United States Patent [19]

Auer et al.

[11] **3,780,369**

[45] **Dec. 18, 1973**

[54] **RADAR**

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[30] **Foreign Application Priority Data**

May 25, 1963 Germany .... T 24054

[52] **U.S. Cl.** .... **343/9,** 343/8, 343/112 CA

[51] **Int. Cl.** **G01s 9/44**

[58] **Field of Search** 343/112, 112.4, 8, 343/9, 7.7, 7.3

[56] **References Cited**

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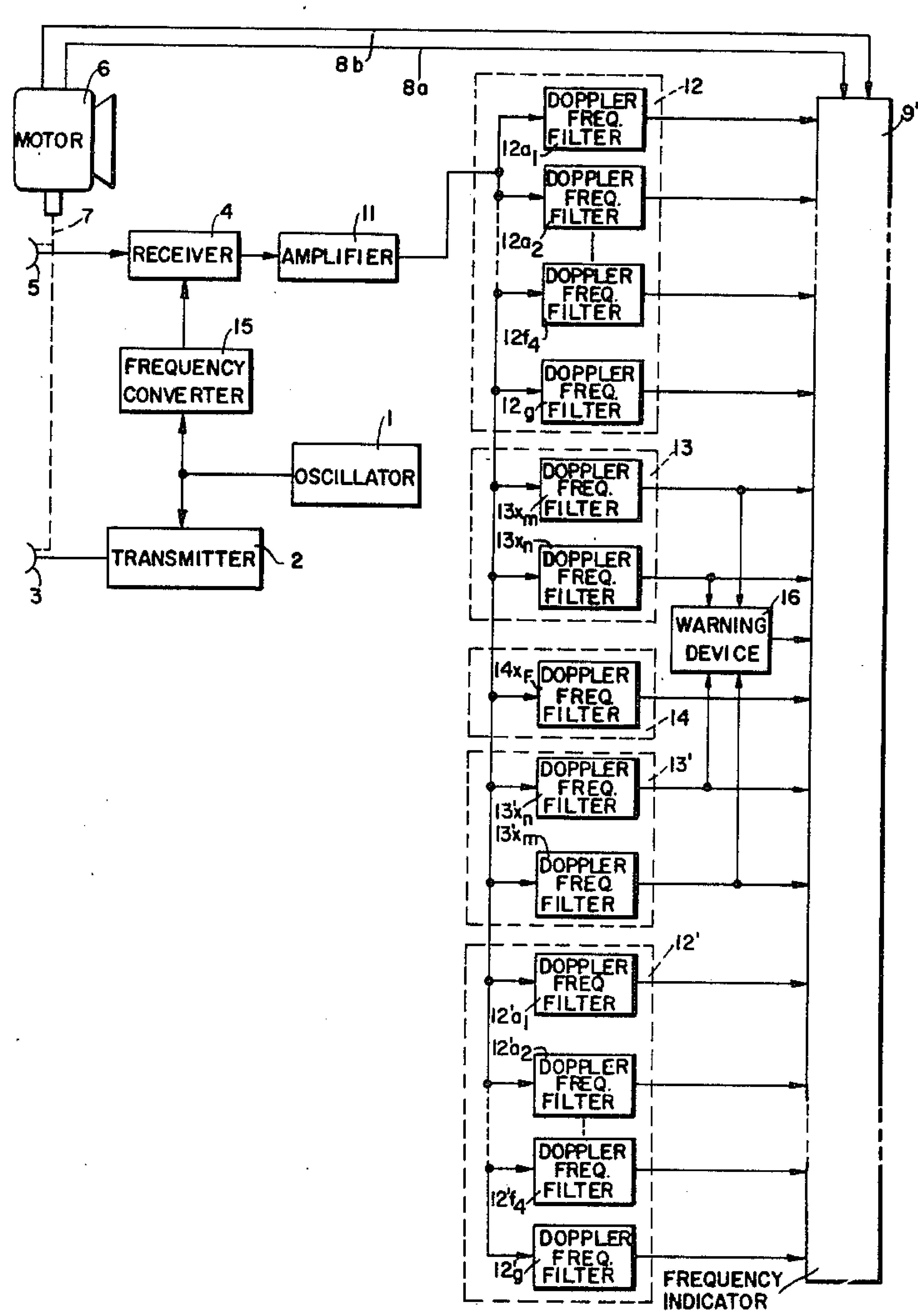
EXEMPLARY CLAIM

1. In combination: means located at an operating site for transmitting signals and for receiving those signals which are reflected by moving targets; and means connected to said transmitting and receiving means for processing those of the received signals which are reflected by targets beginning only at such time as any particular target approaching the operating site first comes to within a predetermined distance of the operating site which predetermined distance is a direct function of the radial speed of the respective target relative to the operating site, in consequence of which signals reflected by targets approaching the operating site at a relatively high speed are first processed when such targets are relatively far away from the operating site whereas signals reflected by targets which are approaching the operating site at a relatively slow speed are first processed while such targets are relatively close to the operating site, said processing means comprising a plurality of Doppler frequency filters each of which is assigned to a given speed range, said filters being assigned to successively slower speed ranges and having successively wider band widths.

23 Claims, 9 Drawing Figures



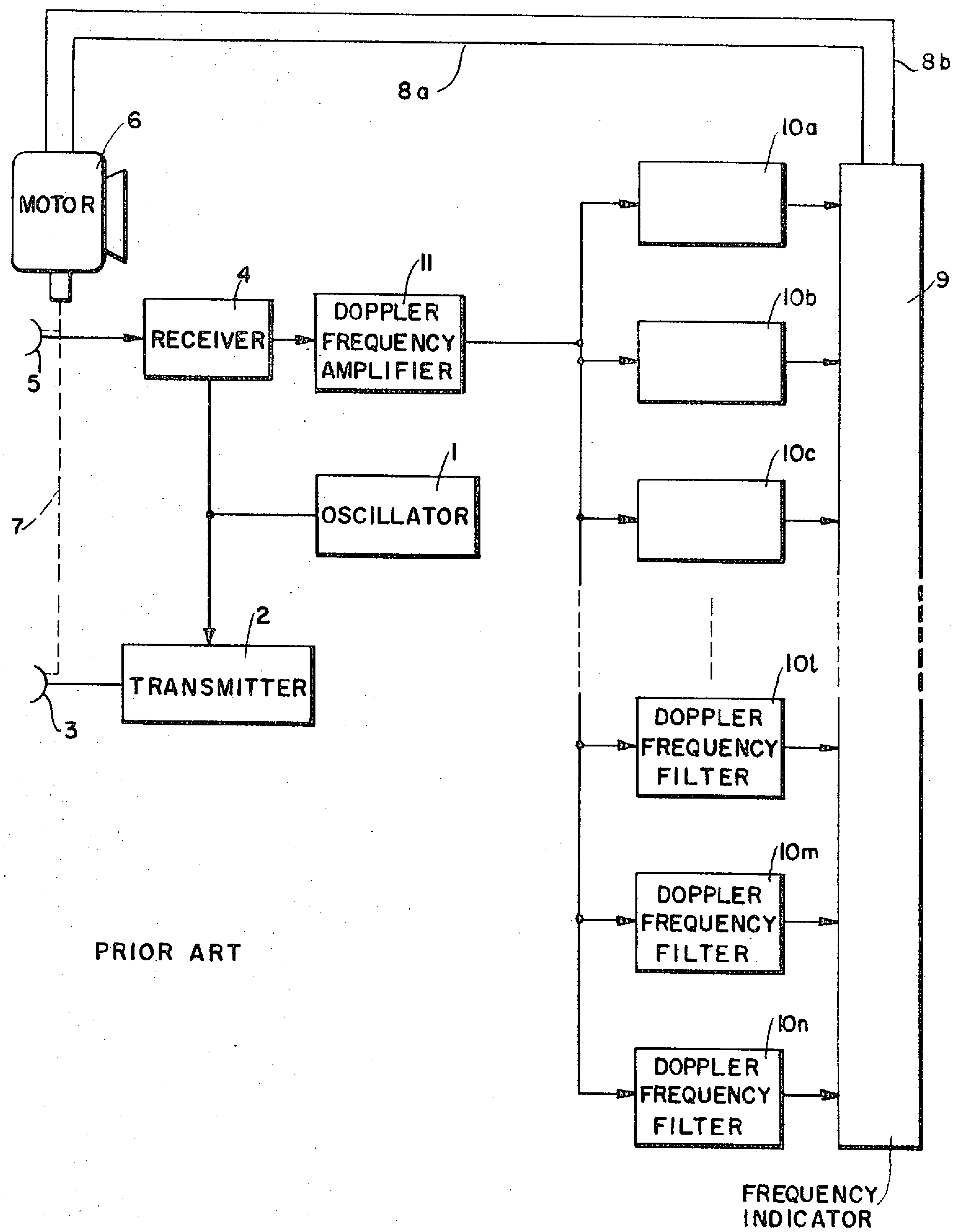


FIG. 1.

