Oct. 29, 1968 JEAN-CLAUDE SIMON ET AL 3,408,646

SYSTEM FOR LOCALIZING TRAINS ALONG A TRACK

Filed May 9, 1967 4 Sheets-Sheet 1

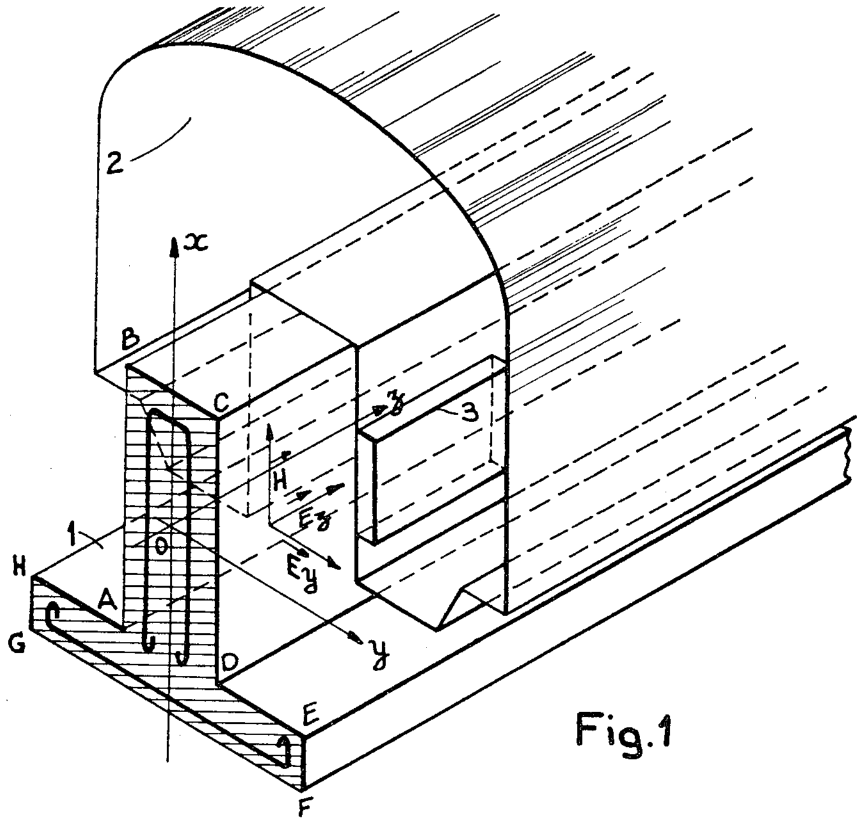


