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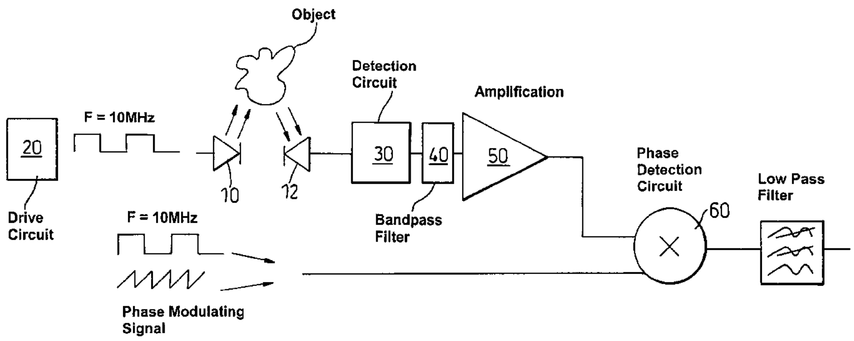
(54) **Title:** A RANGE FINDER AND METHOD OF DETERMINING RANGE



(57) **Abstract:** A range finder comprises a source (10) of radiation, a drive circuit (20) adapted to produce an amplitude modulated drive signal (100) and apply the drive signal to the source (10), and a detector (12) responsive to radiation that has been emitted by the source (10) and which is subsequently reflected from an object whose range is to be determined onto the detector (12). The range finder also includes a detector circuit (30) adapted to produce an amplitude modulated detected signal from the output of the detector (12) dependent upon the radiation from the source (10) that is reflected onto the detector (12), a phase comparison circuit adapted to determine the difference in phase between the drive signal and the detected signal, and a range determining means adapted to determine the range of the object from the source/detector from the determined relative phase. The phase comparison circuit comprises a reference signal generator circuit adapted to produce a reference signal by combining a first signal derived from the drive signal (100) with a second, phase modulating, signal (200); and a comparison circuit which is adapted to compare the detected signal with the reference signal so as to determine the phase of the detected signal relative to the phase of the drive signal. By comparing the phase of the detected signal with that of a reference signal derived from the drive signal (100), the comparison circuit will be independent of any drift in the frequency of the drive signal (100) over time.

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A RANGE FINDER AND METHOD OF DETERMINING RANGE

This invention relates to a range finder, and to a method of determining the range of an object. It is especially but not exclusively related to an optical range finder for use on a vehicle such as may be provided for park distance warning or in a cruise control system.

It is well known to provide range finders on vehicles in order to help the driver of the vehicle to manoeuvre. They may be incorporated into a parking aid system in which it is useful to provide the driver with a warning if they are too near to an obstacle. They may also find application in cruise control systems and lane guidance systems by measuring the distance between the vehicle and a lead vehicle or obstacle on the road ahead.

Where such range finders exist they are often based upon ultrasonic transducers which emit signals that are reflected from obstacles. Such transducers are unreliable, being affected by adverse weather conditions and which generally do not provide an accurate measure of range. Optical devices have been proposed although these are generally based upon laser sources which are relatively expensive and are considered by many to be unacceptable in terms of the publics perception of the devices.

The measurement of range has in the past been based upon time of flight measurements. However, the total time of flight for optical systems over relatively short ranges (up to, say 15m) is very short and accurate measurement therefore requires very high frequency and high accuracy clocks and is impractical to implement at low cost. Similar cost constraints apply with frequency modulated systems in which a frequency modulated signal is emitted by a light source for reflection on to a receiver.

An object of the present invention is to provide a range finding apparatus which in at least one embodiment is suitable for use in an automotive vehicle installation.

According to a first aspect the invention provides a range finder comprising:
a source of radiation;
a drive circuit adapted to produce an amplitude modulated drive signal and apply the drive signal to the source;
a detector responsive to radiation that has been emitted by the source and which is subsequently reflected from an object whose range is to be determined onto the detector;
a detector circuit adapted to produce an amplitude modulated detected signal from the output of the detector dependent upon the radiation from the source that is reflected onto the detector;
a phase comparison circuit adapted to determine the difference in phase between the drive signal and the detected signal; and
a range determining means adapted to determine the range of the object from the source/detector from the determined relative phase.

The amplitude modulated drive signal may be of fixed frequency or of substantially fixed frequency. This allows a relatively simple drive circuit to be provided. By fixed frequency we mean that it does not vary substantially over a period of time sufficient to allow the range to be determined to the object.

The phase comparison circuit may comprise:
a reference signal generator circuit adapted to produce a reference signal by combining a first signal derived from the drive signal with a second, phase modulating, signal; and

a comparison circuit which is adapted to compare the detected signal with the reference signal so as to determine the phase of the detected signal relative to the phase of the drive signal.

By comparing the phase of the detected signal with that of a reference signal derived from the drive signal, the comparison circuit will be independent of any drift in the frequency of the drive signal over time. Again, this overcomes the need for very high accuracy clocks such as are needed in a frequency modulated system.

The range determining means may comprise a processor, an area of memory and a look up table held in the memory which stores a set of phase differences correlated with a set of range values, each phase difference corresponding to one of the range values in the set. Where the determined phase difference has a value which lies between the two closest of the phase differences stored in the look-up table then the range determining means may be adapted to interpolate between the corresponding pair of stored range values.

The provision of a range determining means based upon a look up table may be readily implemented in either hardware or software or perhaps a combination of the two. Conveniently the determined phase difference value may be fed to the input of a microprocessor which allows for considerable flexibility in the way in which the determined value is manipulated to determine range.

It will of course be understood that the phase differences need not be stored in the look up table as real world angular values. They may be stored as incremental numerical values which increase according to phase shift from a minimum to a maximum value. They could, for example, be values from 0 to 100, with zero corresponding to zero phase shift and 100 to 359 degrees phase shift.