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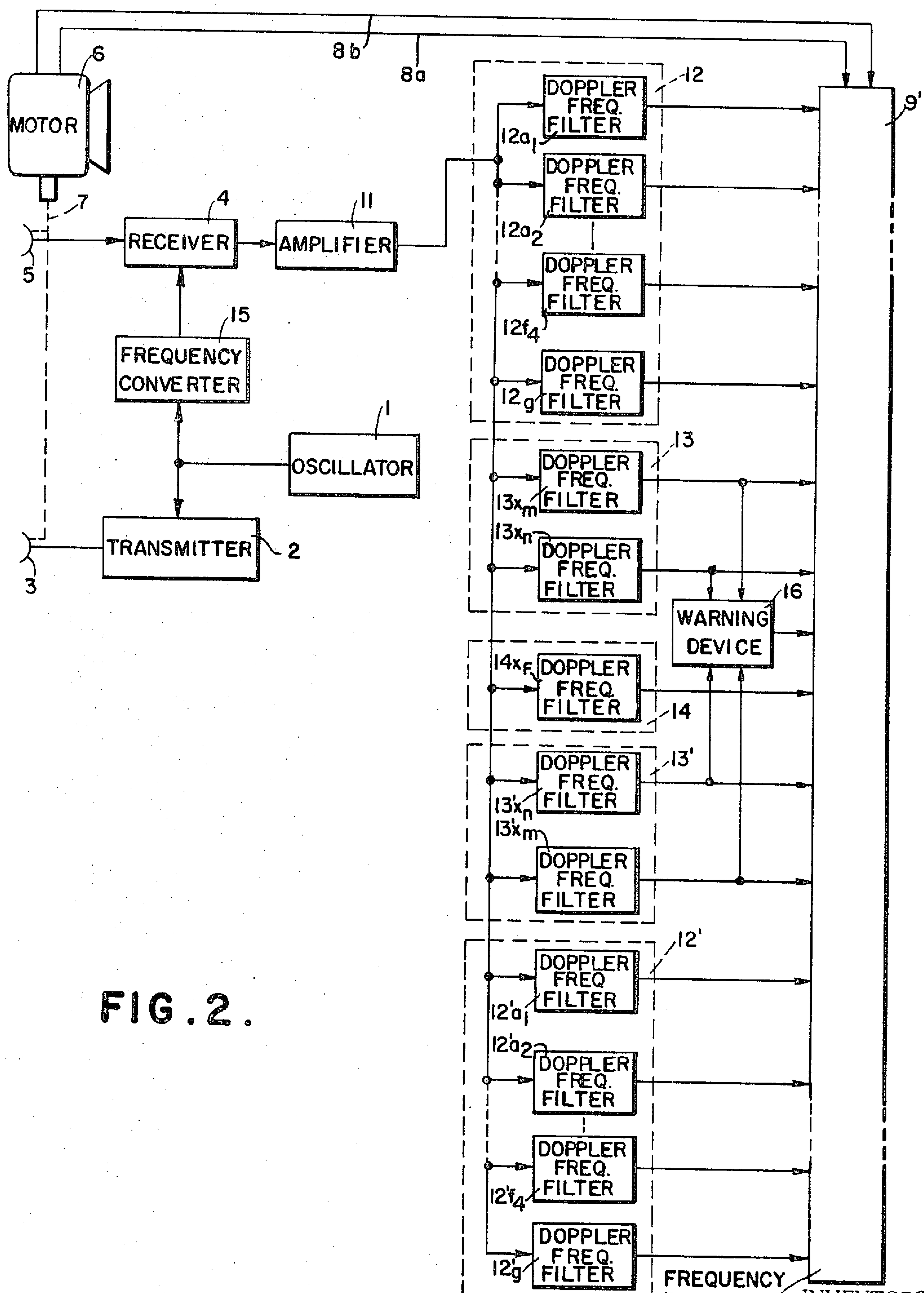

FIG. 2.

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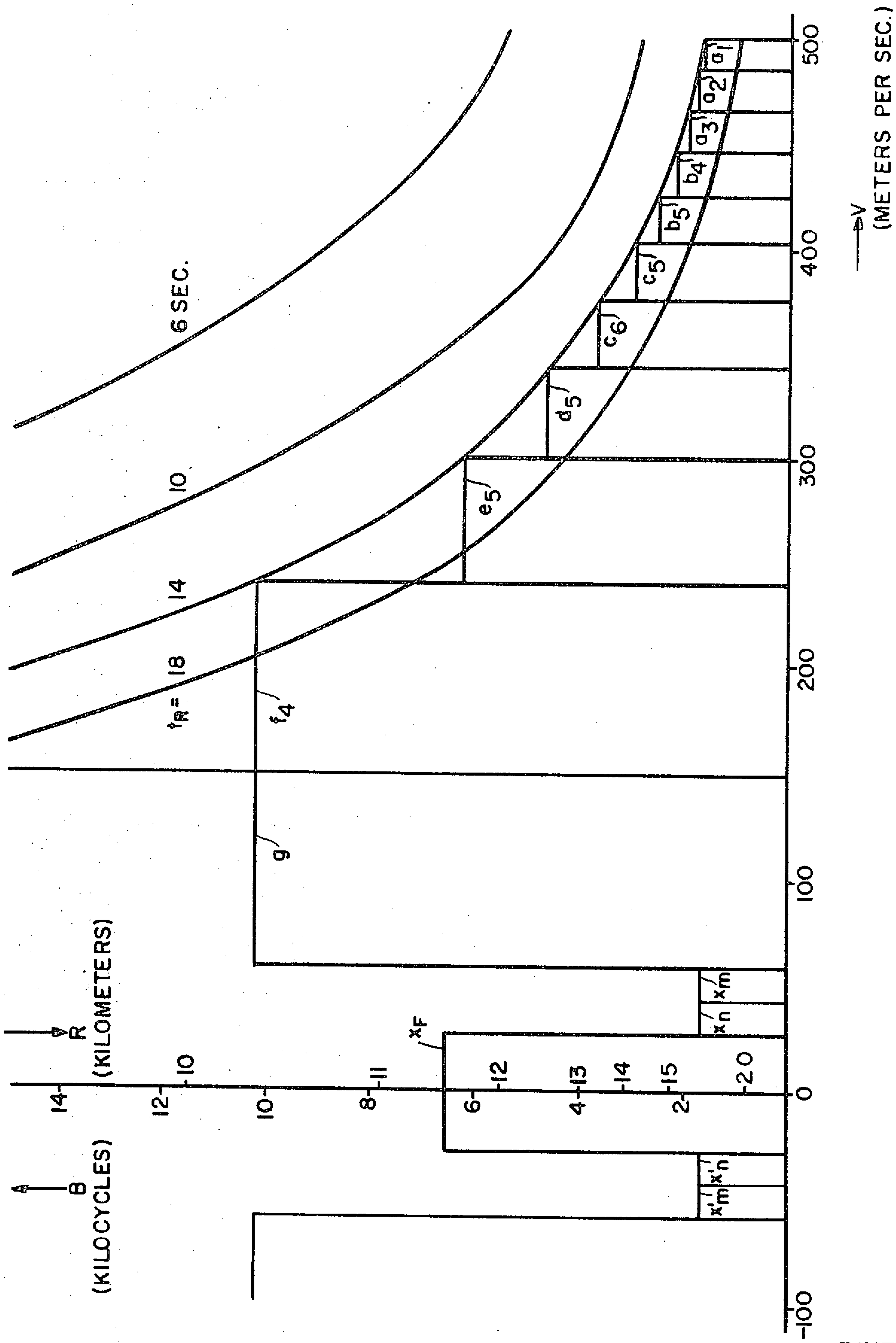

FIG. 3.

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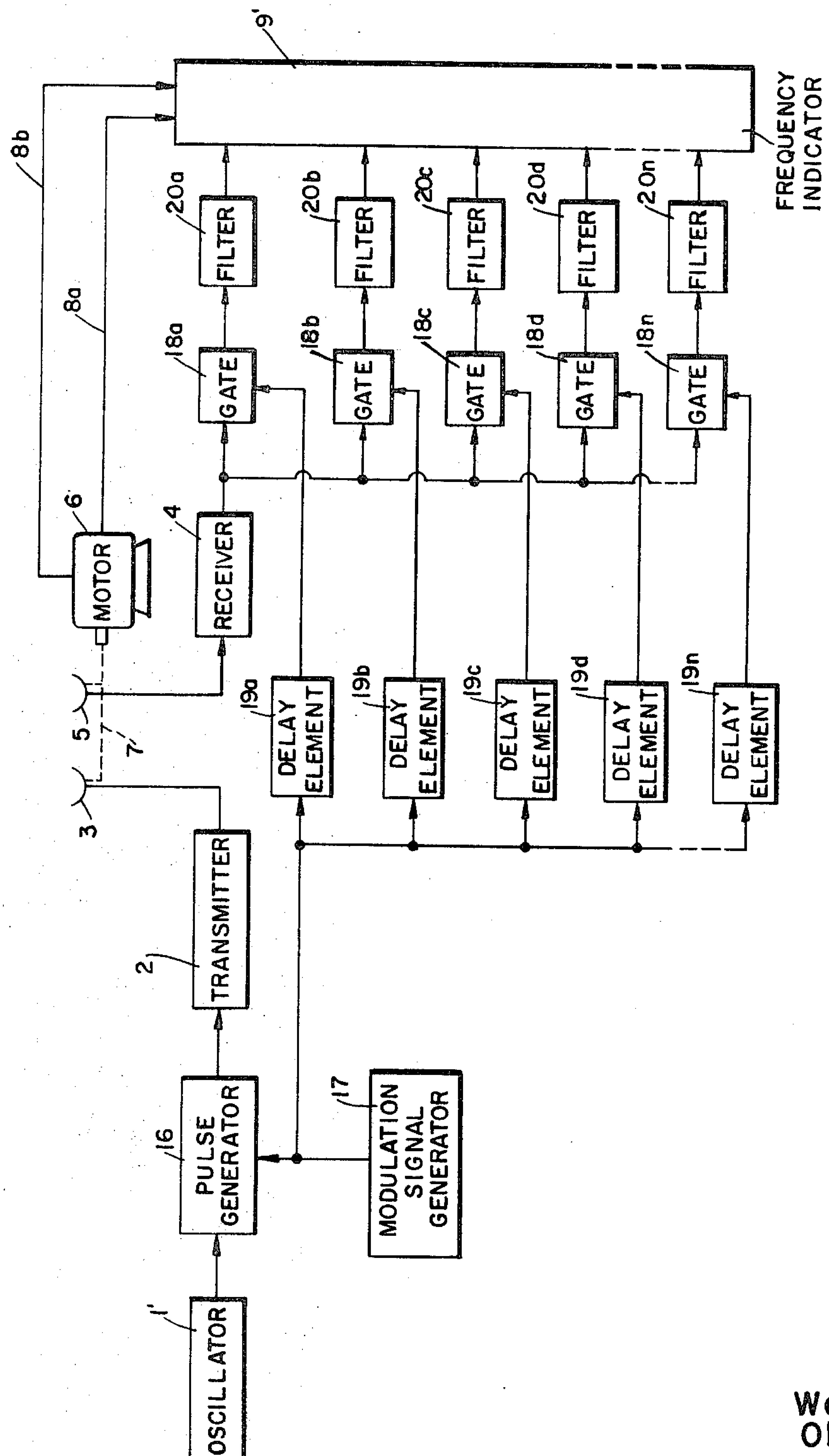