Fig. 1

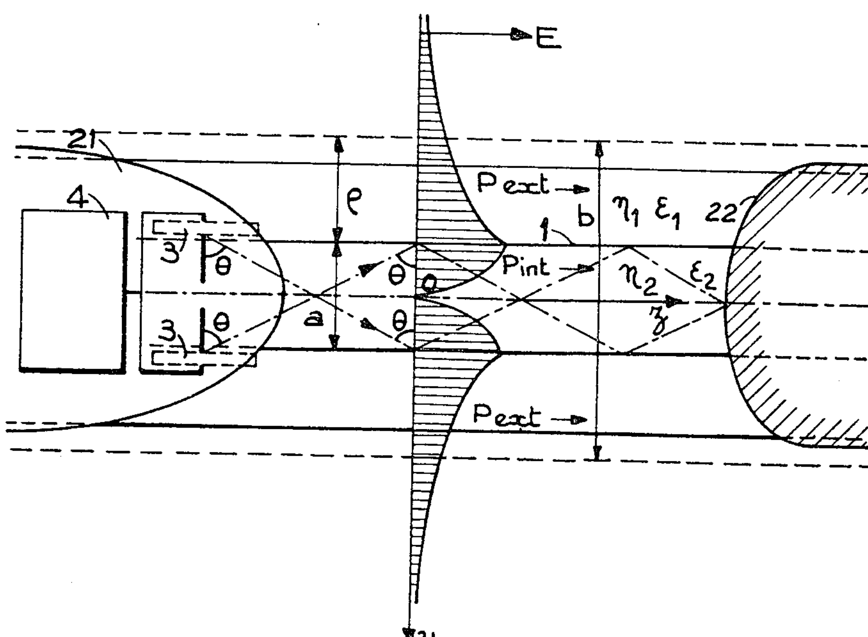
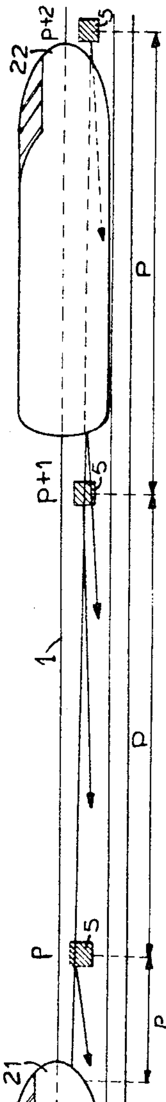
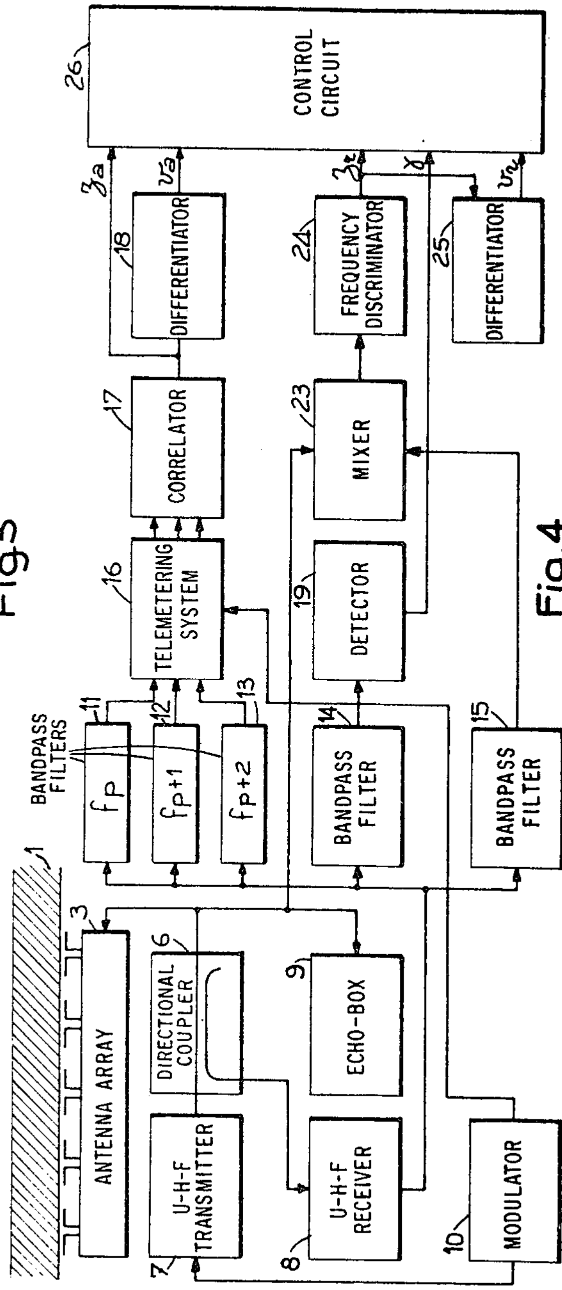