By producing a reference signal which has a varying phase over time and comparing its phase with that of the detected signal there will be a point in time at which the reference "modulated" signal is in a known phase relationship with the detected signal. This can be used as a clear indicator of the time delay in the detected signal path and hence the range to the target.

It will, of course, be understood that it is possible to compare the phase of the reference signal and the phase of the detected signal in many different ways. The most preferred is to compare the signals by subtracting one from the other. This will produce a zero value when they are in phase which is easy to detect. Passing both the reference signal and the detected signal to the two inputs of a standard comparator circuit and feeding the output to a zero crossing detector would achieve this measurement. Another phase relationship could be identified as an alternative, such as the point at which the reference signal and the detected signal are in anti-phase. This would produce a maximum (or minimum) output value from a simple comparator depending on which signal is fed to which input. Again, this could easily be detected.

It will, of course, therefore be understood that it is possible to compare the phase of the (phase-modulated) reference signal and the detected signal in several different ways. The most preferred method is to compare the signals by means of a phase sensitive detector (PSD). The phase modulation applied to the reference signal may conveniently take the form, for example, of a saw-tooth modulation, so that the phase of this signal is repeatedly swept over a range of values. The output of the PSD comparing this phase-modulated reference signal with the detected signal will then be a quasi-sinusoidal signal, with peaks, troughs, zero-crossings, and so on.. The precise form of this output signal (that is, the precise positions along the time axis of the peaks, troughs and zero-crossings of the PSD output signal, relative to the saw-tooth phase modulation applied to the reference signal) will depend upon the actual phase of the detected signal (and hence upon the target range). For example, let it be assumed that a minimum (trough) occurs- which may be a zero crossing- in the PSD output when the detected signal is in phase quadrature with the phase-modulated reference signal. For a particular target distance, this zero-crossing will occur at a particular point during the phase sweep on the reference signal (that is, at a particular time-base position). If the target distance (and, hence, the phase of the reflected signal) now changes, the time-base position at which the reflected signal and the phase-modulated reference signal come into phase-quadrature will also change. By monitoring the time-base position of (in this example) the zero-crossing in the PSD output, changes in target distance can be monitored. The actual target distance can be determined by comparing (in this example) the time-base position of the PSD signal zero crossing with the position of this zero crossing when the target is at a known (preferably zero) distance. This latter position may be stored as a reference against which to compare the measured values during operation of the sensor: alternatively, a range of previously-determined references may be stored in a look-up table to enable the target distance to be inferred.

The main point of this arrangement is that it enables the very small changes in time-of-flight that occur for target distances of a few metres to be transmuted into much more easily measured signal changes on the time-base of the reference signal phase modulation. The repeat frequency of this phase modulation may typically be between 100 Hz and 1 kHz, so that simple, inexpensive electronics may be used to derive the target distance values.

Whilst the example above describes the use of the zero crossing in the PSD output signal for determining target distance, any other regular feature of this signal may be used instead, provided the phase relationship between the detected signal and the phase-modulated reference signal which gives rise to this PSD signal feature is known. For example, it may be more convenient to use the time-base position of the minimum point as the monitoring point. It is necessary to arrange that, for whichever PSD signal feature is used, the phase modulation applied to the reference signal sweeps the phase sufficiently to ensure that the required phase relationship between detected and reference signals occurs for all possible target distances.

The reference signal may be produced by applying a first phase shift to the drive signal, then at a later time applying a second, greater, phase shift, then at a still later time applying a third, greater still, phase shift. This may be done over a period of time and then repeated. It may be performed step wise, with the phase being shifted in stepped increments over a range of phases using a stepped phase modulating signal. Alternatively, it may be varied continuously using a ramp (sometimes described as a sawtooth or triangular) modulating signal waveform.

The drive signal may comprise a square or rectangular waveform having a known period. This period may be chosen as a function of the maximum range of distances to be measured. A simple clock signal may be used to produce the drive signal, the period of the drive signal being fixed at a single (or typically a large multiple of) clock cycles. The square wave may be produced by driving a port alternately to a high and a low signal state (i.e. switching rapidly from On to Off).

The period of the drive signal is preferably chosen so that the maximum phase shift that can arise between the drive signal and the detected signal over the maximum permitted range of distances is less than 360 degrees, providing for a unambiguous relationship between the relative phase of the drive and detected signals.

The phase modulating signal may vary the phase of the drive signal over a range of phases corresponding to the maximum permissible phase shift of the detected signal relative to the drive signal.

The period of the modulating signal should be longer than the period of the drive signal. It is preferred that the period of the modulating signal is at least twice that of the drive signal, and most conveniently may be considerably longer than that. It may be at least one, or two or more orders of magnitude longer.

The source of radiation may comprise an optical source of radiation. It most conveniently comprises a light emitting diode (LED). Of course, it will be understood that other optical sources may be provided such as lasers or laser diodes.

The detector may comprise a photodiode which is sensitive to a range of wavelengths of optical radiation which includes at least one wavelength which is emitted by the source of radiation. Conveniently, the spectral response of the detector and the source are as similar as possible.

The detected signal may be filtered using a bandpass filter having a passband which is centred or close to centred on the frequency of the amplitude modulated drive signal. Such a filter may help to reduce the noise produced by unwanted radiation detected by the detector such as daylight or other external sources of radiation. Filtering may be applied before or after amplification or both.

The output of the comparator (where provided) may also be filtered using a low pass filter if desired.

According to a second aspect the invention provides a method of determining the range of an object comprising:
generating an amplitude modulated drive signal and applying the drive signal to a source of radiation;
providing a detector and producing a detection signal dependent upon the radiation from the source that is reflected onto the detector;
determining the difference in phase between the drive signal and the detected signal; and
calculating the range of the object from the source/detector from the determined relative phase.