FIG. 4.

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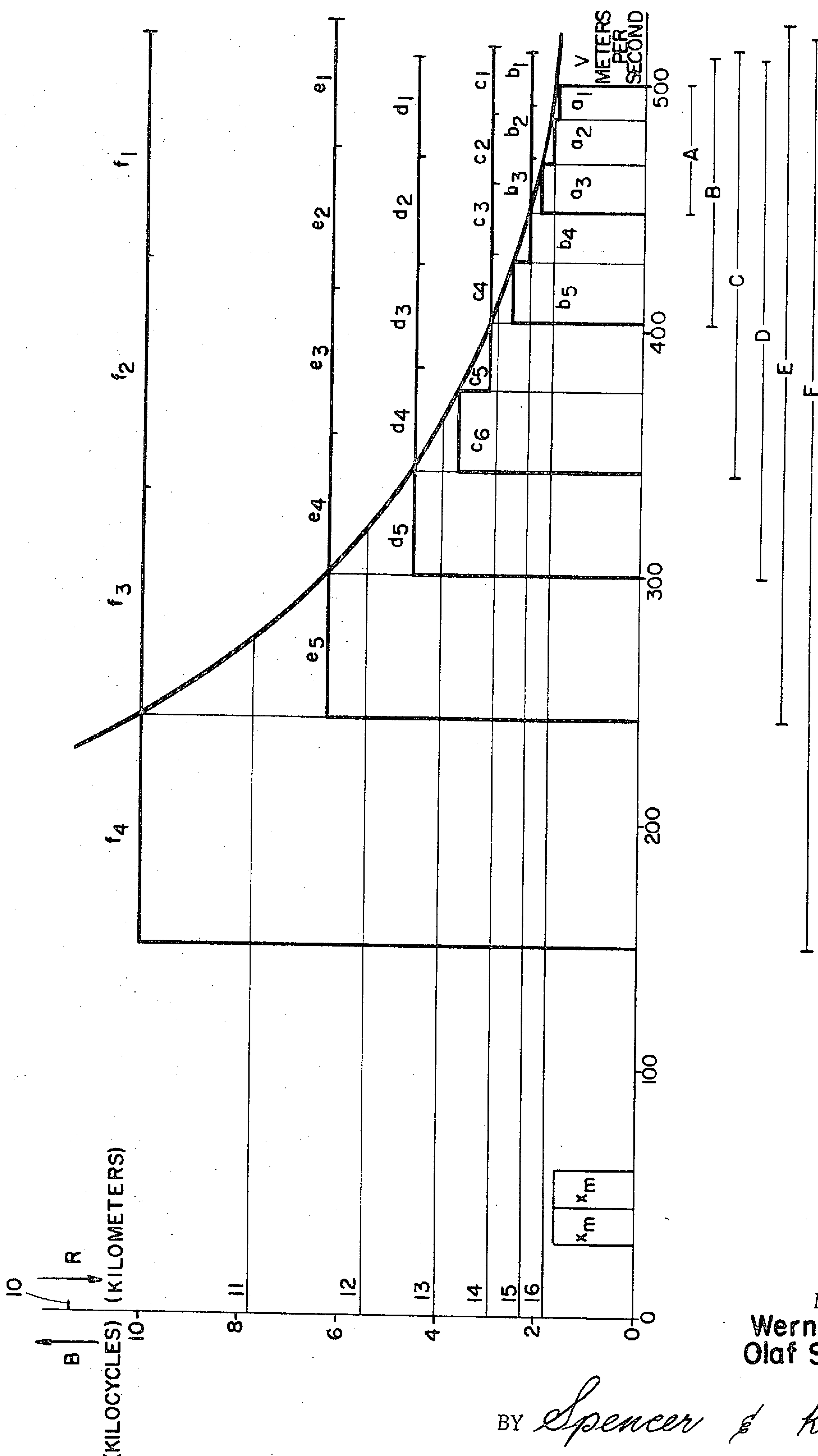

FIG. 5.

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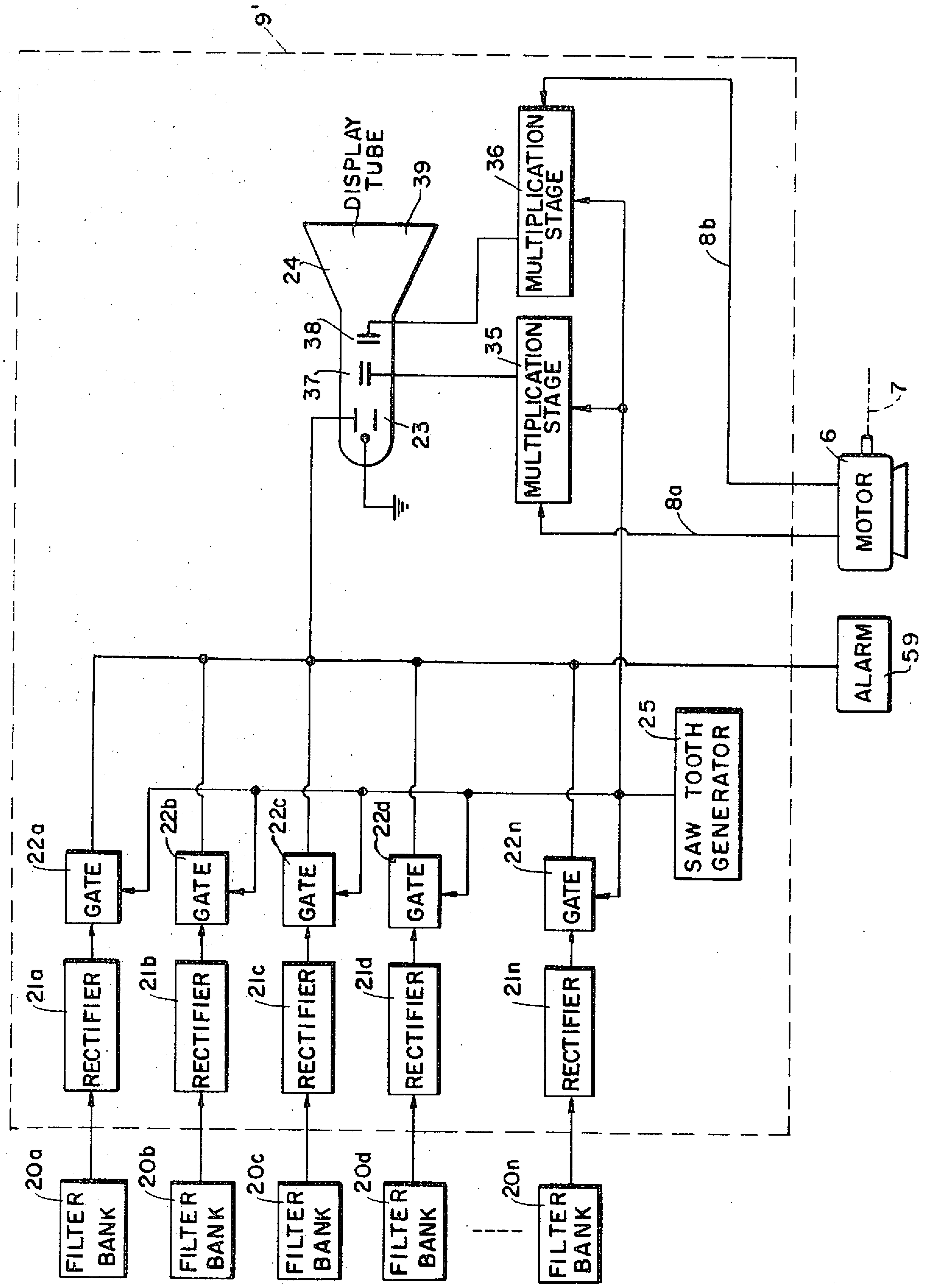

FIG. 6.

