

PATENT SPECIFICATION

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(54) SECONDARY RADAR FOR VEHICLES

(71) We, KARL VOCKENHUBER, of 118 Potzleinsdorferstrasse, Vienna 18, Austria, and RAIMUND HAUSER, of 2 Goldeggasse, Vienna 4, Austria, both of Austrian Nationality, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described, in and by the following statement:—

The invention relates to secondary radar for measurement of distance, in particular spacing or intervals between vehicles in transport systems, "Radar" herein comprises the use of optical and infra-red radiation as well as the more usual microwaves.

Conventional secondary radar systems (see Skolnik, M.I. (ed.): Radar Handbook, Chapter 38: Beacons. McGraw Hill Company, New York, 1970) operate with electromagnetic waves in the microwave region, using a "primary" station (consisting of interrogating transmitter and receiver) which is usually fixed, and a secondary station or transponder consisting of receiver and reply transmitter which is usually carried on board an aircraft, ship and so forth.

Pulses of electromagnetic waves of a fixed wavelength are radiated by the interrogating transmitter of the primary station. When they reach the transponder receiver, they release a reply signal, which usually consists of a definite sequence or train of short transmitted pulses of electromagnetic waves, the wavelength of which differs from that of the original interrogating signals. Owing to the different wavelengths of the interrogating and reply signals ("secondary echo"), the latter can readily be distinguished in the receiver of the primary station from "primary echoes", which have their origin in reflections of the interrogating signal. The target object can moreover be accurately identified from the number and the time sequence of the reply pulses ("reply code") and additional data for example relating to the flying height of

the target object equipped with the transponder can also be transmitted. The known method functions quite satisfactorily for the said purposes or transport system.

Novel types of transport system which are now in the course of development, such as, say those using magnetic levitation tracks, are intended to be controlled fully automatically, i.e. without operating personnel. For this purpose a distance measuring device is necessary, which will prevent vehicles (trains, coaches) running into one another. In the interests of safety and reliability, it is necessary to provide several distance measuring systems which are as different from one another as possible, at the same time. In particular, it is often desirable to know not only the distance to the preceding vehicle but also that to the following vehicle, and this invention seeks to achieve this object in a convenient manner.

According to the present invention there is provided a secondary radar system comprising a first station and a second station each including an energy pulse transmitter and a receiver responsive to pulses transmitted by the other station, the second station being arranged to transmit a response pulse after a predetermined delay following receipt of an interrogation pulse from the first station, wherein the first station is operative to vary the pulse repetition frequency of transmitted interrogation pulses in dependence upon the travel time of the energy between the first and the second stations whereby the frequency of interrogation is representative of the distance between the stations, and wherein both the first and the second station include means for indicating the frequency of interrogation.

The invention will now be described further, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a block diagram of a secondary radar system according to the invention;
 Figure 2 shows a modified system;

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Figure 3 depicts signals arising in the system;

Figure 4 shows a detail of a further embodiment; and

Figures 5 to 7 illustrate the application of the invention to a rail borne transport system.

Figure 1 shows a primary station 1 and a secondary station or transponder 2. The primary station includes a clock pulse generator TIG, which may for example be an astable multivibrator, generating low-frequency clock pulses TI of for example 100 Hz. These clock pulses TI pass via a switch TW to a transmitting pulse generator SIG, which generates the requisite current pulses SIE for triggering a laser diode LD. The laser LD then emits short infra-red light interrogation pulses SIO (Figure 3a) through a transmitting optical system SO. The current pulses SIE synchronized with the light pulses SIO also serve to trigger a delay circuit VZG which after a predetermined delay time τ causes a window pulse generator ZFG to emit a window pulse ZF prism (Figure 3b). Signals received by the primary station can only be processed during the duration of the window pulse ZF after expiration of the interval τ from the release of the transmitted pulse.

On reception of an interrogation pulse, the secondary station produces a signal EIO, sec (Figure 3c) transponder 2 transmits a secondary pulse delayed by τ relative to the received pulse, and therefore delayed by (R/c) relative to the beginning of the window pulse, where R is the distance between the stations and c is the velocity of light.

