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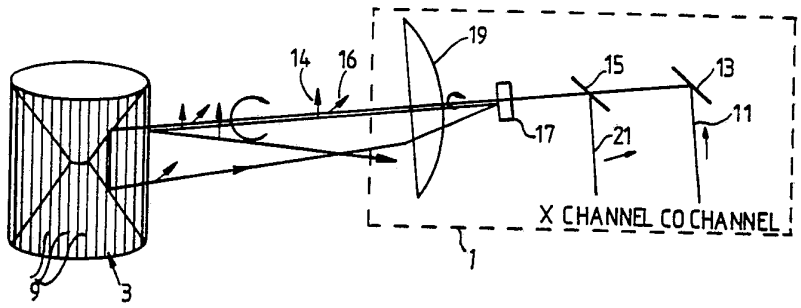
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(54) Title: VEHICLE NAVIGATION SYSTEM



(57) Abstract

A vehicle navigation system including a millimetre wave radar system. Targets may be manufactured or natural, prominent, scene features. In the former case the target (3) is made selectively reflective to one of two orthogonal polarized signals, the ratio of the two reflections providing a good identification of a genuine target. The range and target size also give an amplitude criterion. In the case of natural or incidental targets the azimuth position of prominent features is determined and stored from each of a number of vehicle positions. The change in azimuth disposition of the features at each vehicle position enables the vehicle position to be determined.

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Vehicle Navigation System

This invention relates to vehicle navigation systems and particularly, but not exclusively, to such systems for use in limited areas such as ports and dockside/harbour areas where a number of vehicles may traverse the same overall area repeatedly. It is also applicable in situations where the area of interest gradually changes, for example in a forestry site where trees are being felled over an advancing area or along a corridor.

Vehicle navigation systems have been proposed previously in which a laser beam is scanned around a site in which beacons are positioned. In one such system the beacons incorporate a bar code by which the beacon is identified. Such systems are difficult to operate outdoors because of the uncertainty of transmission in all weathers and the need to keep the reflectors/beacons clean. The need to store the identity codes of the various beacons is an added complexity.

Accordingly, an object of the present invention is to provide a vehicle navigation system which can be used in most environments whether indoor or out and which provides effective determination of vehicle position.

According to one aspect of the present invention a vehicle navigation system comprises a radar system for mounting on a vehicle to be navigated, the radar system comprising means for transmitting a

beam of radiation and determining the direction from which reflections are received, the beam comprising signal components in different polarization planes, the system further comprising a number of beacons each of which reflects one of the signal components preferentially, the radar system including means responsive to the ratio of the magnitudes of the reflected signal components to provide an indication of whether the reflections arise from a beacon. The different polarization planes are preferably orthogonal.

Each beacon may comprise two conical reflecting surfaces disposed co-axially apex to apex and an array of conductive wires extending parallel to the axis and enclosing the conical surfaces, the wire spacing being such as to reflect at least the major part of the beam which part is in a polarization plane aligned with the wires and to transmit at least the major part of the beam which part is orthogonal to the wires, the beacon being disposed so that the different polarization planes are respectively aligned with and transverse to the wires.

The signal components may be orthogonal components of a circularly polarized signal.

The radar system may include means responsive to the magnitude of target reflections for distinguishing beacon reflections from significantly smaller and greater reflections.

The beam may be a fan beam wide in elevation and narrow in azimuth.

The radar system preferably includes means for determining the azimuth position of each detected beacon and providing, in respect of a plurality of beacons, respective azimuth positions from a single position of the vehicle, the respective azimuth positions together providing an indication of the single vehicle position.

According to another aspect of the invention, a vehicle navigation system comprises a radar system for mounting on a vehicle to be navigated, the radar system comprising means for transmitting a millimetre-wave beam of radiation, the beam being a fan beam wide in elevation and narrow in azimuth, means for scanning the beam in

azimuth, means for storing reflections of the beam to provide a panoramic record of a scene, means for detecting from the panoramic record a plurality of distinctive target features and determining the azimuthal position of the target features, means for comparing the azimuthal positions of each target feature determined at displaced positions of the vehicle, and determining the relative disposition of the positions.

Preferably the radar transmitting means includes an antenna feed system having a vertical axis and a reflector mounted for rotation about the axis and inclined so as to produce an azimuthal sweep of the transmitted beam as it rotates.

The system preferably includes, for each vehicle, a dead-reckoning navigation system for determining the vehicle position, and means for correcting the vehicle position, as determined by said dead-reckoning system, by reference to the vehicle position as determined by said radar system.