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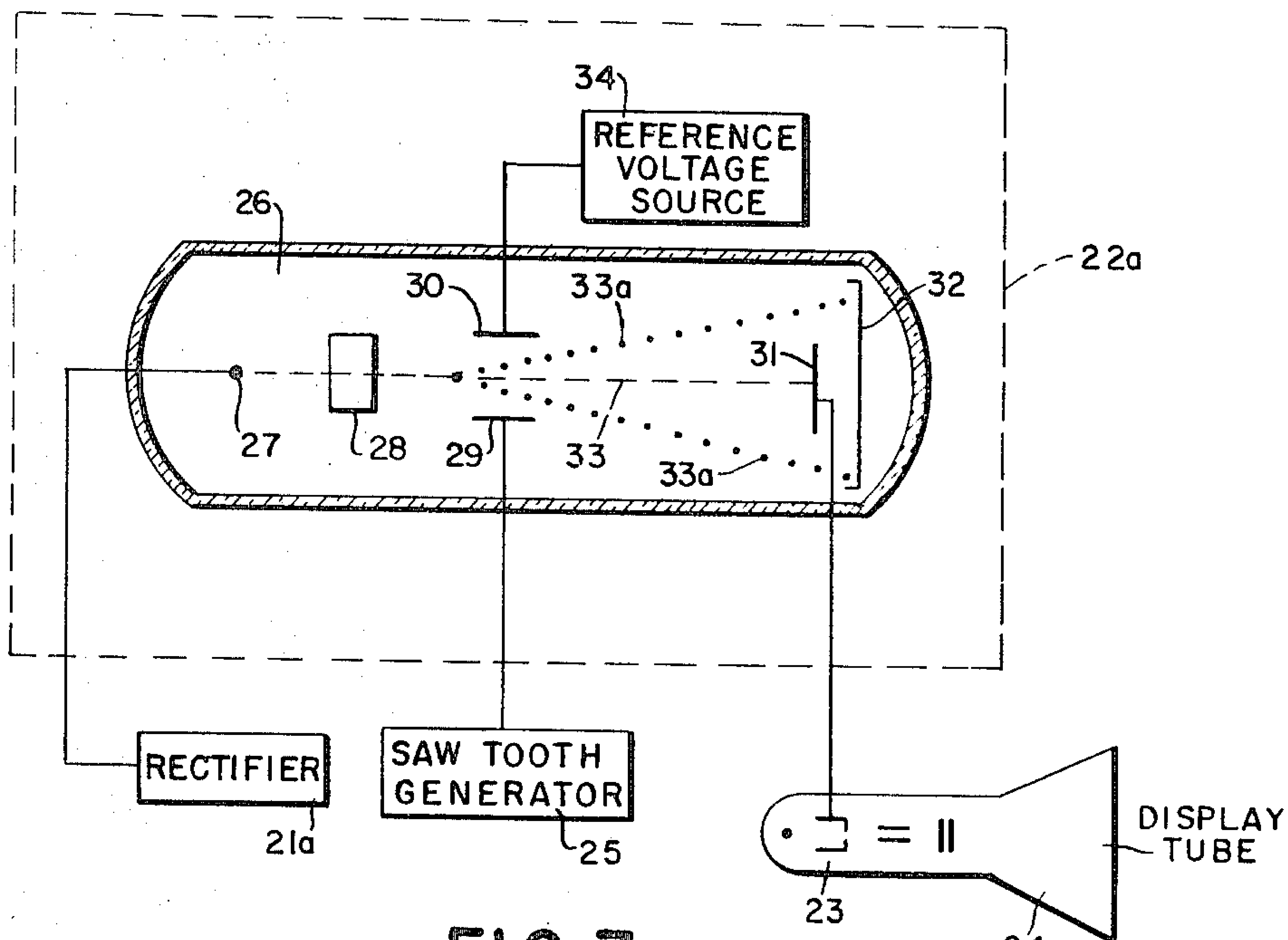

FIG.7.

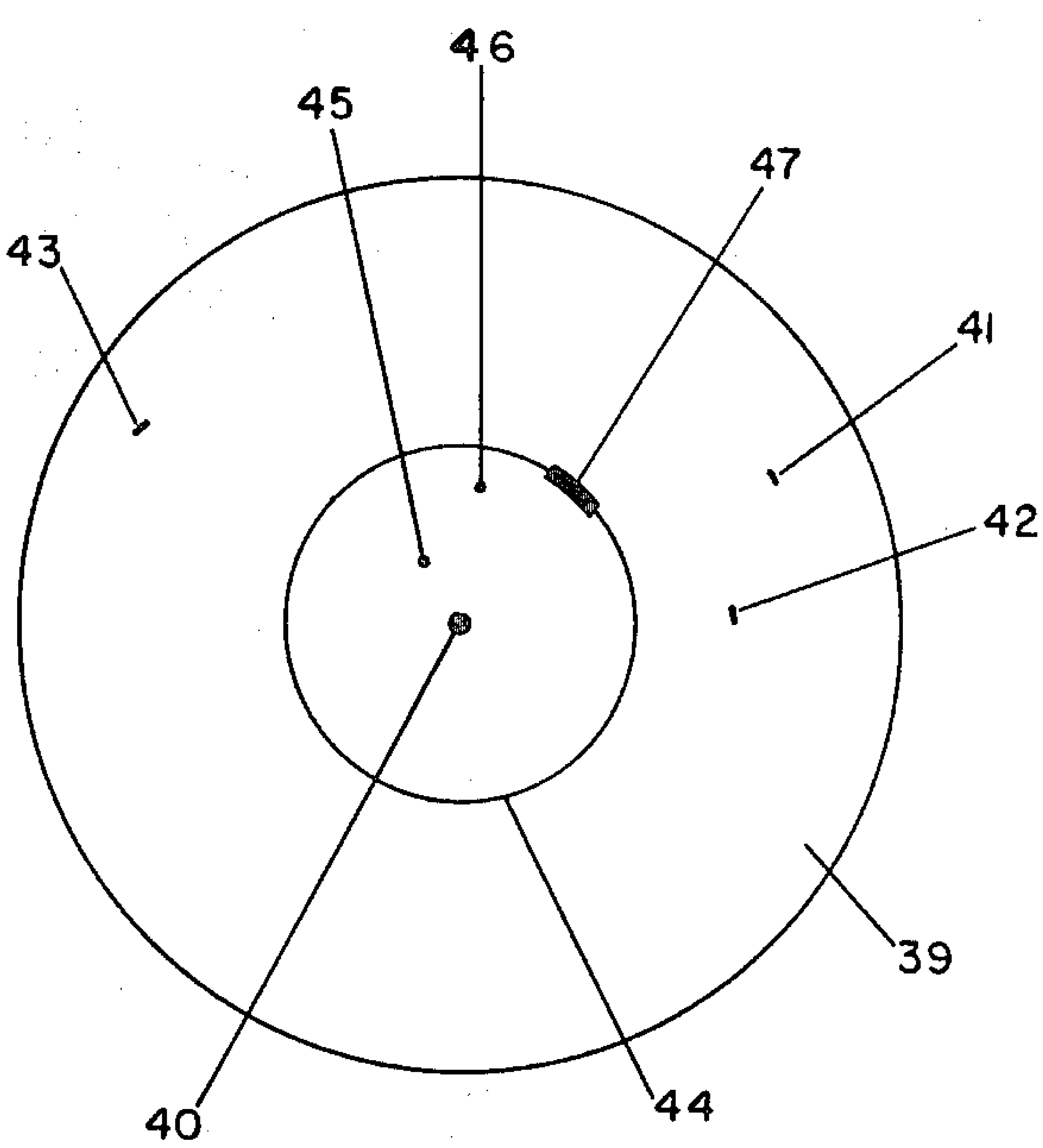

FIG.8.