The method may comprise producing a drive signal which has a varying amplitude but a fixed frequency over time and determining the difference in phase between the drive signal and the detected signal by performing the steps of:
producing a reference signal by combining a first signal derived from the drive signal with a second, phase modulating, signal; and
comparing the detected signal with the reference signal so as to determine the phase of the detected signal relative to the phase of the drive signal.

Most conveniently the phase modulating signal may comprise a ramp or sawtooth or triangular waveform which may have a period greater than the period of the drive signal. Of course, other waveforms may be used and this should not be construed as limiting on the scope of protection sought.

There will now be described, by way of example only, one embodiment of the present invention with reference to the accompanying drawings of which:

Figure 1 is an overview of an optical range finding apparatus in accordance with the present invention fitted to a front bumper of a vehicle;

Figure 2 is a general schematic diagram of the electronic arrangement of the apparatus shown in Figure 1;

Figure 3 is a detailed schematic diagram of the drive circuit for the light source of Figure 2;

Figure 4 is a detailed schematic diagram of the receiver circuit of the detector of Figure 2;

Figure 5 is a typical amplitude modulated drive signal for the light source;

Figure 6 is a typical phase swept waveform for generating a phase modulated reference signal

Figure 7 is an illustration of a simple band pass filter and its frequency response; and

Figure 8 is an illustration of the phase detection circuit used in the apparatus of Figure 1.

The apparatus of Figure 1 comprises a light source 10, such as a light emitting diode, and a light detector 12, such as a photodiode, mounted in a frame alongside one another. The frame (not shown) is secured to a region of the front of a vehicle so that light from the LED is projected in front of the vehicle. An obstacle in front of the vehicle 14, such as a wall or another vehicle, will reflect light from the LED 10 onto the photodiode 12.

The input to the LED 10 and the output from the photodiode 12 are connected to an electronic 14 circuit which is shown in more detail in Figures 3 and 4 of the accompanying drawings, and in general in the schematic of Figure 2. This circuit is powered from the vehicle battery 16.

The LED 10 is driven by a drive circuit 20. A simple drive circuit which is suited to this application is illustrated in Figure 3 of the accompanying drawings. It comprises three amplification stages (shown generally as block 22) arranged in parallel for the generation of relatively high drive currents and connected between a positive 5 volt rail 24 and an earth (zero volt) rail 26 to the light emitting diode 10. A suitable diode 10 is that sold as the type HIRL5015. The input to the three stages 22 is provided as a square wave amplitude modulated drive signal 100 produced by an external waveform generator circuit (not shown) and fed from a clock. Such a drive signal 100 is shown in Figure 5 of the accompanying drawings.

In a prototype which has been produced to verify the system the drive signal 100 has been generated by a laboratory function generator and passed to the drive circuit along a length of BNC cable 28. In a finished system it is envisaged that a digital clock feeding into a counter circuit would provide this functionality. The square wave drive signal 100 applied to the LED 10 has a fixed 10Mhz frequency although other frequencies may be employed. The drive circuit 20 causes the LED 10 to emit a series of short pulses of light. Some of this emitted light is reflected back from objects in front of the vehicle onto the photodiode 12.

The photodiode 12 is connected to an input of a detection circuit 30. A suitable detection circuit 30 is illustrated in Figure 4 of the accompanying drawings.

When light reflected from an object is incident upon the photodiode 12 it produces an amplitude modulated square wave output signal which has the same frequency as the signal that drives the LED. It will also contain noise which is caused by the sensitivity of the photodiode to ambient light which may be present. This low level signal is fed to an op-amp having a trans-impedance gain of 4700volts per amp.

The output of the detection circuit 30 is fed to an optional amplifier and then to an optional bandpass filter 40. The filter 40 removes the noise but allows the frequency(ies) present in the drive waveform to pass. In this example it is chosen to have a narrow pass band centred around 10Mhz. A simple filter which may be used is illustrated in Figure 7 along with its passband given by the equation:

$$\mathbf{f}_0 = \frac{1}{2\pi\sqrt{\mathbf{LC}}}$$

and values of $L = 1.5\mu H$ and $C = 150pF$ provided the required 10MHz centre frequency.

The filtered signal is subsequently amplified 50 and passed to a phase detection circuit 60. A suitable phase detection circuit 60 is illustrated in

Figure 8 of the accompanying drawings. The purpose of the phase detection circuit is to determine the relative phase difference between the drive signal and the detected signal which is a function of the path length between the LED 10, the object 14 whose range is to be determined and the photodiode 12.

The phase detection circuit 60 comprises an MC1496 balance modulator integrated circuit which is connected in circuit as a phase sensitive detector (PSD). The PSD has two inputs and produces an output which is dependent upon the difference between the two inputs. A first one of the inputs is fed with the detected signal generated by the detection circuit. The other ,second, input is fed with a reference signal which is derived from the drive signal and which is phase modulated by a phase modulating signal.

The reference signal fed to the second input of the PSD is obtained by applying a phase modulating waveform 200 to a signal derived from the drive signal 100. An example of a suitable modulating waveform is shown in Figure 6 of the accompanying drawings. In this example the phase modulating signal 200 comprises a ramp or sawtooth waveform which is combined with the drive signal to give a time-varying phase modulation of the reference signal. In this example a ramp frequency of 100Hz was selected. The resulting reference signal fed to the PSD will over a 10millisecond period drift into and then out of phase with the detected signal applied to the first input of the comparator. The output from the PSD will be maximum when the received signal and the phase swept reference signal are in phase and zero (null) when they are in quadrature.

It will therefore be appreciated that for an object at a fixed range the output of the PSD will be pseudo-sinusoidal and pass periodically through a zero point with a period that corresponds to the period of the phase modulating ramp. To determine the range of the object, the phase of the reference signal when the output of the PSD is null is determined. Since it is known that this indicates the relative phase shift between the drive signal and the received signal, a final processing stage can determine the range using an appropriate look up table which tabulates phase against range.