The primary station 1 also includes a receiving optical system EO, which concentrates any incoming optical systems EIO onto a photodiode FD. The incoming optical signals EIO, prism (Figure 3f) may be reflections of the signals SIO prism (Figure 3a) transmitted from the primary station 1 or may be signals transmitted from the secondary station 2. The signal output EIE of the photodiode FD is converted by a receiver amplifier EV into a symmetrical double pulse which is limited and amplified. The details of this procedure are known and are described in the journal "NTZ" 26 (1973), Volume 9, pages 435 to 440. The as yet incompletely limited output signal of the receiving amplifier EV is passed in known manner to a trigger TR for signal identification. If the amplitude of the signal from the receiver amplifier EV exceeds the preset threshold value of the trigger TR, said signal actuates a zero-crossover trigger NGT which thereby fixes the instant when the middle flank of the fully limited output signal from the receiver amplifier crosses

the zero axis. The two trigger circuits TR and NGT are enabled by the delayed window pulse ZF prism so that incoming signals derived from reflections of the signal transmitted by the primary station 1 cannot be processed. The delay τ is chosen that even in the most extreme case reflected radiation will be received before the window pulse ZF prism.

The output signals of the receiver amplifier EV are also fed to a control circuit ER, in which a control voltage proportional to the amplitude of the received signal is generated, which as shown in Figure 1 actuates the pulse transmitter generator SIG so as to adjust the transmitter power depending on the amplitude of the secondary pulses received. Alternatively or in addition, as shown in Figure 2, said control voltage actuates a mechanical diaphragm inserted in front of the photodiode FD for coarse control of the amplitude of the incoming electrical pulse EIE, so as to avoid overloading of the receiver amplifier EV. This adjustment procedure also is only possible during the delayed window pulse ZF prism, in order that the amplitudes of reflections of the transmitted signals should have no effect on the sensitivity of the system. The control arrangements shown in Figure 1 are adapted to achieve the same purpose, since if the primary station 1 and the transponder 2 are of similar design, an incoming signal of excessive amplitude must lead to the conclusion that the amplitude of the transmitted signal is also excessive.

The trigger NGT is actuated on the one hand by the trigger signal TR and on the other hand by the window pulse ZF prism. A gating pulse TOI (Figure 3g) then appears at the output of the trigger NGT, the width of which pulse is proportional to the time of travel of the optical primary signal transmitted from primary station 1 to secondary station 2 plus the time of travel of the optical secondary signal transmitted from secondary station 2 to primary station 1, i.e. to $2 R/c$. This pulse width can be evaluated by known electronic means, for example it may be done in analog mode by means of a distance or range calculator ERA. The output signal from this subassembly constitutes the desired analog measurement AM of the distance between the primary station and the secondary station.

A voltage-controlled oscillator VCO, the pulse frequency of which is adjusted so as to be proportional to the distance measurement, may be used for example to transmit this measurement to the site of the transponder 2. This pulse frequency is now applied by the switch TW instead of the signals from the clock pulse generator TIG

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to trigger the transmitter SIG and the laser diode LD, so long as signals are produced by the trigger circuit TR to indicate the proximity of a secondary station. The clock pulse generator TIG is simultaneously put out of operation by a pulse locking circuit TSG. The pulses of the oscillator VCO have a considerably higher frequency than those of the clock pulses TI, for example a few thousand Hz.

The distance representative frequency at the output of the oscillator VCO should be high so that an excessive time is not required to relay the distance information from the primary station to the secondary station. On the other hand, a high frequency of interrogation of this kind is only necessary when a transponder lies within the range of the primary station. Consequently, in the interests of a long working life of the primary transmitter elements, the pulse generator TIG of low repetition frequency is normally used for periodically triggering the interrogation transmitter, and only in the proximity of a transponder is a switch made to the higher frequency of oscillator VCO.

In the block circuit diagram of the secondary station or transponder 2 parts having substantially similar functions are designated with the same reference letters as in the primary station 1. Since, as will be apparent, the receiving circuitry of the secondary station 2 with its receiving optical system EO, the photodiode FD, the receiver amplifier EV, the receiver control ER, the signal identification or recognition trigger TR and the trigger circuit NGT is constructed in a substantially similar manner to that of the primary station 1, it will not be described in detail. The timing of the output pulse of the trigger circuit NGT coincides with that of an optical incoming pulse EIO; it is then delayed by a delay circuit VZG by the predetermined time lag τ and then via the transmitting pulse generator SIG, and triggers the laser diode LD of the secondary transmitter, which emits short intra-red light pulses by way of a transmitting optical system SO. The predetermined delay time τ of the delay circuit VZG of the secondary station 2 agrees exactly with that of the primary station 1.

The signals transmitted from the secondary station arrive at the receiver of the primary station 1 and are there further processed in the manner described. In some circumstances they may be reflected back to the receiver of the secondary station 2. In order that these interfering reflected signals should not give rise to a further secondary transmitted pulse, the triggers TR and NGT are blocked for a sufficiently long period after the release of a secondary transmitted signal or after reception of the incoming

interrogating signal; these triggers are enabled by means of the window pulse ZF sec (Figure 3d) coming from the window pulse generator ZFG of the secondary station.