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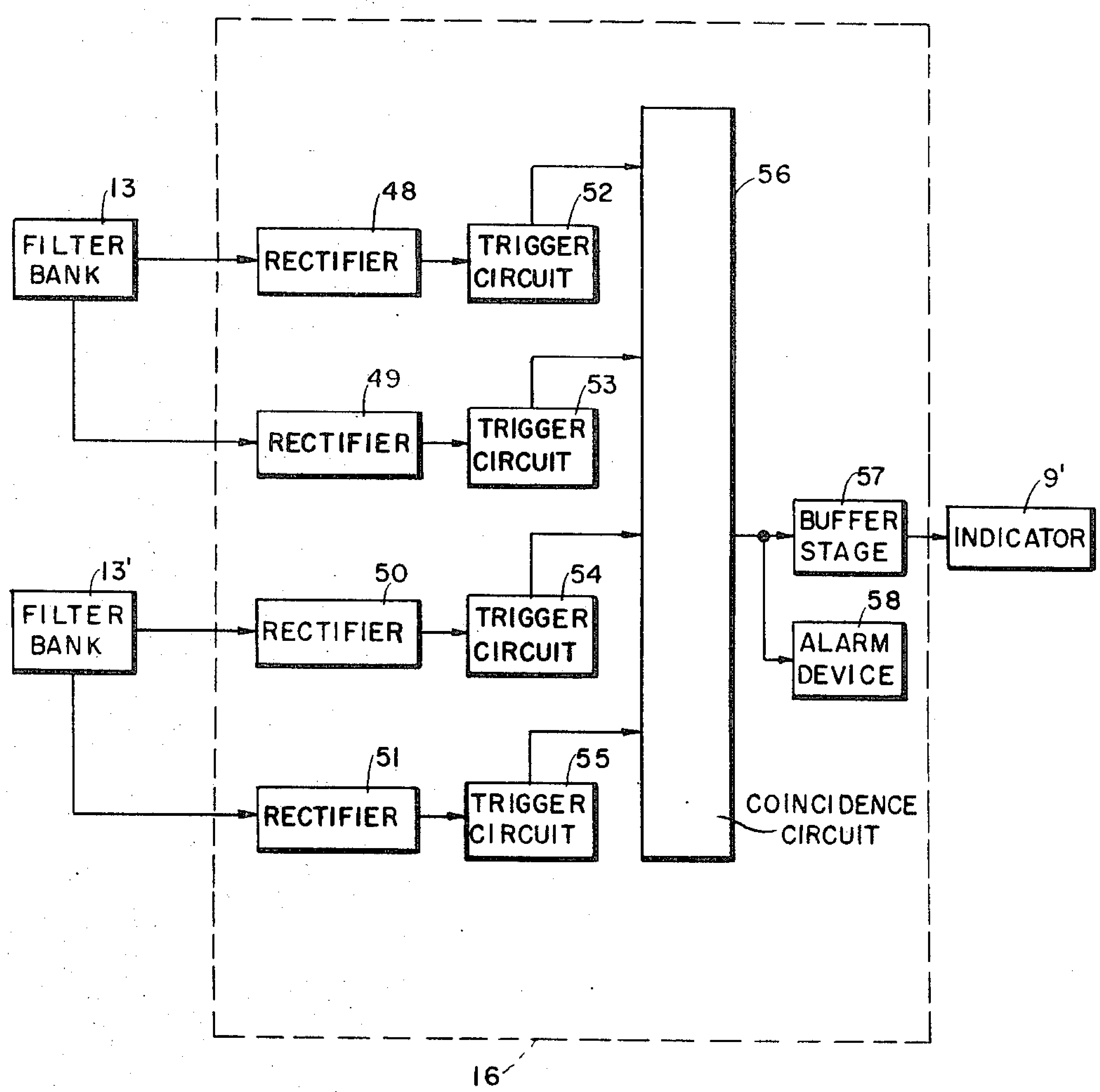

FIG. 9.

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RADAR

The present invention relates to the art of navigation, namely, to locating and position-finding equipment.

More particularly the present invention relates to a method and apparatus for obtaining intelligence concerning targets by means of locating equipment operating on the Doppler effect and the reflecting principle. Such equipment will, generally, be in the nature of a radar set, although the invention is, basically, applicable to other types of equipment, as, for example, sonar and infrared detectors, as well.

Doppler radar is often used in order to obtain information about targets. In some applications, for example when the equipment is used by police authorities for keeping a given section of highway under radar surveillance, the Doppler radar sets are equipped with so-called selection means which enable the radar set to produce readings in connection with only those targets which travel faster than a certain minimum speed relative to the radar site at which the set, and, more particularly, its antenna, is located. In practice, there will be additional selection means by means of which targets approaching the radar site and targets moving away from the site can be distinguished from each other. While Doppler radar sets normally mix the frequency of the reflected signal with the frequency of the transmitted signal in order to obtain a difference frequency, i.e., the Doppler frequency, whose magnitude is directly proportional to the radial speed of the target with respect to the radar site, irrespective of whether the target is coming toward or moving away from the radar antenna, with stationary targets being suppressed by having the difference frequency zero assigned to them, Doppler radar sets which are to produce an indication of whether the target is coming or going operate as follows: difference frequencies which are proportional to the radial speeds of the targets relative to the radar site are derived by mixing the frequencies of the reflected signal with a reference frequency, which reference frequency is different, by a given and constant amount, from the transmitter frequency. This difference between the transmitted frequency and the reference frequency is at least as great as the maximum Doppler frequency which can be expected, and the value of the Doppler frequency which results from stationary targets is equal to the difference between the reference frequency and the transmitter frequency. Furthermore, the difference frequencies which are assigned to the targets that approach the radar site are greater than the difference frequency assigned to stationary targets and the difference frequencies which are assigned to the targets that move away from the radar site are smaller than the difference frequency assigned to stationary targets.

Doppler radar sets are also used for obtaining the intelligence necessary to control anti-aircraft weapons intended to seek out and destroy airborne craft, e.g., for controlling ground-to-air missiles. Defensive systems intended for use against low-flying craft generally make use of pulse-Doppler-radar sets; in the case of more compact, and hence less complicated systems, CW (continuous wave) radar sets are sometimes used. All these systems have certain inherent and immutable limitations. For one thing, the actual combat gear of such an anti-aircraft system has a given average reaction time which can not be reduced below a given value, this reaction time being the time interval measured from the instant at which the target is initially detected or acquired to the instant at which the missile sent to combat the hostile aircraft is launched. Another constant of the system is the maximum range of the individual missile and the time the missile needs to reach the point of maximum range. Furthermore, the range of the radar set is more or less limited, particularly in the case of radar systems intended for use against low-flying aircraft, because the terrain will often limit the horizontal range of the radiation pattern. For all of these reasons, and particularly because of the last-mentioned one, weapon systems intended for use against hostile aircraft, especially low-flying craft, have to make do with exceedinly short warning times.

The fact that a target acquisition radar system has to respond very quickly and has to give out usable information within very short intervals of time, makes it increasingly important for the system to be able to concentrate on targets and to respond even more quickly. Another problem arises when a number of hostile targets are acquired at the same time so that, due to the sudden appearance of many targets on the radar screen, the observer will have no rational basis on which to assign missiles to the respective targets, particularly when the radar screen does not show any stationary targets. All that is then left to the operator is arbitrarily to select targets to be engaged by the missiles at his disposal.

It is, therefore, the primary object of the present invention to provide a way in which the above drawbacks can be overcome. To this end, the present invention is based on the recognition that the operator must be given a reasonable criterion on the basis of which he can intelligently select from among the hostile targets to be engaged. Once this criterion is established, the entire operation may be taken over by automatic means, so that the present invention, which will be described below, is particularly suitable for obtaining intelligence from targets by means of Doppler radar and other reflection-type apparatus, the apparatus being especially adapted for use in conjunction with anti-aircraft weapons, particularly for combating low-flying craft. Accordingly, the present invention resides in a Doppler radar or other type of reflection responsive apparatus, which may incorporate means for suppressing stationary targets, which apparatus operates in such a manner that information is processed — this term, as used through the instant specification and claims being deemed to mean indicated and/or evaluated — at least initially, only for those targets which are located within a distance zone that is assigned to the particular radial speed (radial speed being the velocity of the target with respect to the radar installation) at which the target is travelling. That is to say, faster moving targets will be first processed while they are relatively far away from the radar site while slower moving targets will be noted as and when they are closer to the radar site. Here it will be assumed, for the time being, that the speed and direction of the radial velocity component relative to the radar site remain at least substantially constant during the time while signals from each respective target are being noted and processed; this, in practice, presents no problem.

Thus, if the present invention is used, for example, in an anti-aircraft weapon system, the radar observer will see a display which shows airborne targets in such a manner as to take into consideration the urgency with which they should be processed, i.e., the faster a hostile craft is flying, the sooner signals reflected therefrom should be processed, which means that the signals have to be processed while the craft is still relatively far away from the installation, certainly further than a more slowly flying hostile craft. Also, the information will be presented to the ground observer in such a manner as to enable him to deploy the anti-aircraft missiles at his disposal in the most efficient and rational manner. That is to say, since each anti-aircraft installation has a given reaction time, this — as explained above — being the time interval that elapses between the instant at which a hostile target is first acquired and the instant at which a missile is launched against that target, and since each missile has a certain maximum range and takes a certain amount of time to reach the limit of its range, it becomes important not to dispatch a missile against a hostile target which, due to its speed and distance, is either too far away or already too close to be effectively engaged by the missile. Thus, thanks to the intelligence made available to the ground observer by a system according to the present invention, those hostile targets which the missiles of the installation can not hope successfully to engage will not be shown to the observer, who will therefore not be unnecessarily confused by information which is basically of no use to him. If desired, an automatic servomechanism may be provided for automatically assigning individual missiles to various ones of a plurality of hostile craft.

The present invention is not limited to military use. Instead, the system could be used for civilian aircraft surveillance at airports, thereby to give the traffic controller an indication of the proximity of aircraft in terms of urgency with which the same must be directed to land, thereby to facilitate the control of instrument landing operations. Furthermore, the invention is applicable for preventing collisions in both air and marine navigation, in that potential colliding craft are indicated on a separate radar display to give an indication of craft in the area in terms of likelihood of collision.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIG. **1** is a block diagram of a CW (continuous wave) radar system according to the prior art, not incorporating the present invention, but basically susceptible to being modified to operate in accordance with the present invention.

FIG. **2** is a block diagram of a CW radar system according to the present invention.

FIG. **3** is a graph, relating to the radar system of FIG. **2**, in which certain band widths and distances are plotted, in accordance with different parameters, as functions of target speeds.