It is envisaged that the final processing stage will be performed by a microprocessor. The output of the PSD and the phase modulating ramp waveform are passed through analogue to digital converters (also not shown) and passed to the microprocessor. An area of memory associated with the processor stores a look-up table which has for each digital value of the ramp waveform a range value. When the output from the PSD crosses zero the corresponding ramp value is used to read out the range from the look-up table.

The apparatus described hereinbefore can be arranged to work over a object distances by appropriate selection of the period of the drive signal. The amplitude modulated drive signal should have a period which is suitable for the range of distances which the apparatus is intended to measure.

For this example, where the apparatus forms a part of a parking- distance sensor that helps to tell a driver of a vehicle how near to an object the vehicle is, a working range of 15 metres is useful. For a maximum phase shift of 360 degrees over the total maximum path length of 2*15m= 30m this dictates a frequency of:

Mod freq= c/L = 10 MHz

Where c is the speed of light = =$3*10^8$m/second

and L is the maximum path length =30m.

In such a set up, a range of 0 metres produces a minimal phase shift whereas a maximum of 15 metres produces the full 360 degree phase shift. It should, of course, be noted that the total path length is twice the range of the object from the source/detector.

CLAIMS

1. An optical range finder comprising:

a source of radiation (10);

a drive circuit (20) adapted to produce an amplitude modulated drive signal and apply the drive signal to the source;

a detector (12) responsive to radiation that has been emitted by the source (10) and which is subsequently reflected from an object whose range is to be determined onto the detector (12);

a detector circuit (30) adapted to produce an amplitude modulated detected signal from the output of the detector (12) dependent upon the radiation from the source that is reflected onto the detector;

a phase comparison circuit (50) adapted to determine the difference in phase between the drive signal (100) and the detected signal; and

a range determining means adapted to determine the range of the object from the source/detector from the determined relative phase;

and in which the phase comparison circuit comprises:

a reference signal generator circuit adapted to produce a reference signal by combining a first signal derived from the drive signal (100) with a second, phase modulating, signal; and

a comparison circuit which is adapted to compare the detected signal with the reference signal so as to determine the phase of the detected signal relative to the phase of the drive signal.

2. A range finder according to claim 1 in which the amplitude modulated drive signal (100) is of fixed frequency or of substantially fixed frequency.

3. A range finder according to claim 1 or claim 2 in which the range determining means comprises a processor, an area of memory and a look up table held in the memory which stores a set of phase differences

correlated with a set of range values, each phase difference corresponding to one of the range values in the set.

4. A range finder according to claim 3 in which the range determining means may be adapted to interpolate between the corresponding pair of stored range values in the event that the measured phase difference lies between two adjacent phase difference values held in the look-up table.

5. A range finder according to any preceding claim in which the detected signal and the reference signal are compared by a phase sensitive detector (PSD).

6. A range finder according to claim 5 in which the comparison means comprises a PSD with both the reference signal and the detected signal (100) fed to the two inputs of the PSD, and a zero crossing detector to which the output of the PSD is fed.

7. A range finder according to any preceding claim in which the reference signal is produced by applying a first phase shift to the drive signal, then at a later time applying a second, greater, phase shift, then at a still later time applying a third, greater still, phase shift.

8. A range finder according to claim 8 in which the phase modulating signal comprises a ramp waveform.

9. A range finder according to any preceding claim in which the drive signal (100) comprises a square or rectangular waveform having a known period.

10. A range finder according to any preceding claim in which the source (10) of radiation comprises an optical source of radiation.

11. A range finder according to claim 10 in which the source of radiation comprises a light emitting diode (LED).

12. A range finder according to claim 10 or claim 11 in which the detector (12) comprises a photodiode which is sensitive to a range of wavelengths of optical radiation which includes at least one wavelength which is emitted by the source of radiation.

13. A method of determining the range of an object comprising:
generating an amplitude modulated drive signal (100) and applying the drive signal (100) to a source of radiation (10);
providing a detector (12) and producing a detection signal dependent upon the radiation from the source (10) that is reflected onto the detector (12);
determining the difference in phase between the drive signal (100) and the detected signal; and
calculating the range of the object from the source/detector from the determined relative phase.