Fig. 2



p+2
22
5
P
p+1
5
1
P
p
5
P
21

Fig3



CONTROL CIRCUIT
26
γ_a
v_a
γ_r
γ
v_r
DIFFERENTIATOR
18
FREQUENCY DISCRIMINATOR
24
DIFFERENTIATOR
25
CORRELATOR
17
MIXER
23
TELEMETERING SYSTEM
16
DETECTOR
19
BANDPASS FILTERS
11
12
13
f_p
f_{p+1}
f_{p+2}
BANDPASS FILTER
14
BANDPASS FILTER
15
1
3
ANTENNA ARRAY
DIRECTIONAL COUPLER
6
ECHO-BOX
9
U-H-F TRANSMITTER
7
U-H-F RECEIVER
8
MODULATOR
10

Fig.4

Oct. 29, 1968 JEAN-CLAUDE SIMON ETAL 3,408,646

SYSTEM FOR LOCALIZING TRAINS ALONG A TRACK

Filed May 9, 1967 4 Sheets-Sheet 3

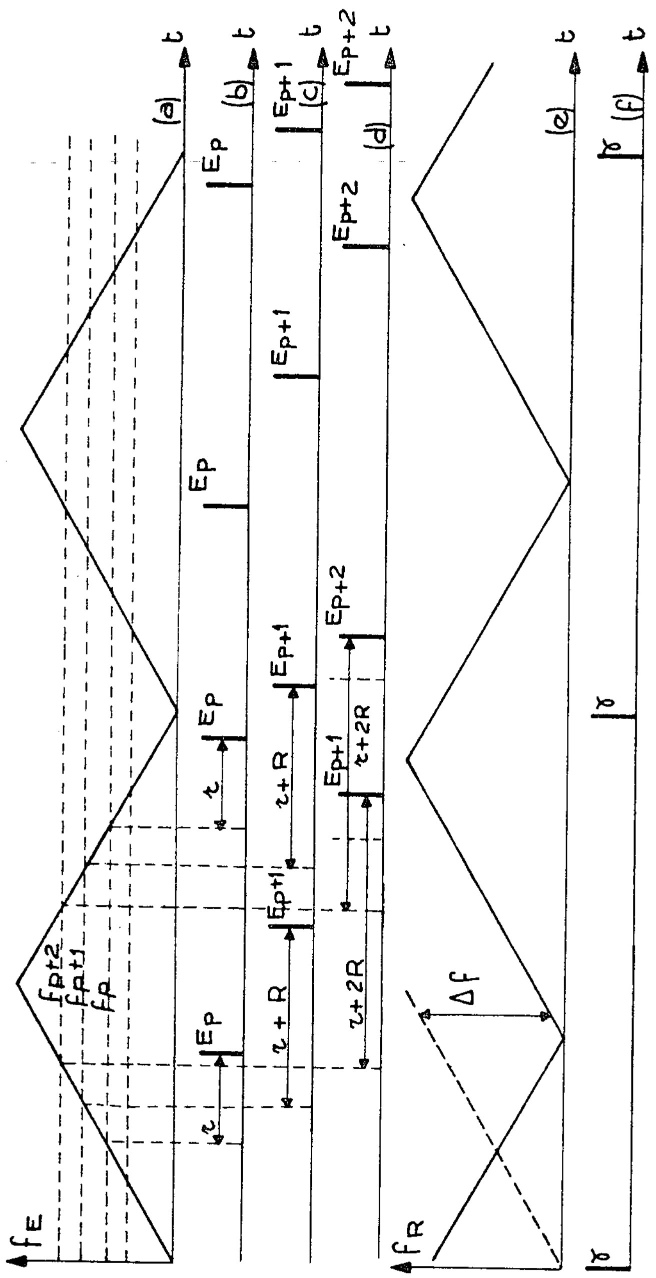


Fig.5

Oct. 29, 1968 JEAN-CLAUDE SIMON ET AL 3,408,646

SYSTEM FOR LOCALIZING TRAINS ALONG A TRACK

Filed May 9, 1967

4 Sheets-Sheet 4

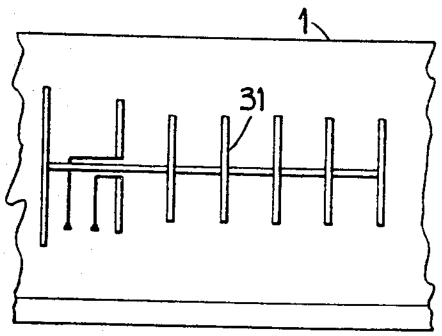


Fig. 6

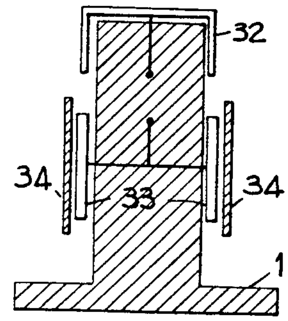


Fig. 7

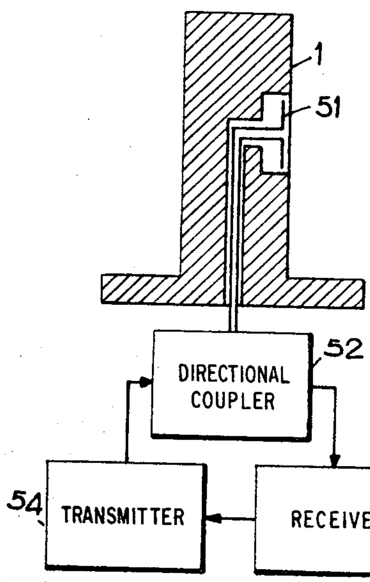


Fig. 8

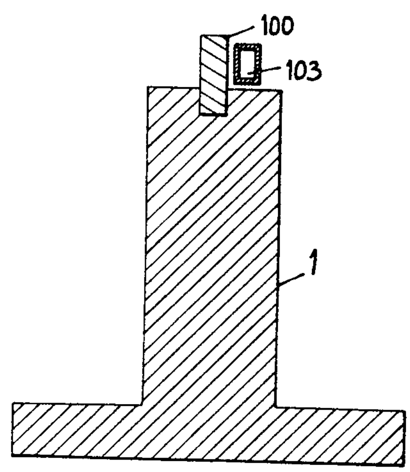


Fig. 9

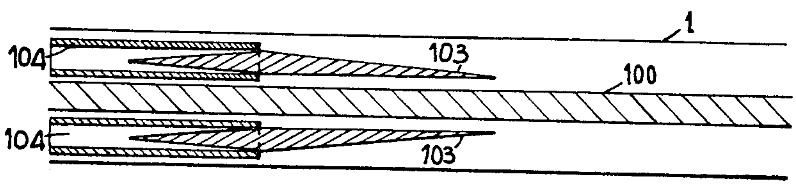


Fig. 10

United States Patent Office 3,408,646
Patented Oct. 29, 1968

3,408,646
SYSTEM FOR LOCALIZING TRAINS ALONG A TRACK

Jean-Claude Simon and Georges Jean Broussaud, Paris, France, assignors to CSF—Compagnie Generale de Telegraphie Sans Fil, a corporation of France

Filed May 9, 1967, Ser. No. 637,187
Claims priority, application France, May 16, 1966, 61,800
10 Claims. (Cl. 343—6.5)

ABSTRACT OF THE DISCLOSURE

An ultra-high frequency radar system for localizing trains along a track wherein a surface wave is propagated from the train along a dielectric wave guide extending along the track and is reflected towards the train either by another train or by responders located along the track. Preferably the track being in the shape of a concrete beam, a part of this beam is used as the wave guide. The responders are coded for responding to the energy received from the train in accordance with a predetermined code.

The present invention relates to safety systems for controlling the train traffic along a track.

The conventional solution of this problem consists in defining track sections and providing signalling devices for preventing collisions, for example by preventing that two trains may be simultaneously in the same section. This solution is no longer appropriate, in view of the rising traffic density, which necessitates an increase in the speed, the frequency and the length of trains which are permitted to run along the same track. It is also subject to atmospherics which can affect the interpretation of signals optically transmitted to the driver.