FIG. **4** is a block diagram of a pulse Doppler-radar system according to the present invention.

FIG. **5** is a graph similar to that of FIG. **3** but relating to the radar system of FIG. **4**.

FIG. **6** is a block diagram of a display device of the type which may be used in a radar system such as is depicted in FIGS. **2** and **4**.

FIG. **7** shows a switching tube of a type which may be used in the circuit of FIG. **6**.

FIG. **8** is a pictorial illustration of the display which is produced by a system according to the present invention.

FIG. **9** is a block diagram of a warning device which may be used in conjunction with a radar system according to the present invention.

Referring now to the drawings and to FIG. **1** thereof in particular, the same shows a CW radar set incorporating a high-frequency oscillator **1** whose output is applied to a transmitter **2** having an antenna **3**, as well as to the mixer stage of a radar receiver **4**, the other input of the mixer being connected to receive the signals picked up by the receiving antenna **5**. The transmitting antenna **3** is fixedly connected to the receiving antenna **5** by means of a rotary drive coupling **7**, the latter being driven by a motor **6** which thus serves to rotate both of the antennas so that the air space surrounding the radar set is scanned, in the usual manner. The motor **6** is controlled by an angular position generator (not shown), and the angular position of the motor **6**, and hence that of the antennas **3** and **5**, is applied to a frequency indicator **9** via two leads **8*a*** and **8*b***, the former being used for transmitting the sine-component and the latter for transmitting the cosine-component. The indicator **9** has a number of inputs to which are connected, respectively, the outputs of Doppler frequency filters **10*a***, **10*b***, **10*c***, . . . **101**, **10*m***, **10*n***. Each of these filters passes a different frequency band, but all bands are of the same widths. There are as many frequency filters as there are expected Doppler frequencies corresponding to the radial speeds of possible targets. These Doppler frequencies are taken from the output of a Doppler frequency amplifier **11** whose input is connected to the output of the receiver **4**, so that the inputs of the frequency filters are connected in parallel with each other to the output of amplifier **11**. Here it is pointed out that a radar set such as is shown in FIG. **1** will, in order to be practical, have to have a substantially larger number of individual Doppler frequency filters than is illustrated. Experience has shown that about one hundred such filters will have to be provided in order to produce reasonably satisfactory results.

The radar set shown in FIG. **2** incorporates the same components **1**, **2**, **3**, **4**, **5**, **6**, **7**, **8*a***, **8*b***, and **11** as described above, but is modified so as to operate in accordance with the present invention, in that before any target information is processed, i.e., indicated and/or evaluated, the signals are screened with respect to "urgency" of the target from which they are reflected, i.e., the intelligence signals undergo a selection on the basis of an urgency criterion. The arrangement of FIG. **2** has the still further advantage that it requires substantially fewer Doppler frequency filters than does the radar set of FIG. **1**, it being assumed that both operate throughout the same over-all Doppler frequency range.

In order to make certain that the total reaction time of the anti-aircraft system will be sufficient to engage a hostile craft, the minimum distance at which fast targets have to be initially detected or acquired must be greater than the minimum distance at which slower-moving targets have to be initially detected or acquired. This result is very simply achieved, in the embodiment of FIG. **2**, by "stacking," in a manner of speaking, the receiver-side sensitivity of the radar set by using Doppler frequency filters having different band widths, in the filter banks **12**, **12'**, **13**, **13'**, **14**, depending on the different radial speeds of the targets with respect to the radar site at which the equipment is located. Each filter bank includes one or more filters identified by the reference number of the filter bank, together with an appropriate subscript, as will be described below.

In order to be able to distinguish, in a simple manner, targets moving away from the radar site from targets coming toward the site, the received frequency is mixed, not with the frequency of the oscillator **1** as was the case in the system of FIG. **1**, but with a reference frequency which is coherent with respect to the transmitter frequency, which reference frequency differs from the transmitter frequency by a constant value that is greater than the maximum expected Doppler frequency. Accordingly, the radar set of FIG. 2 includes a coherent frequency converter **15**, known per se, which is interposed between the transmitter oscillator **1** and the mixer stage of the receiver **4**.

The filter bank **12** has assigned to it targets approaching the radar site at radial speeds of, for example, between 500 meters per second and 50 meters per second, while the filter bank **12'** has assigned to it targets moving away from the radar set within the same speed range. But since in many cases, particularly for air defense purposes, targets moving away from the radar site are either of no interest or of interest only under specified conditions, certain ones of the individual filters of bank **12'**, particularly the filters assigned to the higher speeds, can be eliminated. In general, only the relatively slow targets with which filter bank **12'** is concerned will be of interest.

Filter bank **14**, shown as incorporating but a single filter, is assigned to stationary and very slowly moving targets, as, for example, rustling leaves, pedestrians, ground vehicles, and the like. The center of the frequency band passed by filter **14** is equal to the difference between the output frequency of the coherent frequency converter **15** and the transmitter oscillator **1**.

Should a target moving away from the radar site reverse its course and thus become an approaching target, it may be expedient to trigger a separate indicator or warning device, preferably automatically. The arrangement of FIG. **2** is therefore provided with filter banks **13, 13'** which serve as so-called changed direction or turning filters, whose outputs are connected to a warning device **16**, the structure and operation of which will be described more fully below in conjunction with FIG. **9**.

The individual filters of the filter banks **12, 12', 13, 13', 14** of FIG. **2** have pass bands and cut-off frequencies which are selected to meet the requirements of the weapon system with which the radar set is to be used.

The following is an example:

It will be assumed that the radar set is to be used in conjunction with a ground-based anti-aircraft installation intended for use against low-flying craft having a maximum speed of $v_z = 500$ meters per second with respect to the installation, that the target locating means are constituted by a radar system, that the weapons to be used against hostile craft are missiles whose maximum range $R_o = 5$ kilometers and whose maximum flight time $t_{FK} = 8$ seconds. FIG. **3** is a graph showing, for the parameters of the reaction times $t_R = 6$, 10, 14 and 18 seconds (the reaction time t_R being, as explained above, the time that elapses between the instant at which the target is first noted and the instant at which the anti-aircraft missile is launched), the dependency of the minimum detection range R on the velocity v of the target. The distance R can readily be derived from the equation

$$R = R_o + v_z\ (t_{FK} + t_R)$$

and represents the minimum distance from the installation at which the target must be detected in order to enable the system — which has given and basically unchangeable values for R_o, t_{FK} and t_R — to be able effectively to combat a craft moving at a speed v_z. In order to provide a reasonable margin of safety, the parameter t_R which is built into the system will be made greater than that computed theoretically.

The system will further be assumed to have the following characteristics:

Transmitted output: 50 watts.

Gain of the transmitter and receiver antennas, each having a cosecant radiation pattern (only for indication of azimuth): each 1,300.

Wave length: 1.8 centimeters.

Receiver sensitivity: 10 KT_o

(K = Boltzmann constant

T_o = degree Kelvin)

Effective cross-sectional area of target = 1 meter².

The above data make it possible to derive, on the basis of the fundamental radar equations, the effective receiver band width, i.e., the band width B needed for the respective Doppler frequency filters as a function detection distance R:

$$B = 1.14 \cdot 10^{17} \cdot R^{-4}$$
$$= 1.14 \cdot 10^{17} \cdot [R_o + v_z\ (t_{FK} + t_R)]^{-4}$$

With the proportionality factor being $1.14 \cdot 10^{17}$, the value B will be in kilocycles if R_o is in meters, v_z is in meters per second, and t_{FK} and t_R are each in seconds. The relationship expressed by the above equation is shown in FIG. **3**.

FIG. **3** also shows the filter bank if the parameter t_R = 14 seconds. Here it is assumed that the maximum speed v of a hostile craft is 500 meters per second. This produces a band width for filter a_1 of 1.75 kilocycles. The speed which corresponds to a Doppler frequency lower than this frequency is 485 meters per second. Plotting this value at the curve $t_R = 14$, there is obtained, for the next filter a_2 a band width of 1.9 kilocycles. The speed pertaining to the next lower filter flank can then be read off, and so on, thereby to derive the stepped curve representing the filter bank having the widths a_1 to f_4. The band widths are shown in FIG. **3**, so as to indicate the correlation of target speed ranges to filters. For example, the filters **12**a_1 to **12**f_4 of filter bank **12** will, if the system of FIG. **2** is to be used in conjunction with a ground installation having a reaction time of **14** seconds, have the filter band widths a_1 to f_4. The filter band widths g, x_m, x_n, x_F, x_n', x_m', of filters **12**g, **13**x_m, **13**x_n, **14**x_F, **13**x_m', **13**x_n', in filter banks **12, 13, 14**, and **13'**, respectively, are not calculated in accordance with the above relationships, but have been selected, within given tolerances, as having been found to be particularly well suited. The ordinate of the graph of FIG. **3** also shows the detection distance R.

On the basis of FIG. **3**, it will be seen that if the system of FIG. **2** is to be used only for approaching targets, i.e., if no filters are provided for stationary targets or targets changing direction, only eleven filters are required (filters **12**a_1 to **12**g), whereas a system such as is shown in FIG. **1**, which is not in accordance with the present invention, requires no less than thirty-three filters (**10***a*, **10***b*, . . .) to produce the same results. This, it will be appreciated, is a very significant advantage.