Two embodiments of vehicle navigation system according to the invention will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a diagram of a radar transceiver 1 and beacon 3;

Figure 2 is a diagram of the 'front end' of the transceiver including rotating reflector 5 and quasi-optic feed 7;

Figure 3 is a block diagram of the transceiver 1;

Figure 4 is a diagram of microwave integrated circuit (MIC) components coupled to the quasi-optic feed;

Figure 5(a) and (b) is a diagram of the cyclic operations of the radar system;

and Figure 6(a), (b) and (c) is a diagram of various frequency modulations employed in operation of the system. The vehicles may be un-manned and adapted to carry freight. They may alternatively carry passengers with or without a 'driver'. Radar beacons are disposed around the site at strategic positions taking account of obstructions, accessibility of beacon position etc.

Referring to Figure 1, this shows, very diagrammatically, part of a radar transceiver 1, which is mounted on a vehicle, and a passive radar beacon 3 which may be of the order of 100 metres distant. The beacon comprises two conical reflecting surfaces fixed together, apex to apex, on a common axis, in the manner of a diabolo. The apex angle of each cone section is 90°. An incident beam normal to the cone axis would therefore strike the two cones each at 45° and be reflected back along its own path. According to a feature of the invention the beacon differentiates between incident waves polarized in planes parallel to the cone axis and transverse to the cone axis. This is achieved by enclosing the cones in a cage of conductor wires 9 parallel to the cone axis and spaced apart a distance approximating to or less than the wavelength of the operating frequency. To take advantage of this beacon design the radar beam transmitted by the vehicle transceiver is adapted to be circularly polarized. Assuming the beacon is mounted with its axis vertical, the vertical component of the circularly polarized signal is reflected from the wire cage. The significant part of this component in the incident beam - in the plane of the cone axis and radar - will in general not be exactly normal to the cone axis and will be reflected away from the radar transceiver. The horizontally polarized component on the other hand will pass through the wire cage and be reflected from the two cone surfaces back along the incident beam path in the manner of a reflex or corner reflector.

The beacon can therefore be made to present a clearly distinctive target by the use of a beam having both horizontal and vertical polarization components. The two such components do not need to be related as in circular polarization but this is a convenient form for them to take.

Recognition of such a beacon can be achieved in several ways, each based on the relative proportions of the two polarizations in the reflected beam (ie the beam detected by the radar receiver).

In the present design a vertically polarized wave is generated in the co(polarization)-channel 11 (Figure 1). After reflection at one suitably oriented wire grid 13 and transparent passage through another, 15, the polarized wave intercepts a quarter-wave-plate 17 of known type which is a disc of sapphire for example, which has one diametral plane - the 'fast' plane - through which a polarized wave is passed substantially without delay, and an orthogonal diametral plane - the 'slow' plane - through which a polarized wave passes with a quarter wavelength delay. The quarter-wave-plate is arranged with the incident wave plane bisecting the angle between the fast and slow planes. Of this wave the slow plane component is delayed with respect to the fast plane component so providing a circularly polarized wave as required.

The circular wave is then transmitted through a lens 19 and scanned in azimuth, searching for beacons, as will be explained.

On reflection as explained above, the horizontally polarized wave will again intercept the quarter-wave-plate on the bisector of the fast and slow planes and thus will again produce the two components of a circularly polarized wave. These two components will be of equal amplitude and will be separated by the grids 15 and 13 into the co(polarization)-channel 11 (same plane on transmission and reception) and cross(polarization)-channel 21 (orthogonal transmission/reception relation). A balance betweeen the components in the co and cross-channels is thus a very positive indication of beacon recognition. In a typical industrial/commercial port environment there are a considerable number of hard, clear cut, vertical edges which reflect vertically polarized components strongly. Such reflection causes a strong unbalance in the two channels such as to discount the possibility of a beacon target.

In an alternative approach the quarter-wave-plate can be oriented so that only a single component is accepted on reflection from a beacon. However, detection of a balance between two channels gives a much more unambiguous indication of a beacon than would a heavy predominance in one channel.

While the particular design of beacon described above has advantages of simplicity and cheapness it will be appreciated that any reflector which differentiates strongly between orthogonal polarizations and has a reflex function could be employed. The beacon described does have the considerable advantage of being effective for 360° of incident beam angle.

Referring now to Figure 2 the quasi-optic 'front end' of the system is shown in its operating orientation, ie the main axis of the quasi-optics is vertical and the reflector 5 is mounted to reflect the transmitted beam horizontally. Azimuth scanning is achieved by rotation of the reflector about the vertical axis. For this purpose the reflector is mounted suspended from a turntable 23 which is

controllable to rotate continuously or to reciprocate over a small angle of 10°.

In transmission the co-channel 11 provides a swept frequency signal of basic frequency 94 GHz generated on a microwave integrated circuit 25 to be explained further with reference to Figure 4. The transmitted wave is reflected by grid 13, passes through grid 15, and is converted to circular polarization, as explained previously, by quarter-wave-plate 17. It is then focused by lens 19 to a beam of 1.0° divergence and reflected by reflector 5. Various lenses 27 focus the beam and limit its dispersion which inherently occurs at the less-than-optical frequency at which the system is operative.