A modern solution of problems of detection and telemetering is provided by radar systems. However, most of radar systems are based on the angular detection of targets by means of a highly directional antenna radiating into space. This is obviously superfluous for locating trains running along a track and it is suitable to use the track itself for guiding the radioelectric control signals. Unfortunately, railway rails have a geometry which lends itself badly for guiding electromagnetic waves. This results in the use of complex transmission lines for guiding the waves parallel to the track.

According to the present invention there is provided a system for locating trains of cars along a track comprising a dielectric wave guide, extending along said track, for receiving ultra-high frequency wave energy from said cars and propagating said energy as a surface wave and reflector means spaced along said track for reflecting said energy towards said cars.

For a better understanding of the invention and to show how the same may be carried into effect, reference will be made to the drawings accompanying the following description and in which:

FIG. 1 is a view in perspective of a carriage moving along a track;

FIG. 2 is a plan view showing the principle of the system according to the invention;

FIG. 3 is an elevation view of the track equipped with responders;

FIG. 4 is a block diagram of the radioelectric locating system;

FIG. 5 is an explanatory drawing;

FIG. 6 shows in elevation a first device for exciting ultra-high frequency waves;

FIG. 7 is an end view of a second device for exciting ultra-high frequency waves;

FIG. 8 is a transverse section of one embodiment of a responder;

FIG. 9 is an end view of a third embodiment of a device for exciting ultra-high frequency waves; and

FIG. 10 is a plan view of the arrangement of FIG. 9.

FIG. 1 shows a track **1** of a special type along which moves a carriage **2**, only the outline of which has been drawn. By way of non-limitative example, the track **1** has the form of a horizontal T shaped concrete beam having a base EFGH. The carriage **2** floats on this track, being supported there upon on a cushion of air. However, without departing from the principle of the invention, the construction may be modified to comprise rails and wheels adapted to roll the carriage **2** along the track **1**.

According to the invention, a part of the track **1** behaves after the manner of a dielectric waveguide with the axis $o–z$, having in the plane $x–o–y$ a predetermined transverse cross-section ABCD. In FIG. 1, this cross-section is formed by the vertical arm of the concrete beam **1**. On board of the carriage **2**, excitation means **3** are provided, which are coupled to the track **1**, serving as a waveguide, in order to excite therein a surface wave, progressing parallel to $o–z$.

FIG. 2 shows the front of a train **21** and the rear of a train **22**, which precedes the former one. The train **21** is equipped with an ultra-high frequency system **4**, adapted to transmit and to receive locating signals via antennae 3, connected to the vertical arm of the runway **1**. Inside the environment with the refraction index η_2 and the permittivity ϵ_2, forming the dielectric guide, the transmitted waves suffer a total reflection, when their incidence θ is greater than the critical angle θ_o given by

$$\sin \theta_o = \frac{\eta_2}{\eta_1}$$

where η_1 is the index of the environment surrounding the guide.

Under these conditions, a surface wave can be formed about the dielectric guide and may progress along $o–z$ with a phase velocity v given by the formula:

$$v = \frac{c_2}{\cos \theta}$$

where c_2 is the phase velocity of electromagnetic waves in the environment with the index η_2.

It can be shown that the surface wave excited around the guide with the width a is damped exponentially with increasing distance from the lateral surfaces of the guide. It can also be shown that the efficient section, where the electromagnetic field has an attenuation less than $1/e$, has a radius ρ with

$$\rho = \frac{\lambda^2}{2\pi a} \cdot \frac{\epsilon_2}{\epsilon_2 - \epsilon_1}$$

where λ is the wavelength of the surface wave propagated along $o–z$ and ϵ_1 is the permittivity of the surrounding space.