The slower moving air-borne targets will generally be constituted by propeller-driven craft or helicopters. The rotating blades of the helicopter rotor produce a relatively wide Doppler spectrum. Slow moving targets, however, automatically find a large evaluating band width in a system according to the present invention and can therefore be identified more readily than is possible with conventional systems in which the individual components of the Doppler spectrum will pass through separate filters so that the system will initially react as if a number of different targets, travelling at different speeds, had been picked up.

The present invention can also be used to advantage in conjunction with pulse Doppler-radar sets, as shown, for example, in FIG. **4.** Such a pulse Doppler radar system comprises a high-frequency oscillator **1′** and a pulse generator **16** which pulses the output signals of a modulation signal generator **17** in synchronism with the oscillations put out by oscillator **1′**. The output of pulse generator **16** is applied to a transmitter **2** and radiated via antenna **3.** The signals picked up by the receiving antenna **5** are applied to receiver **4** which has its output connected to a plurality of distance gates **18***a* . . . **18***n*. The gates serve to select the intelligence appearing at the output of receiver **4** in dependence on the distance, i.e., the different gates will pass signals due to targets located different distances away from the antenna. The number of gates will depend on the distance resolution, i.e., the number of individual distance "windows" into which the space scanned by the antenna is to be divided, the term "distance window" as used throughout the instant specification and claims being intended to refer to a region which is bounded by two arcs of different radius, each having its center at the radar site. To accomplish this, each of the gates **18** has connected to its other input one of the time delay elements **19***a* . . . **19***n*, whose inputs are connected to the generator **17.** These delay elements are designed to delay a signal produced by generator **17,** a time interval which is to correspond to the particular distance window to which the respective gate is to respond, i.e., the time delay element associated with the gate which is to respond to the nearest distance window will provide the shortest delay while the time delay elements associated with gates that are to respond to progressively further distance windows will have longer delays. In this way, signals reflected by targets closest to the installation will be given priority over signals reflected by targets further away from the installation.

Connected between the gates **18** and the indication and/or evaluation unit **9′** are the filter banks **20***a* . . . **20***n*. Each of these banks will have to contain only that number of individual filters, of proper band width, as to enable the indicator unit **9′** to process intelligence from only those targets that are located within the above-defined minimum detection distance *R*.

FIG. **5** is a graph essentially similar to that of FIG. **3,** but relates to the pulse Doppler-radar system of FIG. **4.** The values for B as a function of v are plotted, as in the case of FIG. **3,** for $t_R = 14$ seconds, it being assumed that the other parameters of the installation are likewise the same as those assumed in conjunction with the system of FIG. **3.** If the gate **18***a* . . . **18***n* are to represent distance windows of 1 kilometer each, with a total

range of 11 to 16 kilometers, i.e., 11 km $\leq R \leq$ 16 km, the filter banks **2***oa* . . . **2***on* of FIG. **4** would, in FIG. **5,** have to cover the speed ranges shown, along the abscissa of FIG. **5,** by A, B, C, D, E and F. That is to say, for example, the filter bank 2oa connected to gate **18***a*, which has assigned to it the window of 15 to 16 kilometers, has to cover the speed range A; the filter bank **2***ob*, connected to gate **18***b*, which has assigned to it the window of 14 to 15 kilometers, has to cover the speed range B, and so on. Those targets from which the signal echo is to be first processed, i.e., indicated and/or evaluated, are, within the respective distance windows, assigned to the speed ranges B–A, C–B, D–C, and so on, while those targets which are already located within the above-defined minimum detection distance and whose echo signals are therefore already being processed, are assigned to the other speed ranges up to the maximum indicated speed. For example, targets within the distance window between 14 and 15 kilometers, to which is assigned gate **18***b* and filter bank **20***b*, will first have echo signals processed so long as the speed of such target is within the speed range B–A; if, however, the speed of the target is in speed range A, the echo signals reflected by the target will have already been processed, for the first time, via a distance gate which represents a higher minimum distance (in the case of speed range A, the distance window between 15 and 16 kilometers, which is handled by gate **18***a* and filter bank **20***a*).

All targets having speeds which are assigned to the minimum detection window or higher should have their echo signals passed through all of the distance gate channels, that is to say, all targets in, for example, the distance window between 13 and 14 kilometers and having speeds within the speed range D(FIG. **5**). In order to accomplish this, — it being assumed, in the instant example, that only those targets which are approaching the installation and which are away from it a distance 11 km $\leq R \leq$ 16 km are to be picked for the first time and are to be continuously kept under surveillance thereafter — the filter banks **20***a* . . . **20***n*, connected to the outputs of the distance gates **18**a. . .**18**n, are provided not only with the filters having the band widths $a_1, a_2, a_3, b_4, b_5, c_5, c_6, d_5, e_5, f_4$, but also with filters for targets whose speed is greater than the speeds corresponding to the minimum detection distance. That is to say, that, for example, filter bank **20***b*, which is connected to the output of gate **18***b* which itself is assigned the distance window between 14 and 15 kilometers, has to have not only the filters b_4 and b_5, which are the filters that filter out, for the first time, signals reflected by targets travelling at speeds within the speed range B–A, but also filters having the band widths b_1, b_2, b_3 each of which is equal to b_4, which filters b_1, b_2, b_3 filter out signals reflected from targets travelling at speeds within the speed range A, so that targets pertaining to this distance window (14 to 15 kilometers) — the signals from which targets were, to be sure, first processed while the targets were still within a more distant distance window (for example, via the gate **18**a and the filter bank **20***a*) — will continue to be followed. In general, it can be said that as the number of filters in the individual filter banks becomes larger, the smaller the mean distance of the distance window to which the distance gates to which the respective filters are connected becomes, in order to make it possible to continue following a target throughout all distance windows. But it is not absolutely essential that each of the individual filters which are assigned to speeds greater than the minimum detection distance, i.e., each of the filters of the filter bank connected to the gate which is assigned the distance window between 14 and 15 kilometers, have a band width which, in accordance with the above equation, is dependent on the minimum detection distance R. Instead, it is usually advantageous if in each filter bank there are filters with the same band width as the particular filter in the particular filter bank which, within the distance window given by the respective distance gate, is assigned to the target having the greatest speed, assigned to the minimum detection range. That is to say, for example, that in the case of the distance window between 14 and 15 kilometers, namely, the distance gate **18***b* and the filter bank **20***b*, the latter will have six filters each having the same band width $c_1, c_2 \ldots c_6$, the band width c_5 being the one which determines the band width of the other filters in the filter bank **20***b*.

A very significant advantage of the present invention when applied to a pulse Doppler radar set, is that, besides there being a substantial reduction in the number of filters needed, the ambiguity as to the target distance information will have to be resolved only when necessary since only the fast targets lie in the region of ambiguity.

The present invention may also be used to advantage as secondary or supporting radar in conjunction with both civilian and military applications, e.g., IFF (identification friend or foe). Airport surveillance radar may then be arranged to identify approaching targets on the basis of their range and speed, thereby to establish the priorities with which the craft are to land. In this way, incoming craft may be assigned their landing turn in a logical manner so as to enable the available landing facilities to be put to optimum use.

FIG. **6** shows an embodiment of an indicating and evaluating unit such as may be used in conjunction with the present invention, this unit being shown at **9** and **9'** in FIGS. **2** and **4**. For purposes of explanation, the unit will be that used in conjunction with the circuit of FIG. **4** and is therefore identified by reference character **9'**.

The output signals of the filter banks **20***a* . . . **20***n* are applied to respective rectifiers **21***a* . . . **21***n* whose outputs are applied, via gate circuits **22***a* . . . **22***n*, to the Wehnelt cylinder **23** of a cathode ray display tube **24** when the respective gates are opened by the control signals put out by a saw tooth generator **25**, i.e., a generator putting out a signal having the wave form of saw teeth.

The gate circuits **22***a* . . . **22***n* can be constituted by gate tubes, one of these, e.g., gate **22***a*, being shown in FIG. **7**, together with that portion of the circuitry of FIG. **6** which pertains to the gate circuit shown. The gate tube is in the form of an electron beam switching tube and comprises an evacuated housing **26** within which is arranged a cathode **27**, a ring-shaped accelerating electrode **28** which also serves for focussing the beam emitted by the cathode, plate-shaped deflection electrodes **29** and **30**, a disc-shaped collector electrode or anode **31** and another anode **32** which is simply an electron catcher illustrated as being larger than anode **31**. When the potentials applied to the two deflector electrodes **29** and **30** are equal to each other, the electrons emitted by the cathode **27** follow the path shown in dashed lines at **33** and strike anode **31**, so that the gate **22***a* is open. The electron beam can, however, be deflected in two opposite directions, this being effected by connecting the electrode **29** to the saw tooth generator **25** and electrode **30** to the comparison or reference voltage source **34**. Two of the possible electron beam paths are shown in dotted lines at **33***a*, which show the electrons as striking the electron catcher **32**. This represents the closed condition of the gate circuit **22***a*.

The output signals of the saw tooth generator **25** are shown, in FIG. **6**, as being applied also to one input of each of two multiplication stages **35** and **36**. The other input of stage **35** has applied to it, via line **8***a*, the sine component of the angular position of the motor **6**, while the other input of stage **36** has applied to it, via line **8***b*, the cosine component. The output signals of stages **35** and **36** are applied, respectively, to two pairs of deflection plates **37** and **38**, arranged mutually perpendicular to each other and deflecting the beam of the display tube **24**. The screen of the tube is shown at **39**, whereat will be produced a display such as is shown, for example, in FIG. **8**. FIG. **6** also shows the outputs of the gates as being connected to an audible alarm device **59**.