Two oscillation sources 29, 31 cooperate with the MIC circuitry. The local oscillator 29 is a fixed frequency oscillator operating at 94 GHz, while the oscillator 31 provides a linearly frequency swept signal centred on 94 GHz. It is this latter signal which is transmitted.

The outputs from the MIC 25 are: the co (11) and cross-polar (21) signals already referred to; an azimuth difference channel 33 and an elevation difference channel 35. These latter two channels are derived from a phase comparison target angle measuring arrangement on the MIC, as will be described later (Figure 4). The elevation channel

is not used in general but is readily available if needed. This phase comparison system enables the system to measure the azimuth angle of a beacon with reference to a datum angle on the vehicle.

The pointing direction of the reflector 5, and thus of the transmitted (and reflected) beam, is determined relative to this datum by an optical angle decoder coupled to the turntable 23.

A final output from the MIC 25 is a lineariser signal, channel 37, which consists of the transmitted signal shifted down in frequency by the fixed local oscillator frequency. This is used for the generation of an error signal to control the frequency sweep.

Figure 3 shows the overall arrangement of the system. The quasi-optics 38 and MIC 25 together contain the components of Figure 2. The outputs of the MIC 25 are applied to respective head amplifiers 39, intermediate frequency circuitry 41 and a digital signal processing unit 43. Range and angle of a detected beacon are derived in conjunction with a host computer 45. A lineariser circuit 47 employs the error signal from the MIC 25 to control modulation drivers 49 in an attempt to maintain linearity of the frequency sweep. This linearity is, of course, essential in an FMCW range finding system, since range is determined from the instantaneous frequency difference between the currently transmitted signal and the (delayed) reflection. Any non-linearity of slope will produce a range-dependent error and thus a range error.

Referring now to Figure 4 this shows, schematically, the arrangement of the MIC stripline circuitry 25. There are two sets of 'antenna' pads, 51 for the co-channel and 53 for the cross channel. The arrows indicate the plane of polarization.

The co-channel is used for transmission and production, on reception, of a sum signal only. Hence the pads are coupled together by way of coupler 55. The swept signal, from oscillator 31, is applied to the pads by way of a circulator 57. The pads radiate (see Figure 2) to reflecting grid 15 by way of lens 27 and the swept signal is thus transmitted. On reception, the co-channel signal is received

by the four pads 51 and the sum signal is fed, by way of circulator 57, to a mixer 59 in which the transmitted signal frequency is subtracted. The resulting signal is the co-channel signal.

The cross-channel is used to provide the basic cross-channel signal for comparison with the co-channel signal in detecting a beacon, and also to provide the azimuth (and elevation) angle signal. The signals rceived by the four pads 53 are summed and differenced (in magnitude) in known manner by couplers 61 to produce a cross-channel sum, A + B + C + D; an elevation difference (A + B) - (C + D); and an azimuth difference (A + D) - (B + C). These received signals are frequency differenced with the currently transmitted signal in mixers 63, 65 and 67.

The azimuth angle of a target (beacon) is determined as the scanner angle when a zero (or near zero) azimuth difference coincides with a substantial sum signal. The 'target' is then 'on boresight'. The target is determined as a beacon if the co-channel sum signal (11) is substantially equal to the cross-channel sum signal (21).

Referring now to Figure 5, this illustrates the operation of the system in detecting range and bearing of a target beacon. In Figure 5(a) successive sweeps of the transmitted frequency are shown, each extending over 500 microseconds. If the maximum operational range is 150 metres this amounts to a displacement of 1 microsecond between the transmitted and received sweeps. The three significant outputs co-channel, cross-channel sum and azimuth difference, are processed sequentially. In the first sweep shown in Figure 5(a) the co-channel signal is applied to a fast fourier transform (FFT) filter bank and any significant bin contents recorded. The time-scale for this is indicated in Figure 5(b). In the following sweep the same thing is done for the cross-channel signal. If the same bin in each process has a target content and the magnitude is equal or close, this is a strong indication of a detected beacon. The bin number will indicate the range. In addition to this balance between the channels

as an indication of a beacon target, the actual magnitude of the signals in view of the range will give an independent indication since the beacon is of known form and size and returns from it at specified ranges can be predicted.

Following this identification and range detection of a beacon the third sweep is employed for angle determination, ie bearing. In this case, as mentioned above, the azimuth difference channel 33 and the cross-channel sum 21 are employed, the angle being given at the instant of minimum ratio of difference to sum.

Range resolution will depend upon the total swept frequency range that is 'spread' over the fixed number of frequency bins in the FFT filter bank. Once a target beacon has been detected and its range determined coarsely, a limited frequency band corresponding to the range ambit including the target, can be spread over the whole FFT bank so that each bin will have a smaller 'bin width' (in frequency) and thus a smaller range step. For practical purposes it is better to maintain the original bin width (or something approximating to it) which can be achieved by increasing the slope of the frequency modulation. Thus Figure 6(b) shows a sweep of +/- 15 MHz over 500 microseconds for coarse range resolutions, and Figure 6(c) shows a sweep of +/- 250 MHz over the same period for fine range resolution. Figure 6(a) shows the unmodulated transmit frequency of 94 GHz which may be employed to detect and compensate for target motion.