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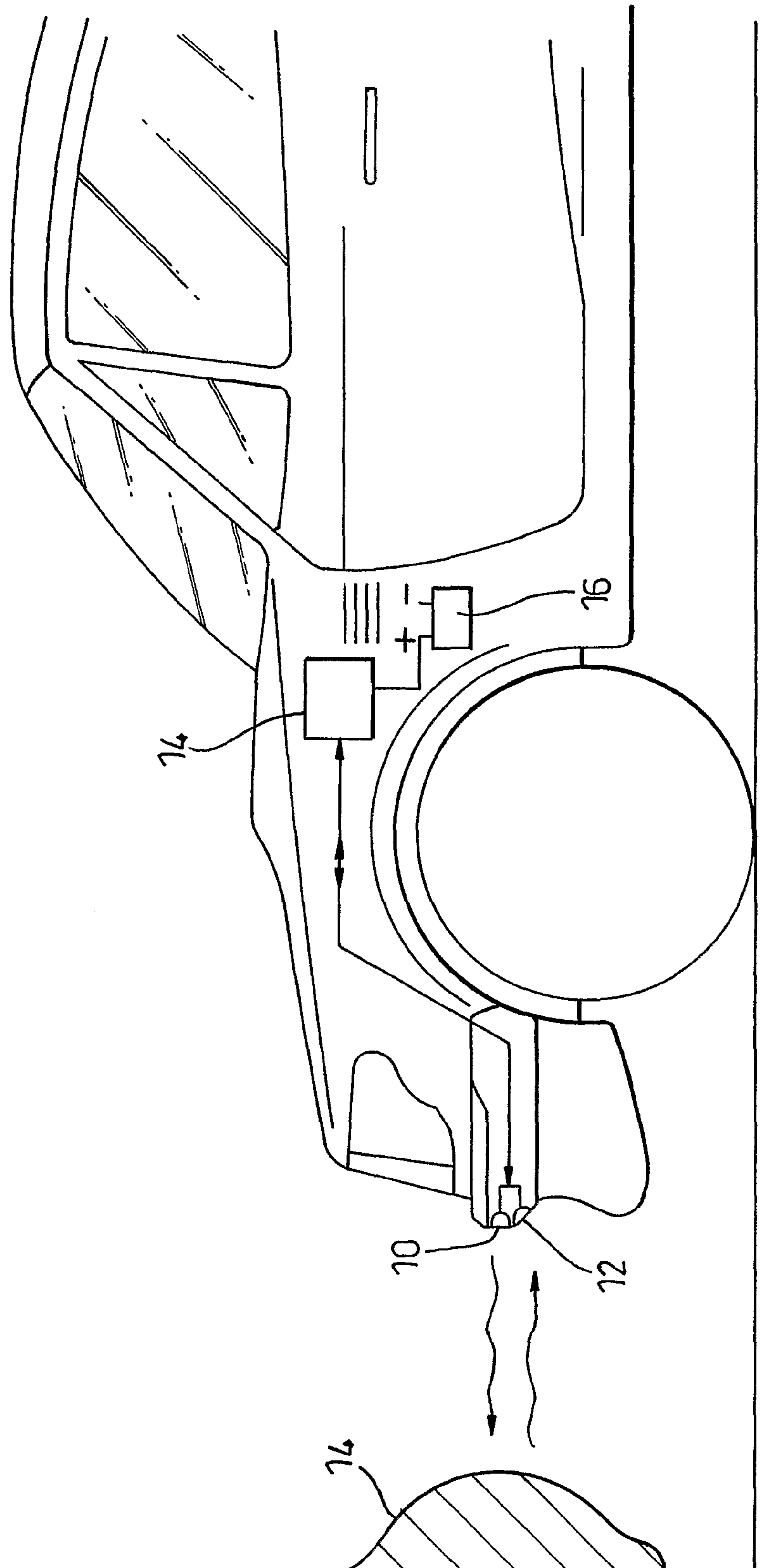

Fig. 1

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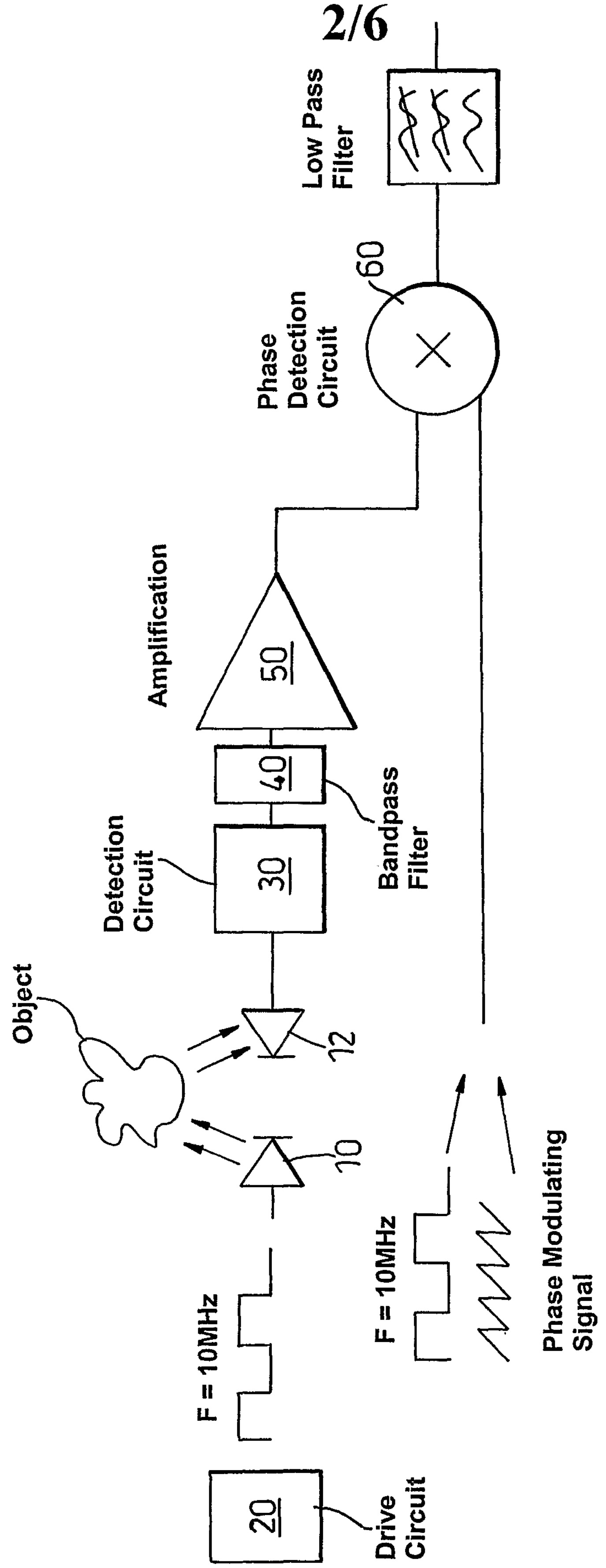
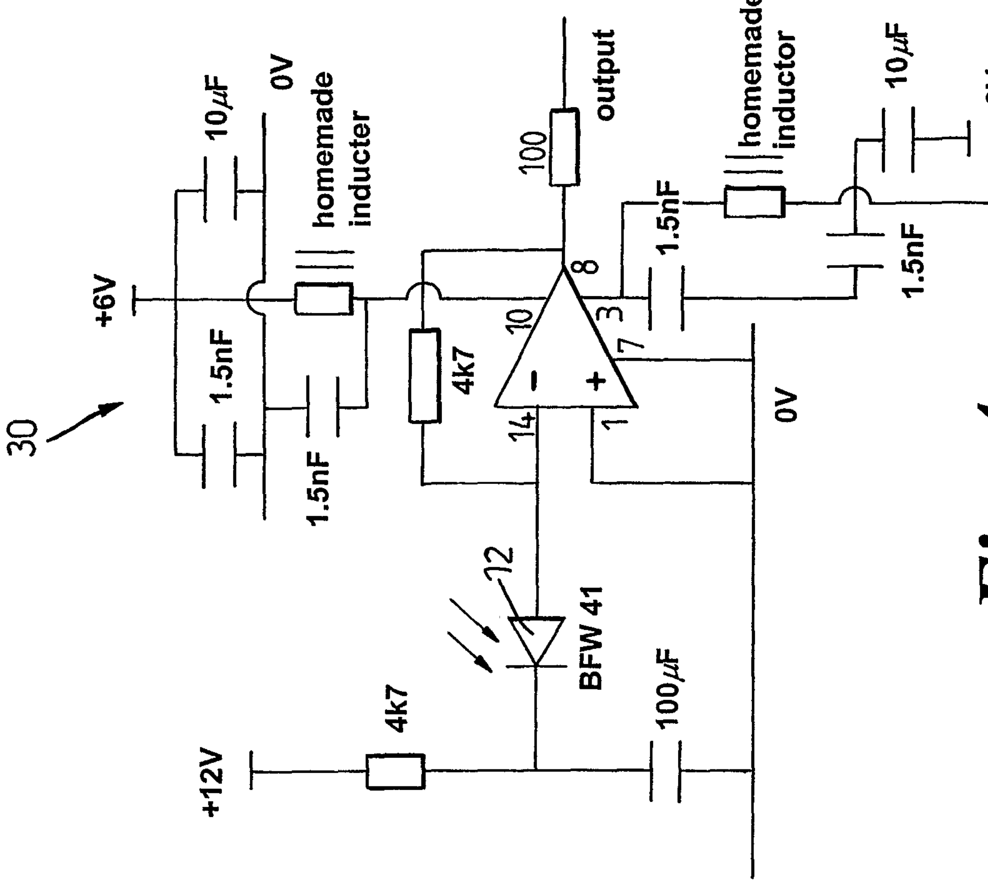