Hence, the energy, carried by the surface wave and propagated along $o–z$, is divided into two fractions $P_{int.}$ and $P_{ext.}$, respectively, contained in the media having respective refractive indices η_2 and η_1; the ratio of these energies is given by the relation:

$$\frac{P_{int.}}{P_{ext.}} = \frac{2a}{\rho} \cdot \frac{\epsilon_1}{\epsilon_2}$$

It is therefore possible to use the dielectric guide for propagating with low attenuation a surface wave which remains confined within the immediate vicinity of the track **1**. If the surface wave encounters during its progression along the track a conducting obstacle, such as the rear of the train **22**, the electromagnetic energy is reflected in the same wave mode towards the train **21** which receives a delayed echo in response to the incident wave train. The guiding of the wave is still effective if the guide is slightly curved. Amongst the modes capable of being propagated in the form of surface waves about a dielectric waveguide, may be mentioned the mode TM shown in FIGS. 1 and 2; it is also possible to excite a TE mode or a hybrid TEM mode.

According to a first embodiment of the radioelectric system according to the invention, one branch of the track **1** is used as dielectric guide. The permittivity of the concrete used being three times as high as that of air, and the losses remaining small at the intended frequencies, it can be shown that, with a carrier frequency of 300 to 500 mc./s., a beam one metre high and 40 cm. thick can transmit a surface wave having a linear attenuation of a few decibels per kilometre.

Taking into account possible homogeneity defects, ranges of several kilometres are possible with a transmitting power of a mean value of a few watts.

FIG. 3 shows, in elevation, a track **1** and two trains **21** and **22** moving one behind the other from the left to the right. At regular intervals P (for example, of one kilometre), responder beacons **5** have been incorporated into the track, which, on interrogation by the locating system mounted on board the train **21**, transmit according to a predetermined code a surface wave directed towards this system.

According to the invention, the beacons p, $p+1$, $p+2$, . . . $p+i$ . . . $p+k$, are interrogated one after the other by the radioelectric system mounted on board the train **21**, and if no train **22** is between it and the train **21**, the beacons **5** supply $k+1$ coded information items, which enable the radioelectric system of locating instantaneously the exact position of the train **21**. In the case that the train **22** masks the $(p+i)$th beacon **5**, the surface wave coming from the train **21** is reflected by the train **22** without interrogating the following beacons; the telemetering system of the train **21** receives i coherent information items instead of $k+1$ and it may be concluded that there is an obstacle or that there is a failure in the operation of the beacons, which necessitates anyway the stopping of the train **21**.

In FIG. 4, an embodiment is shown of a block diagram of the radioelectric system according to the invention. The dielectric guide **1** is connected to an antenna **3**, comprising for example an array of radiating elements and phase shifting means, for excitating a surface wave propagating towards the right and for picking up the wave propagating in the opposite direction. With the dipoles shown in FIG. 4, a surface wave TM can be excited the electrical and magnetic vectors of which are shown in FIG. 1. The antenna **3** is coupled through a directional coupler **6** to an ultra-high frequency transmitter **7** and to an ultra-high frequency receiver **8**; the transmitter **7** is modulated by a modulator **10** which causes a frequency modulation in the shape of symmetrical saw-teeth. The output of the receiver **8** feeds bandpass filters **11**, **12**, **13**, **14** and **15** which separate, in accordance with their respective frequencies, the different locating signals collected by the antenna **3**. The locating signals transmitted by the filters **11**, **12** and **13** are compared in a telemetering system **16** according to the law of modulation provided by the modulator **10**, in order to determine their respective propagation times. These times are then compared between themselves by means of a correlator **17** which supplies the indication of the position z_a of the vehicle carrying the radioelectric system. A differentiator **18**, connected to the output of the correlator **17** gives the absolute velocity v_a of the train. The filter **14** transmits directly to a detector **19** a fixed echo γ produced by means of a resonant cavity **9**, a so-called "echo-box," permanently connected to the output of the transmitter **7**. This makes it possible to control permanently the operation of the transmit-receive assembly. The filtre **15** transmits an echo caused by the reflection from an obstacle **22**, located at any distance z_r in front of the transmitting vehicle **21**; this echo is mixed with a signal transmitted by the antenna **3** in a mixer **23**, which supplies a signal whose frequency is proportional to this distance. A frequency discriminator **24** converts this measuring signal into the distance z_r which is applied to a differentiator **25** to supply the relative speed v_r of the transmitting vehicle **21** relative to the obstacle **22**. The information z_a, z_r, v_a, v_r and γ are finally applied to a circuit **26** which ensures the control of the propulsion unit of the train **21**.