A typical operational procedure is as follows.

On vehicle power up the sensor performs an initial collision avoidance routine to detect any obstacles or personnel at the front of the vehicle. If no object is present then the sensor employs range detection.

In this mode the sensor hunts for targets or beacons from the vehicle out to 150m. If targets are found then their position and bearing are reported to the central guidance system. In the meantime the sensor continues in the coarse range mode until instructed to change modes.

The navigation controller on the automatic guided vehicle (AGV) will then analyse the target data to decide the next action. The choice of passive beacons is made on the accuracy that any particular orientation will give. The controller will then instruct the sensor to enter either collision avoidance or fine range and angle measurement mode.

In anti-collision mode the sensor will switch into a coarse scan in the direction of motion for a defined time and if there are any targets in the vicinity of 30m their motion will be tracked and a decision upon threat/no threat.

The fine range mode may also be switched in for a preset time on a particular range ambit. This selection of ambit allows a frequency range to be more finely divided by an FFT and therefore provide a higher accuracy.

The mode illustrated by constant transmit frequency in Figure 6(a) is to remove any frequency variation due to any relative motion between the vehicle and the target. The waveform consists of a CW transmission. The transmission of frequency f reflects off a target back to the vehicle with a frequency f+fd where fd is the doppler offset.

This doppler offset is then used to produce an accurate correction factor for the following FMCW modes and also allows tracking to be performed on obstacles which move in to the vehicle's path thus allowing real time tracking.

It will be apparent that a vehicle carrying the described navigation system can, with the aid of the pre-set beacons, the positions of which are stored, determine its own position and its freedom to move in any required direction. It will also be appreciated that, while the ranging ability of the system is valuable, it would be possible to determine its own position at least, by determining the bearing of a sufficient number of known beacons.

The above description concerns the application of the system to a situation in which beacons are predisposed in known locations. In an alternative embodiment beacons are dispensed with and the environment itself is used as a 'reference'.

By operating the scanner described above and recording range and bearing of prominent features a series of reference points is obtained. Any movement of the vehicle will in general change the range and bearing of these features which will (assuming sufficient prominence) remain recognisable at least for limited travel. The position of the vehicle can therefore be calculated with reference to a previous position by correlation between new and old ranges and bearings. Navigation of an unmanned vehicle is therefore possible using solely the environment as reference. A radio link to a control station can provide a display of the vehicle track and, in the reverse direction, control of the vehicle track.

A major advantage of the present system in either embodiment is its ability to operate outdoors in almost any weather conditions. The operating frequency - in the region of 94 GHz - is such as to give good penetration in most weather conditions.

The ability of the system to operate in the open air means that it has many agricultural and forestry applications. A vehicle so provided with the navigation system of the invention and in particular with the no-beacon embodiment, can operate in a forestry environment using tree edges as radar targets, to an accuracy of several centimetres at 100 metres or so. In such an environment the ground is likely to be uneven so that a 'good' target might be lost between two vehicle positions because of a change in beam elevation. A cylindrical lens can be introduced into the beam path to provide a fan beam wide in elevation and narrow in azimuth.

CLAIMS

1. A vehicle navigation system comprising a radar system for mounting on a vehicle to be navigated, the radar system comprising means (1) for transmitting a beam of radiation and determining the direction from which reflections are received, said beam comprising signal components in different polarization planes, the system further comprising a number of beacons (3) each of which reflects one of said signal components preferentially, the radar system including means responsive to the ratio of the magnitudes of the reflected signal components to provide an indication of whether the reflections arise from a said beacon (3).

2. A vehicle navigation system according to Claim 1, wherein said different polarization planes are orthogonal.

3. A system according to Claim 2 wherein each said beacon (3) comprises two conical reflecting surfaces disposed co-axially apex to apex and an array of conductive wires (9) extending parallel to the axis and enclosing the conical surfaces, the wire spacing being such as to reflect at least the major part of said beam which part (14) is in a polarization plane aligned with said wires and to transmit at least the major part of said beam which part (16) is orthogonal to said wires, the beacon being disposed so that said different polarization planes are respectively aligned with and transverse to said wires.

4. A system according to any preceding claim, wherein said signal components (14,16) are orthogonal components of a circularly polarized signal (18).

5. A signal according to any preceding claim, wherein said radar system includes means responsive to the magnitude of target reflections for distinguishing beacon reflections from significantly smaller and greater reflections.

6. A system according to any preceding claim, wherein said radar system comprises means (23) for scanning said beam (18) in azimuth.

7. A system according to Claim 6, wherein said beam is a fan beam wide in elevation and narrow in azimuth.

8. A system according to any preceding claim, wherein said radar system includes means for determining the azimuthal position of each detected beacon and providing, in respect of a plurality of beacons, respective azimuthal positions from a single position of the vehicle, said respective azimuth positions together providing an indication of said single vehicle position.

