direction only; energy reflecting means remote in the direction of wave propagation from said energy coupling means and disposed near said transmission line for reflecting said wave energy toward said source thereof; and at a location thereof means near said transmission line and at a location thereof intermediate said energy coupling and energy reflecting means and spaced from said energy coupling means a distance sufficient to avoid any appreciable direct coupling from said energy coupling means for simultaneously extracting a first signal from the transmitted wave energy in said transmission line and a second signal from the reflected wave energy in said transmission line; and means for phase comparing said first and second signals so extracted to provide a range signal.

2. The ranging system of claim 1 wherein said coupling means and said reflecting means are of the inductive type.

3. The ranging system of claim 1 wherein said continuous carrier is frequency modulated.

4. A ranging system comprising: a transmission line; means for generating a continuous carrier having a frequency in the range of about 20 to 100 megacycles; means for modulating said continuous carrier to produce a continuous carrier modulated signal; inductive energy coupling means arranged to be disposed near said transmission line and at a first location thereof for coupling said continuous carrier modulated signal to said transmission line; means arranged to provide inductively an open circuit on said line operative to cause propagation of a wave therein in one direction only, said means including energy reflecting and energy absorbing means in spaced-apart operative association which means are displaced from said energy coupling means in the direction opposite the direction of propagation of said wave energy; a second energy reflecting means disposed near said transmission line remote in the direction of wave propagation from said energy coupling means for causing said wave to be reflected towards the source thereof; signal extracting means disposed near said transmission line and at a location thereof intermediate said energy coupling means and said second energy reflecting means and spaced from said energy coupling means a distance sufficient to avoid any appreciable direct coupling from said energy coupling means for simultaneously extracting a first signal from said transmitted wave energy in said transmission line and a second signal from said reflected wave energy in said transmission line; and means for phase comparing said first and second signals to produce an output signal proportional to the phase difference therebetween, said output signal being representative of the distance between said signal extracting means and said second energy reflecting means remote therefrom.

5. A system for continuously measuring the distance from one vehicle to another vehicle ahead and on the same pathway comprising: a transmission line disposed parallel with said pathway; means carried by said vehicle for generating a continuous carrier signal; means for modulating said carrier to produce a continuous carrier modulated signal; energy coupling means carried by said vehicle for coupling said continuous carrier modulated signal to said transmission line; means including an energy absorbing device carried by said vehicle to the rear of said energy coupling means for assuring propagation of wave energy in said transmission line in one direction only; wave energy reflecting means carried by said vehicle ahead and disposed near said transmission line for reflecting said wave energy toward said source; signal extracting means carried by said following vehicle at a sufficient distance forward of said energy coupling means to avoid any appreciable direct coupling between said energy coupling means and said signal extracting means for simultaneously extracting a first signal from the transmitted wave energy in said transmission line and a second signal from the reflected wave energy in said transmission line; and means for phase comparing said first and second signals to derive a signal representative of the distance between said signal extracting means and said wave energy reflecting means.

6. A system for producing a continuous measurement of the distance from one vehicle to another vehicle ahead and on the same pathway comprising: a transmission line disposed parallel with said pathway; means for generating a continuous carrier signal; means for modulating said carrier to produce a continuous carrier modulated signal; energy coupling means at a first location for coupling said continuous carrier modulated signal to said transmission line; at least one energy reflecting means associated with said transmission line and carried by the vehicle ahead for reflecting the wave produced in said line by said continuous carrier modulated signal toward said source; at least one wave energy absorbing means also carried by said vehicle and disposed near said transmission line for absorbing non-reflected wave energy; signal extracting means at a location intermediate said signal coupling means and said energy reflecting means for simultaneously extracting from said transmission line a first signal from the transmitted wave energy and a second signal from the reflected wave energy therein, said signal extracting means having a definite amount of signal leakage between the first signal extracting end and the second signal extracting end thereof but which signal leakage is at least 10 db lower than the lowest reflected signal; and means for comparing said first and second signals to produce a signal representative of the distance from said signal extracting means to said reflecting means.

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