FIG. 5 shows at (*a*) the variation as a function of the time of the frequency of the signal transmitted by the radioelectric system of FIG. 4. The transmission wave is continuous and propagates as a surface wave along the dielectric guide **1**. During its propagation in front of the vehicle **21**, the wave encounters the beacons **5** which are frequency coded so as to reflect a signal only if its frequency has a certain value. The beacon p responds to the frequency of interrogation f_p, the beacon $p+1$ responds to the frequency $fp+1$ and so on, and the echoes received are Ep, $Ep+1$, $Ep+2$ etc., in accordance with the diagrams (*b*), (*c*) and (*d*) in FIG. 5. It may be seen, upon comparing these diagrams with the diagram (*a*), that the propagation times r, $r+R$, $r+2R$ are directly related to the distances p, $p+P$, and $p+2P$ which separate the beacons **5** from the train **21** in FIG. 3. Hence, from these times, the absolute position of the train **21** along the track **1** can be calculated. If the propagation time $r+2R$ is abnormally small, it may be assumed that an obstacle **22** masks the beacon $p+2$ which should have determined its duration. This abnormality reveals primarily the presence of an obstacle between two consecutive beacons. This obstacle is also detected by an intensive echo which it returns towards the receiver of the radioelectric system. This echo, delayed as a function of the propagation distance, has a frequency modulation delayed relative to that of the transmitted wave. Diagram (*e*) shows in solid lines the modulation of the received echo and in broken lines that of the transmitted wave and it may be readily seen that the gap Δf is proportional to the distance z_r separating the train **21** from the obstacle **22**. By measuring the frequency gap Δf, a second means is provided for locating the obstacle along the track **1**. These two methods of location insure a great operational reliability of the system and provide valuable information for controlling the run of the vehicles. The echo-box **9** affords additional safety since it creates a systematic echo γ, such as is shown in the diagram (*f*) in FIG. 5 which makes it possible to control permanently the operation of the transmit-receive assembly.

Without thereby departing from the principle of the invention, the block diagram shown in FIG. 4 may be modified in many ways. More particularly, the radioelectric system may be pulse modulated. This makes it possible to use in the receiver a compression method which improves the precision in the locating of targets. In this case, the beacons may be coded, for retransmitting a pulse train forming a digital position code. Whatever the method adopted, it is possible, without using pulse compression, to determine distances within ±1.5 metres with a radioelectric system transmitting within a frequency band of 50 mc./s. This band may be reduced by providing the suitable information processing and this reduction is limited only by the signal-to-noise ratio which is anyway favourable in view of the small ranges required.

If the modulation shown diagrammatically in FIG. 5 is used, it can be readily shown that the choice of symmetrical saw-teeth makes it possible to compensate frequency shifts caused by the Doppler-Fizeau effect. It is also possible to utilise systematically this measurable effect as a means for determining the speeds at which the train is approaching the beacons and fixed or mobile obstacles.

FIG. 6 shows in elevation a track **1** and an antenna of the "YAGI" type, capable of exciting about the vertical arm of the track **1** a surface wave according to the TE mode. The aperture of the antenna **31** must cover the efficient section of the surface wave which leads to arrange the antenna on either side of the vertical arm of the track **1**.