9. A vehicle navigation system comprising a radar system for mounting on a vehicle to be navigated, the radar system comprising means (31,7) for transmitting a millimetre-wave beam of radiation, said beam being a fan beam wide in elevation and narrow in azimuth, means (23) for scanning said beam (18) in azimuth, means for storing reflections of said beam to provide a panoramic record of a scene, means for detecting from said panoramic record a plurality of distinctive target features and determining the azimuthal position of said target features, means for comparing the azimuthal positions of each target feature determined at displaced positions of the vehicle, and determining the relative disposition of said positions.

10. A system according to Claim 8 or Claim 9, wherein said radar system comprises a frequency-modulated continuous-wave range determining system for use in combination with said azimuthal positions in determining the vehicle position.

11. A system according to any preceding claim, wherein the radar transmitting means (31,7) includes an antenna feed system having a vertical axis and a reflector (5) mounted for rotation about said axis and inclined so as to produce an azimuthal sweep of the transmitted beam as it rotates.

12. A system according to any of claims 8, 9 or 10, including, for each vehicle, a dead-reckoning navigation system for determining the vehicle position, and means for correcting the vehicle position, as determined by said dead-reckoning system, by reference to the vehicle position as determined by said radar system.

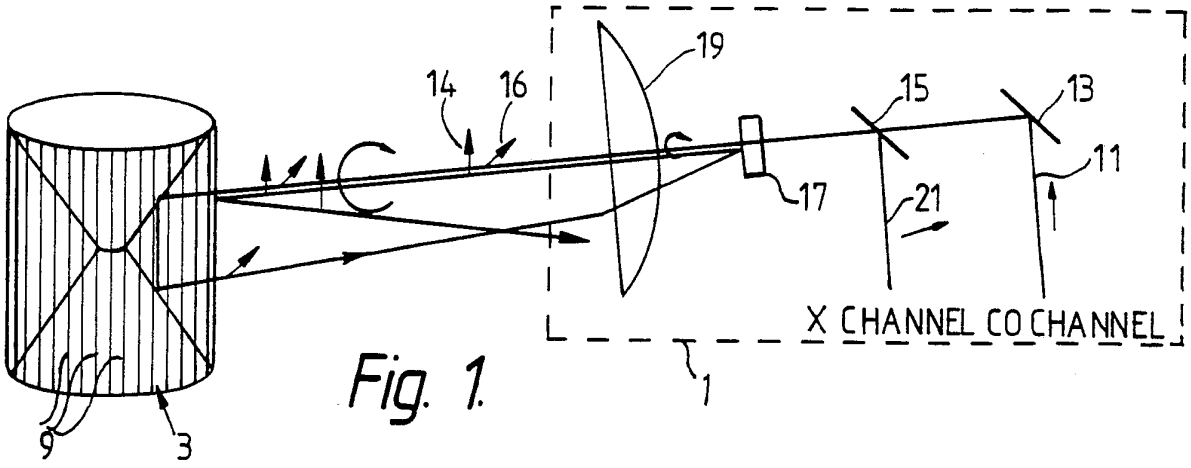

19
14
16
15
13
11
17
21
X CHANNEL CO CHANNEL
1
9
3

Fig. 1.

Fig.2.