Drive Circuit
20
F = 10MHz
10
Object
12
Detection Circuit
30
40
Bandpass Filter
50
Amplification
Phase Detection Circuit
60
Low Pass Filter
F = 10MHz
Phase Modulating Signal

Fig. 2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10μF
0V
1.5nF
1.5nF
homemade inducter
4k7
100
output
8
10
3
14
7
1
1.5nF
homemade inductor
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0V
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-5V
0V
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BFW 41
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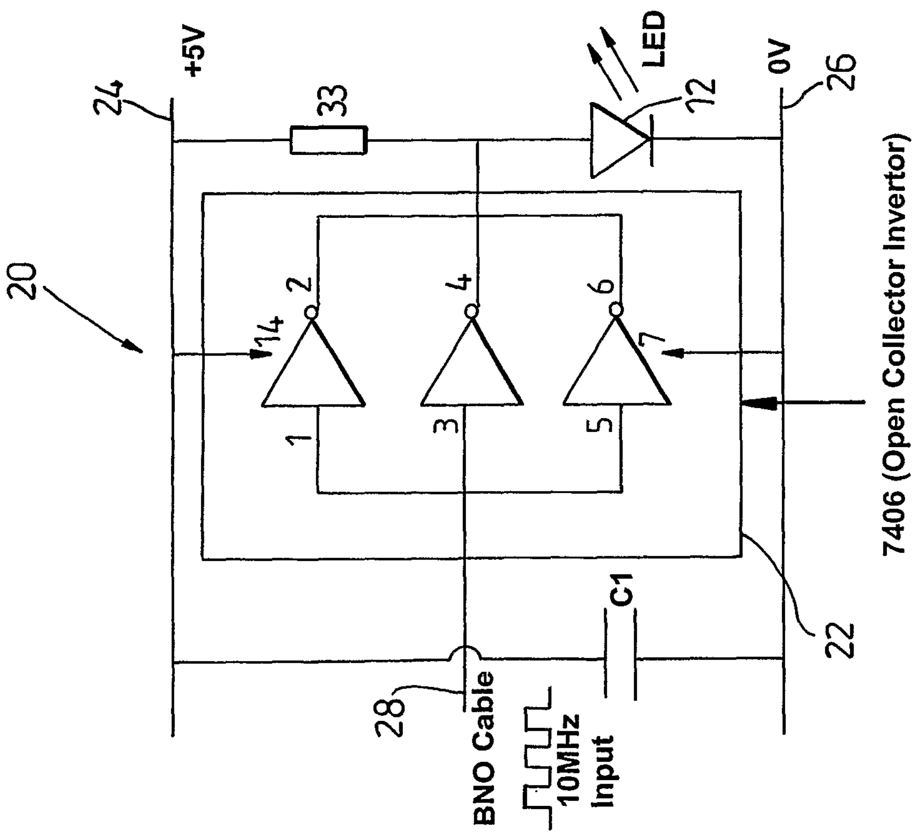
100μF

Fig. 4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24
+5V
33
LED
12
0V
26
14
2
4
6
7
1
3
5
7406 (Open Collector Invertor)
22
C1
28
BNO Cable
10MHz Input