FIG. 7 shows an end view of an antenna with distributed excitation. It comprises an electrode **32** sliding over the top of the track **1** and a pair of electrodes **33**, connected electrically. The electrodes **32** and **33** form an excitation line with the axis parallel to the track **1**. This line is coupled to a radiating line formed by two dielectric plates **34** which excite the surface wave according to one of the modes TE, TM or TEM.

FIG. 8 shows diagrammatically a responder beacon **5** embedded in the track **1**. It consists of a radiating element **51** placed into a cavity formed in the wall of the track **1**. This element is weakly coupled with the surface wave whose efficient cross-section surrounds the vertical arm, acting as a dielectric guide. The element **51** is electrically coupled through a directional coupler **52** with a receiver **53** and a transmitter **54** which are both tuned to a predetermined frequency f_p, depending on the rank of the beacon. When the beacon is interrogated by a signal with the frequency f_p, the receiver **53** controls the retransmission of the same frequency f_p by the transmitter **54**.

FIG. 9 shows an end view of a track **1** surmounted by a dielectric guide **100**. This arrangement is used where the vertical arm of the beam **1** is unsuitable for guiding the surface wave. This is the case where centimetre waves are used in preference to metre waves. For exciting the surface wave around the guide **100**, an antenna according to FIG. 10 is used. It comprises an exciter waveguide **104**, one end of which is equipped with a dielectric block **103**, cut to a wedge in order to obtain a gradual coupling with the efficient section of the wave to be excited around the guide **100**. The guide **100** can be formed from a dielectric with low losses at the frequencies used. It may also be formed of a periodic array of conducting obstacles forming an artificial dielectric.

Of course the invention is not limited to the embodiments described and shown which were given solely by way of example.

What is claimed is:

1. A system for locating trains of cars along a track comprising a dielectric wave guide extending along said track for receiving ultrahigh frequency wave energy from said cars and propagating said energy as a surface wave and a plurality of passive responder-beacons spaced long said track and programmed for reflecting received energy towards said cars in accordance with a predetermined code.

2. A system as claimed in claim **1**, wherein said wave guide is a concrete beam.

3. A system as claimed in claim **1**, wherein, said train being shaped for floating along the vertical branch of a T shaped beam, resting upon its horizontal branch, said wave guide is said vertical branch.

4. A system as claimed in claim **1**, wherein said guide is an artificial dielectric guide.

5. A system as claimed in claim **1**, wherein said responder-beacons are programmed for responding to respective predetermined frequencies only.

6. A transmit-receive system for transmitting from cars ultrahigh frequency energy and for receiving echoes from responder-beacons and obstables in a system as claimed in claim **1** comprising transmitter means for exciting a surface wave along said wave guide in the direction of motion of said cars, receiving means for picking up said surface wave as reflected by said responder-becaons and obstacles ahead of said cars, first metering means, coupled to said receiving means, for measuring the distance from said obstacles to said cars and second metering means, coupled to said receiving means, for determining, from said echoes from said responder-beacons, the position of said cars along said track.

7. A system as claimed in claim **6**, further comprising means for differentiating said position and said distance with respect to time for respectively determining the absolute speed of said cars and the relative speed of said cars with respect to said obstacles.

8. A system as claimed in claim **6**, wherein said excitation means comprises an end-fire antenna.

9. A system as claimed in claim **8**, wherein said antenna comprises two elements respectively coupled to the two sides of said wave guide.

10. A system as claimed in claim **6**, wherein said transmitter means comprise means for frequency modulating said surface wave and said second metering means comprises a plurality of channels respectively tuned to different frequencies respectively corresponding to different responder-beacons.

References Cited

UNITED STATES PATENTS

3,305,682	2/1967	Bolster et al.	246—167
2,716,186	8/1955	Ford	246—187
2,702,342	2/1955	Korman	246—187
2,698,377	12/1954	Korman	246—187

FOREIGN PATENTS

1,378,440	10/1964	France.
939,248	11/1948	France.

RODNEY D. BENNETT, *Primary Examiner.*

C. L. WHITHAM, *Assistant Examiner.*