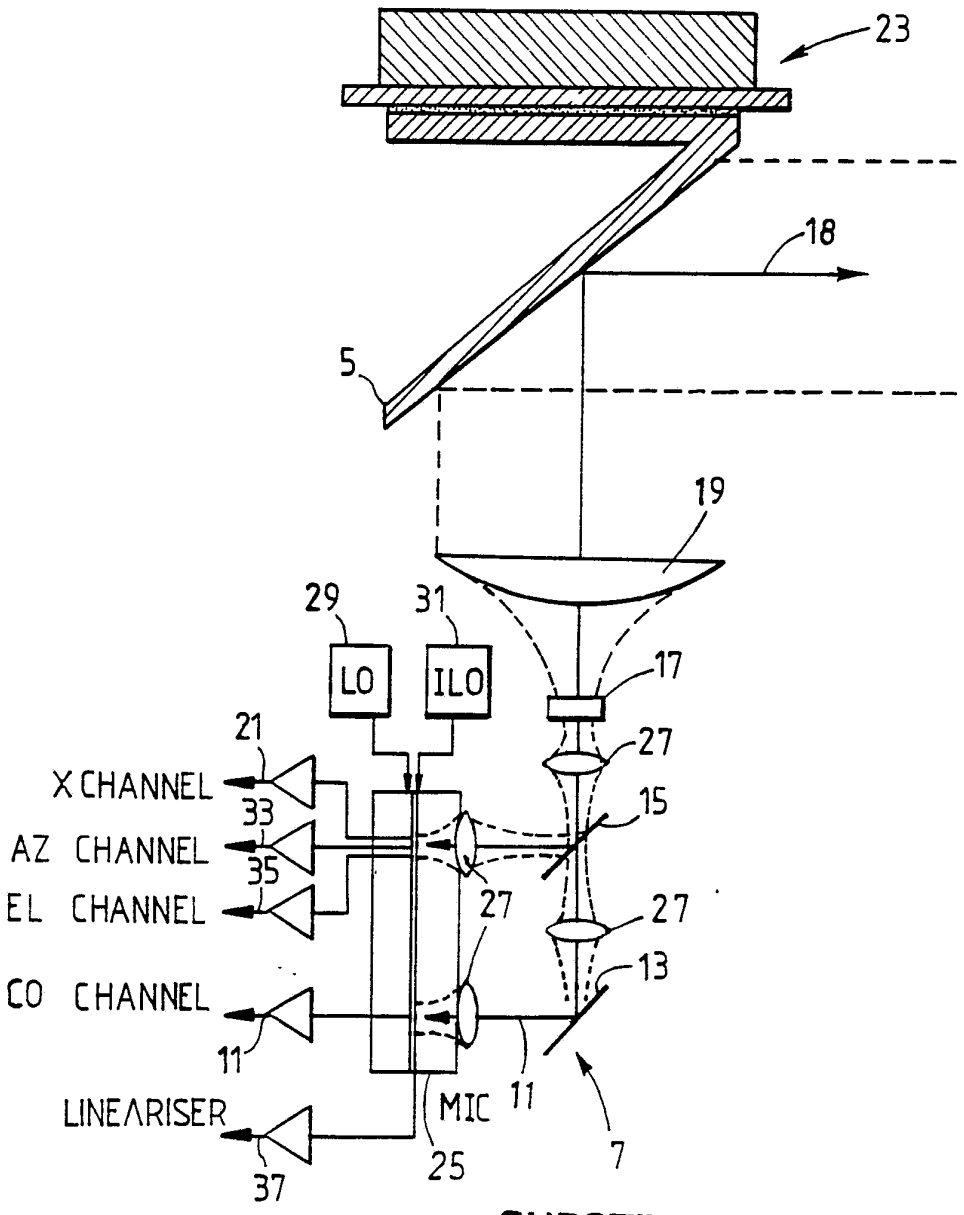
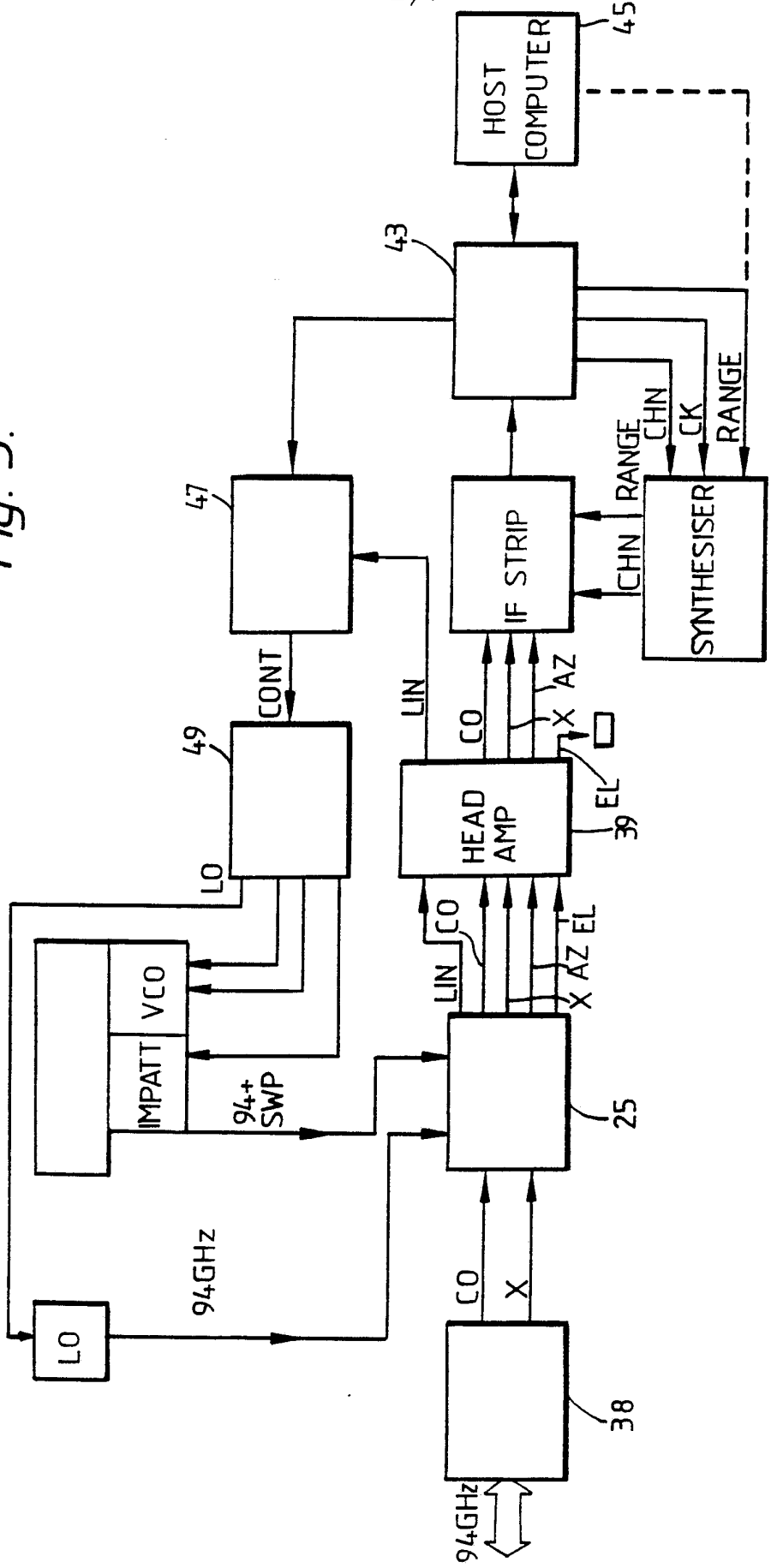