If the measured distance determined in the primary station 1 is transmitted to the secondary station by linear alteration of the pulse frequency of the primary station, the analog version of the distance measurement can be arrived at simply by integration of the window pulses ZF by means of an integrator INT at the secondary station.

Figure 2 shows a station which may be used as a primary or a secondary station, a mode switch having five ganged sections being provided to change from primary to secondary station on switching over to the switch terminals I (as shown) the apparatus can be operated as a primary station, and on switching to terminals II it operates as a transponder. This changeover facility is especially easy to bring about because in practice the primary and secondary stations are scarcely distinguishable. The essential difference consists in the connection of the integrator INT when the apparatus is used in its secondary function.

Figure 4 illustrates the possibility of varying the frequency of the interrogation pulses by means of a feedback circuit in the primary station which causes a fresh interrogation pulse to be transmitted after each receipt of a response pulse. The drawing merely shows the clock pulse generator TIG, the switch TW, the pulse blocking unit TSG, and the two triggers TR and NGT. The width of the gating pulse TOI of the trigger NGT is in this case advantageously amplified by a pulse duration amplifier IDV in the feedback circuit, in order thereafter to be counted digitally at a low pulse frequency, which offers advantages as regards recognizability at the receiver end. The pulse duration amplifier IDV is not absolutely essential and the trailing edge of the gating pulse itself may be utilized to trigger the primary transmitter. In practice, however, this is only possible when the laser diodes used can handle the resulting high pulse frequency of, for example 1 MHz without damage.

The width and concomitantly therewith the timing of the trailing edge of the gating pulse TOI is directly linearly proportional to the distance between the primary and secondary transmitters. Consequently, the timing of the trailing edge of the amplifier gating pulse TOV is also proportional to the measured distance, the proportionality factor being equal to the multiplication factor of the amplification of the pulse duration. If therefore the trailing edge of the amplified gating pulse TOV is used for example via the pulse switch TW to trigger

the primary transmitter, the period of the pulse frequency of the primary transmitter pulse is representative of the distance measurement. This may therefore be evaluated at the site of the secondary installation for example, simply by analog integration of the window pulses by means of the integrator INT. In this case also a pulse blocking generator TSG is provided in the primary transmitter to cut out the clock pulse generator TIG.

Figure 5 is a diagrammatic plan view of a rail transport system. Two vehicles 3, 4 travel along a track 5 containing a curve 6. At the front of each vehicle there is a primary transmitter 1 whilst a transponder 2 is mounted at the rear of each of the two vehicles. In the region of the curve 6 of the track 5 there is a reflecting surface 7, by means of which the energy radiated from primary transmitter 1 can be transmitted to the secondary apparatus 2 through the curve region.

The design of the reflecting surface 7 may for example be such that if a current collecting rail 8 is present, from which the vehicle 3 obtains its driving current (Figure 6), the primary apparatus may be mounted in the region of this rail, so that the latter itself serves as a reflector. This is of particular advantage when using an optical transmitting system, because the rail can be relatively easily prevented from getting dirty. When using an ordinary radar installation on the other hand, the presence of dirt is in any case of minor importance.

In Figure 6, the rail 8 is of substantially U-shaped cross section. In such a case, however, the influence of the vehicle 3 on the alignment of the primary apparatus 1 can easily lead to mal-adjustment of the direction of the transmitted beam. It is therefore more advantageous to design the rail with a flat open box profile, as is shown in Figure 7. In such case, the rail 8a has a lateral slit 9, through which guide pins 10 project into the interior of the rail. The guide pins 10 are fast on a lever 11 mounted on the vehicle chassis, which is loaded by a tension spring 12. The slit 9 is wide enough to allow the guide pins 10 to move therethrough with adequate clearance. The guide pins 10 also transmit the tension of the spring 12 to a travelling trolley 13, on the leading edge of which is mounted the primary apparatus 1. The fact that the trolley 13 with its rollers 14 is continually urged against the rail 8a always ensures accurate alignment of the primary apparatus 1. Larger apertures are arranged at intervals in the rail 8a, which enable the trolley 13 to be introduced into the interior of the rail.