FIG. **8** depicts the azimuth and speed display presented by the tube. The center **40** of the display represents, as is conventional, the position of the radar installation, the targets being shown, in their proper azimuthal position and as a function of speed, in dependency on their urgency. The echo signals of three possible targets are shown and indicated at **41, 42** and **43.** The ring **44**, which can be formed by means of a template arranged on the screen **39** or which can be made to appear on the screen electronically, by conventional means, enables the observer to distinguish between approaching and departing targets. Approaching targets are, preferably, displayed outside the circle **44** while departing targets are displayed within the circle. Stationary targets are displayed on the circle **44.** The targets represented by echo signals **41, 42, 43,** are thus approaching the installation, while the two further signals **45** and **46,** shown in FIG. **8,** are reflected by targets moving away from the installation. The target from which the echo signal **47** is reflected is a stationary target, or possibly a very slowly moving target whose signals will, in any event, come within the pass band of those filters having the band width x_F (FIG. 3).

Inasmuch as the display of FIG. **8** can be used for many types of target indication, its use is not limited to the radar system described above.

FIG. **9** shows one embodiment of an alarm or warning device **16** of FIG. **2**, it being understood, of course, that such a warning device may also be used in conjunction with the arrangement of FIG. **4**. The output signals of filters $13x_m$, $13x_n$, $13x_m'$, $13x_n'$ of the turning-filter banks **13** and **13'** are applied, via rectifiers **48, 49, 50, 51,** to monostable trigger circuits **52, 53, 54, 55** having different time constants, i.e., in each circuit there is a different time interval between the instant at which the circuit is triggered from stable to astable state and the instant at which the circuit comes back to its stable state. The time constants of the trigger circuits are such that, after they have been triggered at different times in response to the turning of a target, they are returned to their stable states at approximately the same instant. When an approaching target changes its course and becomes a target moving away from the installation, the coincidence circuit **56** does not respond. If, however, a target travelling away from the installation changes its course and approaches the radar set, such a target will, at first, have a progressively slower radial speed relative to the radar antenna, which speed ultimately becomes zero but thereafter increases, so that signals will appear at the outputs of filters **$13x_m'$**, **$13x_n'$**, **$13x_n$**, **$13x_m$**, in that sequence. As a result, the trigger circuits **55, 54, 53, 52,** will — in that sequence — be triggered into their astable states. If the target being tracked has completed its turning before all of the trigger circuits have come back to their stables, each of the inputs of the coincidence circuit **56** will have a signal applied to it, in consequence of which a buffer stage **57** will cause the representation on the display to appear more brightly, thereby to emphasize the same, i.e., to call specific attention to the observer that a given target which was previously a target leaving the radar site has now become a target approaching it. If desired, an acoustic alarm device **58** can also be connected to the output of the coincidence circuit **56** to give an audible indication of the fact that a target, previously moving away from the installation, has changed course and is now approaching.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

What is claimed is:

1. In combination: means located at an operating site for transmitting signals and for receiving those signals which are reflected by moving targets; and means connected to said transmitting and receiving means for processing those of the received signals which are reflected by targets beginning only at such time as any particular target approaching the operating site first comes to within a predetermined distance of the operating site which predetermined distance is a direct function of the radial speed of the respective target relative to the operating site, in consequence of which signals reflected by targets approaching the operating site at a relatively high speed are first processed when such targets are relatively far away from the operating site whereas signals reflected by targets which are approaching the operating site at a relatively slow speed are first processed while such targets are relatively close to the operating site, said processing means comprising a plurality of Doppler frequency filters each of which is assigned to a given speed range, said filters being assigned to successively slower speed ranges and having successively wider band widths.

2. The combination defined in claim **1** wherein the band widths of said filters increase, with decreasing speed range, at least in one predetermined speed range as to cause a fixed time lag, throughout the distance-versus-speed range, until a target reaches a given distance from said operating site.

3. In combination with an anti-aircraft installation having anti-aircraft missiles having, as one parameter, a given maximum range and requiring a given time to reach said maximum range, said installation having, as a further parameter, a given reaction time between the instant at which a hostile target is first acquired and the instant at which a missile is launched, the apparatus defined in claim **1,** said filters having band widths which assign to them such speed ranges which are correlated with said parameters of said installation.

4. The combination defined in claim **1,** further comprising means for mixing the frequency of the received signals with a predetermined coherent frequency which is at least as great as the maximum expected Doppler frequency.

5. The combination defined in claim **1,** further comprising means for processing reflected signals reflected by stationary targets.

6. The combination defined in claim **1,** further comprising means responsive to signals reflected by targets which change their direction of travel with respect to said operating site.

7. The combination defined in claim **6** wherein said target direction change responsive means comprise narrow-band filters for passing signals whose frequency is close to that of the frequency of signals reflected by stationary targets.

8. The combination defined in claim **1** wherein said processing means further comprise gate means interposed between said receiving means and said filters for passing signals to said filters in accordance with the distance of the target which reflects the signals.

9. The combination defined in claim **1** wherein said filters are arranged in a plurality of banks, the filters of each bank having pass bands which are consecutive to each other in the frequency spectrum.

10. The combination defined in claim **9** wherein said processing means include gate means interposed between said receiving means and at least some of said filter banks.

11. The combination defined in claim **10** wherein each of said filter banks includes filters which pass frequency bands representing targets moving slower than the speed range to which the respective filter bank is assigned, in consequence of which signals will be processed which are reflected by targets while the same are closer to the operating site than they were when their reflected signals were initially processed.

12. A Doppler radar system comprising, in combination: means, located at an operating site, for transmitting signals and receiving signals reflected by targets; a plurality of Doppler frequency filter means connected to the output of said receiving means, said filter means incorporating a plurality of individual filters having band widths to pass signals which are correlated with respect to the distance of the target from the site and the speed of the target with respect to the site; and means connected to the outputs of said filter means for processing the signals passed by said filter means.

13. A Doppler radar system as defined in claim **12** wherein said filters are divided into a plurality of banks assigned, respectively, to different speed ranges.

14. A Doppler radar system as defined in claim **13** wherein one of said banks is assigned to stationary targets.

15. A Doppler radar system as defined in claim **13** wherein one of said banks is assigned to slowly approaching targets and another of said banks is assigned to slowly departing targets, said processing means further comprising means connected to said two last-mentioned filter banks for indicating when a departing target changes its course and becomes an approaching target.

16. A Doppler radar system as defined in claim **15** wherein said course change indicating means comprise a plurality of time delay means having different time delays, and a coincidence circuit connected to the outputs of said time delay means for putting out a signal when all of said time delay means apply a signal to said coincidence circuit, thereby to give an indication at the output of said coincidence circuit when a departing target assumes a progressively slower speed away from the site and ultimately a progressively higher speed toward the site.

17. A Doppler radar system as defined in claim **16,** further comprising an alarm device connected to said output of said coincidence circuit.

18. A Doppler radar system as defined in claim **16** wherein said time delay means comprise monostable trigger circuits having different time constants.

19. A Doppler radar system as defined in claim **12** wherein each of said filter means further comprises a gate having one input connected to the output of said receiving means and an output connected to the input of the respective filter, and a time delay element having its input connected to said transmitting means and its output connected to a second input of said gate, the time delay elements pertaining to the respective filter means having different time constants.

20. A Doppler radar system as defined in claim **12** wherein said processing means comprise a display device for presenting a pictorial illustration of targets as a function of speed relative to said site.

21. A Doppler radar system as defined in claim **20** wherein said display device presents the targets also as a function of azimuthal bearing relative to said site.

22. A Doppler radar system as defined in claim **21** wherein said display device comprises: a plurality of gates each having one input connected to a respective one of said filters; a saw tooth generator having its output connected to a second input of each of said gates; a display tube having a cathode, a Wehnelt electrode, and two sets of mutually perpendicular deflection plates, said Wehnelt electrode being connected to the outputs of said gates; two multiplication stages having outputs connected, respectively, to said pairs of deflection plates; means connected to a motor for driving antenna means of said transmitting and receiving means to sweep the air space; means for applying the sine component of the azimuthal position of said motor to one of said multiplication stages; means for applying the cosine component of the azimuthal position of said motor to the other of said multiplication stages; and means for applying the output of said saw tooth generator to another input of each of said multiplication stages.

23. An anti-aircraft installation comprising:

a. a weapon system located at a given site for firing anti-aircraft missiles having a given maximum range and requiring a given time to reach said maximum range, said weapon system having a given reaction time between the instant a hostile target is first acquired and the instant at which a missile is launched;

b. a Doppler radar set for transmitting signals and receiving signals reflected by targets; and

c. radar signal processing means connected to the firing mechanism of said weapon system, said processing means incorporating a plurality of Doppler frequency filter means each connected to the output of said radar set and having a plurality of individual filters whose band widths pass signals which are correlated with respect to the distance of the target from the site and the speed of the target with respect to the site such that signals pertaining to fast targets are applied to the firing mechanism while such fast targets are relatively far away from the site and that signals pertaining to slow targets are applied to the firing mechanism only when such slow targets have progressed to within a distance relatively close to the site, said filters being correlated to said maximum range of said missiles, to the time required for such missiles to reach said maximum range, and to said reaction time of said weapon system.

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