23
18
5
19
29
31
LO
ILO
17
21
27
X CHANNEL
33
15
AZ CHANNEL
35
EL CHANNEL
27
27
CO CHANNEL
13
11
11
LINEARISER
MIC
7
37
25

Fig. 3.


HOST COMPUTER
45
43
47
IF STRIP
SYNTHESISER
RANGE
CHN
CK
RANGE
CHN
CONT
LIN
CO
X
AZ
EL
49
HEAD AMP
39
LO
VCO
IMPATT
94+ SWP
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LO
CO
X
38
94GHz

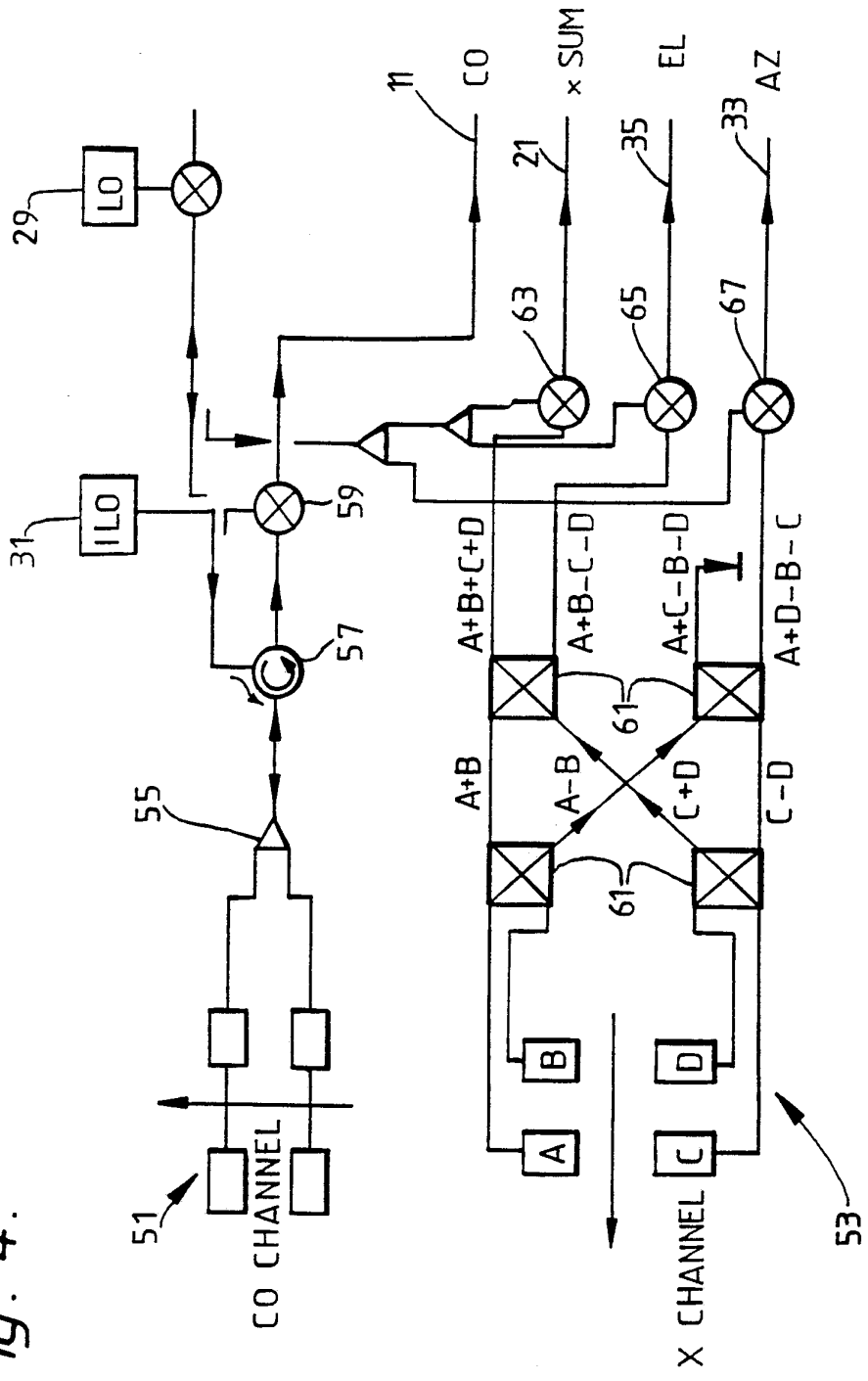

CO
x SUM