WHAT WE CLAIM IS:—

1. A secondary radar system comprising a

first station and a second station each including an energy pulse transmitter and a receiver responsive to pulses transmitted by the other station, the second station being arranged to transmit a response pulse after a predetermined delay following receipt of an interrogation pulse from the first station wherein the first station is operative to vary the pulse repetition frequency of transmitted interrogation pulses in dependence upon the travel time of the energy between the first and the second stations whereby the frequency of interrogation is representative of the distance between the stations, and wherein both the first and the second station include means for indicating the frequency of interrogation.

2. A secondary radar system as claimed in Claim 1 in which in the absence of detection of response pulses from the second station, the first station is operative to transmit interrogation pulses at a predetermined pulse repetition frequency.

3. A secondary radar system as claimed in Claim 2 in which means are provided for measuring the travel time of pulses between the two stations and a voltage controlled oscillator controlled in dependence upon the measured duration and connected to the energy pulse transmitter by way of a switch which is further connected to a clock generated of fixed frequency, whereby the frequency of interrogation is determined by the voltage controlled oscillator or by the clock generator in dependence upon detection of response pulses.

4. A secondary radar system as claimed in Claim 3 wherein the frequency of the clock generator is substantially lower than the mean frequency of the voltage controlled oscillator.

5. A secondary radar system as claimed in Claim 1, wherein the first station includes a feed-back circuit from the receiver to the pulse transmitter such that an interrogation energy pulse is re-transmitted after a time following receipt of a response pulse determined by the travel time of energy between the first and second stations, whereby the frequency of interrogation varies with the distance between the two stations.

6. A second radar system as claimed in Claim 5, wherein the said feed-back circuit includes a pulse duration amplifier for amplifying a pulse having the same duration as the travel time of energy between stations.

7. A secondary radar system as claimed in any preceding claim, wherein the transmitted energy is infra-red light.

8. A secondary radar system as claimed in any preceding claim, comprising a plurality of stations each provided with a mode switch by means of which each may be

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the primary transmitter, the period of the pulse frequency of the primary transmitter pulse is representative of the distance measurement. This may therefore be evaluated at the site of the secondary installation for example, simply by analog integration of the window pulses by means of the integrator INT. In this case also a pulse blocking generator TSG is provided in the primary transmitter to cut out the clock pulse generator TIG.

Figure 5 is a diagrammatic plan view of a rail transport system. Two vehicles 3, 4 travel along a track 5 containing a curve 6. At the front of each vehicle there is a primary transmitter 1 whilst a transponder 2 is mounted at the rear of each of the two vehicles. In the region of the curve 6 of the track 5 there is a reflecting surface 7, by means of which the energy radiated from primary transmitter 1 can be transmitted to the secondary apparatus 2 through the curve region.

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first station and a second station each including an energy pulse transmitter and a receiver responsive to pulses transmitted by the other station, the second station being arranged to transmit a response pulse after a predetermined delay following receipt of an interrogation pulse from the first station wherein the first station is operative to vary the pulse repetition frequency of transmitted interrogation pulses in dependence upon the travel time of the energy between the first and the second stations whereby the frequency of interrogation is representative of the distance between the stations, and wherein both the first and the second station include means for indicating the frequency of interrogation.

2. A secondary radar system as claimed in Claim 1 in which in the absence of detection of response pulses from the second station, the first station is operative to transmit interrogation pulses at a predetermined pulse repetition frequency.

3. A secondary radar system as claimed in Claim 2 in which means are provided for measuring the travel time of pulses between the two stations and a voltage controlled oscillator controlled in dependence upon the measured duration and connected to the energy pulse transmitter by way of a switch which is further connected to a clock generated of fixed frequency, whereby the frequency of interrogation is determined by the voltage controlled oscillator or by the clock generator in dependence upon detection of response pulses.

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5. A secondary radar system as claimed in Claim 1, wherein the first station includes a feed-back circuit from the receiver to the pulse transmitter such that an interrogation energy pulse is re-transmitted after a time following receipt of a response pulse determined by the travel time of energy between the first and second stations, whereby the frequency of interrogation varies with the distance between the two stations.

6. A second radar system as claimed in Claim 5, wherein the said feed-back circuit includes a pulse duration amplifier for amplifying a pulse having the same duration as the travel time of energy between stations.

7. A secondary radar system as claimed in any preceding claim, wherein the transmitted energy is infra-red light.

8. A secondary radar system as claimed in any preceding claim, comprising a plurality of stations each provided with a mode switch by means of which each may be

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selected to operate as said first or said second station.

reference to any of the embodiments illustrated in the accompanying drawings.

9. A secondary radar system constructed, arranged and adapted to operate substantially as hereinbefore described with

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