Fig. 3

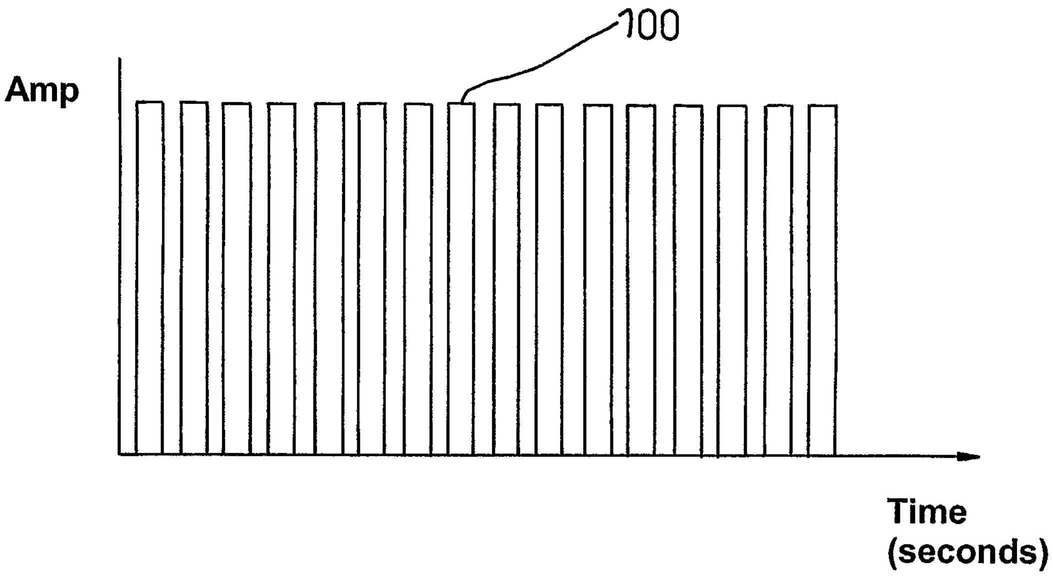

Fig. 5

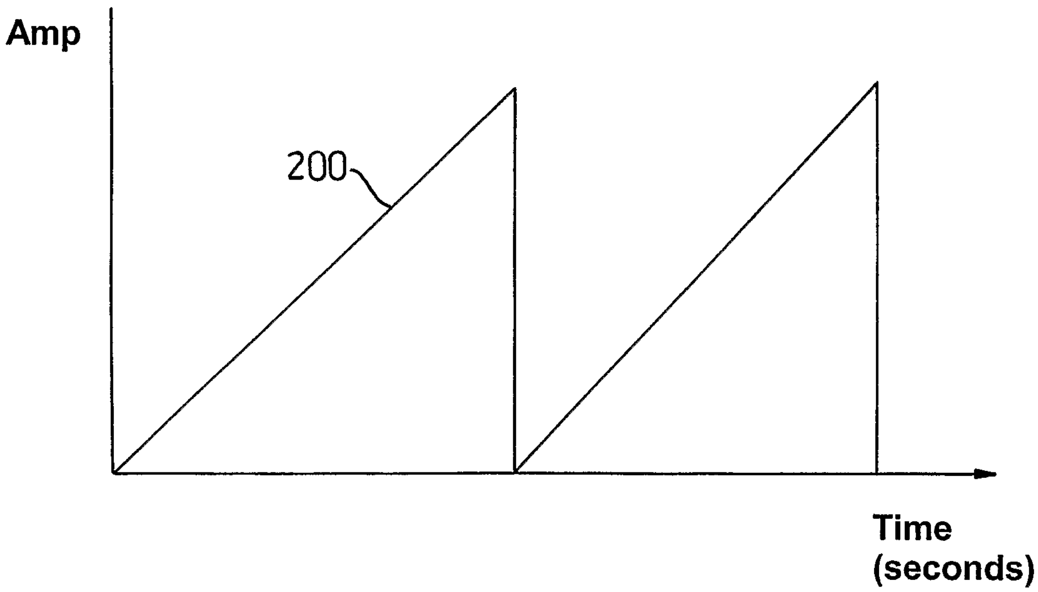

Fig. 6

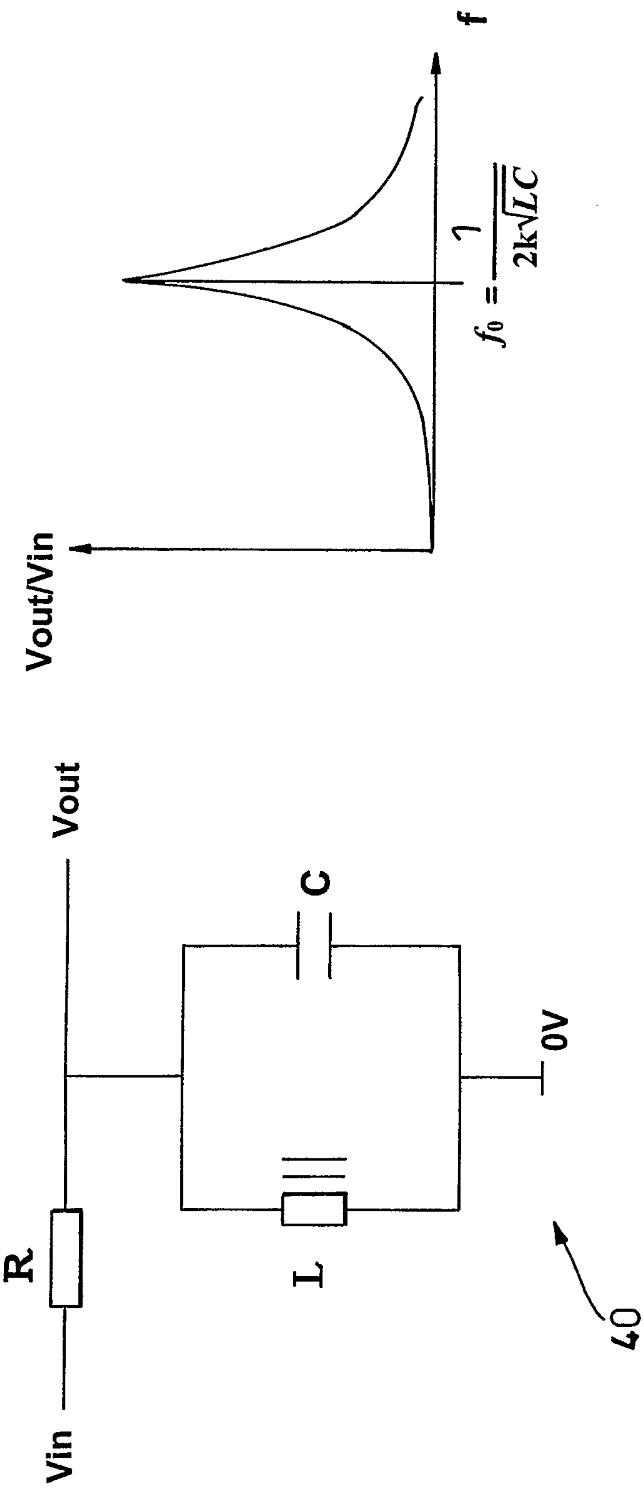

Fig. 7

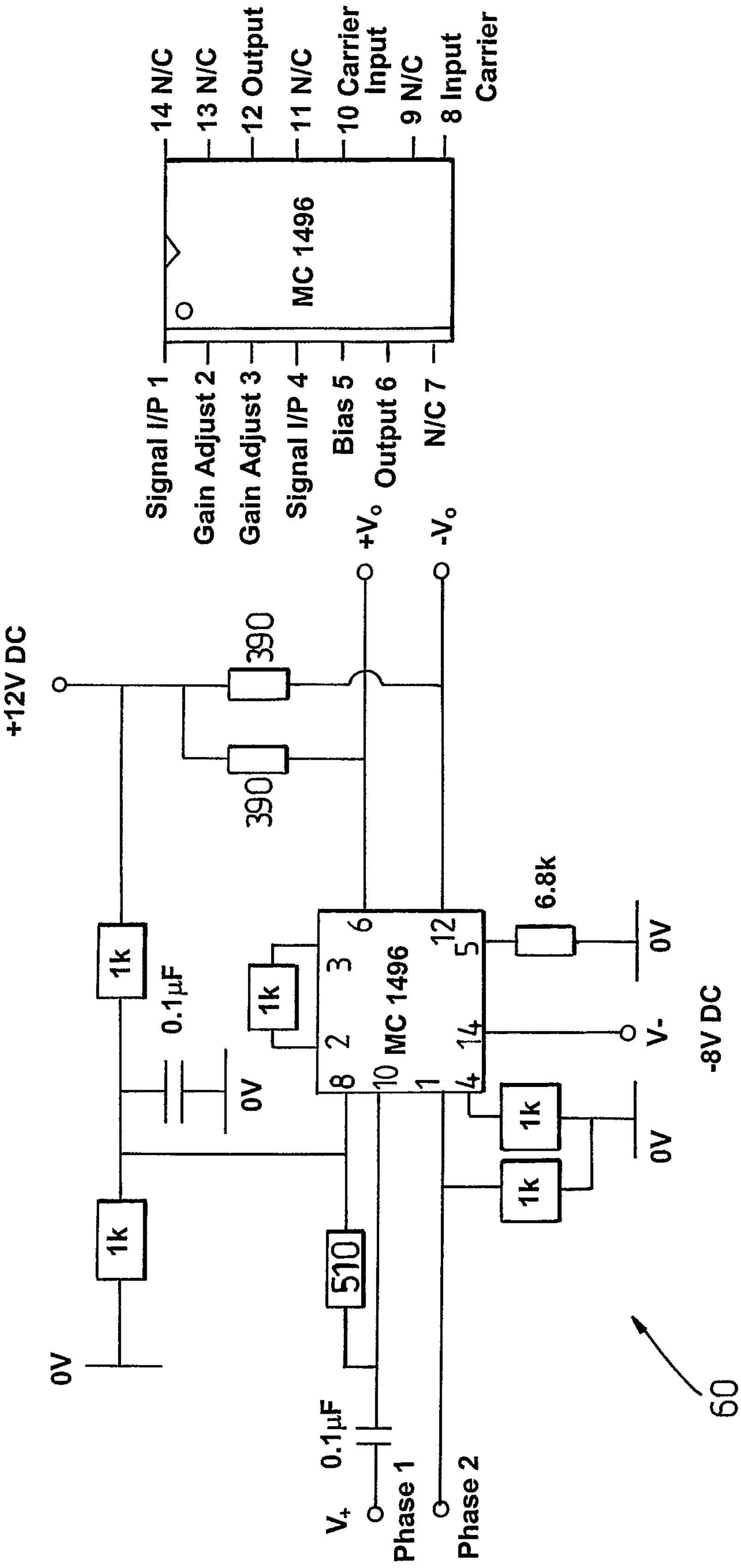
14 N/C
13 N/C
12 Output
11 N/C
10 Carrier Input
9 N/C
8 Input Carrier
MC 1496
Signal I/P 1
Gain Adjust 2
Gain Adjust 3
Signal I/P 4
Bias 5
Output 6
N/C 7
+12V DC
390
390
+Vo
-Vo
1k
0.1μF
0V
1k
MC 1496
6.8k
0V
V-
-8V DC
1k
1k
0V
1k
510
0V
0.1μF
V+
Phase 1
Phase 2
60

Fig. 8

INTERNATIONAL SEARCH REPORT

PCT/GB 03/04156

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S17/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01S H03D H03L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 768 877 A (TORREGROSA MICHEL ET AL) 6 September 1988 (1988-09-06) figure 2 column 1, line 5-29 column 3, line 45-51 ---	1,2,5,7, 9-13 3,4,6
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 January 2004	15/01/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Kern, O

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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