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AZ
11
21
35
33
LO
29
ILO
31
63
65
67
59
57
55
A+B+C+D
A+B-C-D
A+C-B-D
A+D-B-C
61
A+B
A-B
C+D
C-D
A
B
C
D
51
CO CHANNEL
X CHANNEL
53

Fig. 4.

Fig. 5a.

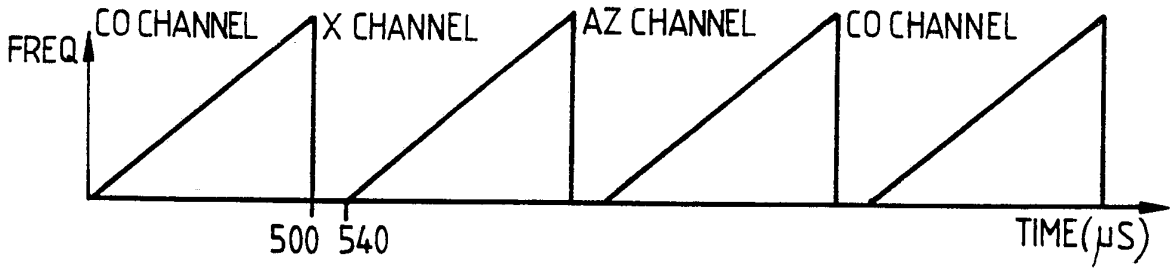


Fig 5b

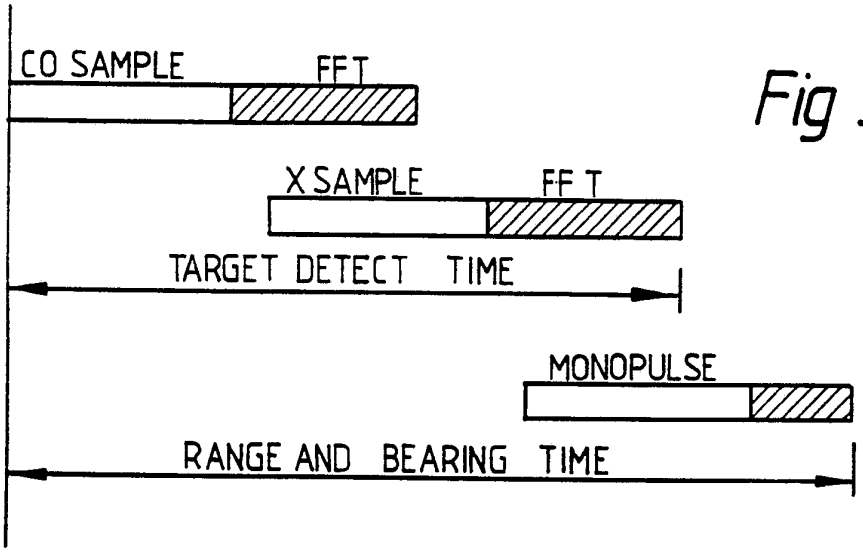


Fig. 6a.

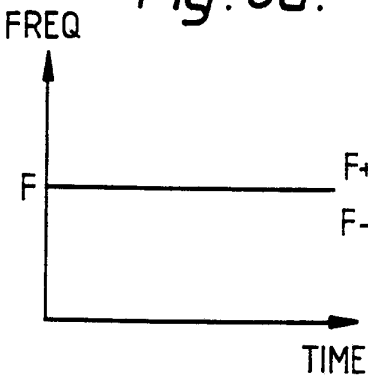


Fig. 6b.

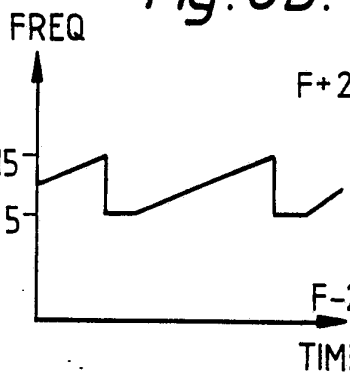


Fig. 6c.

