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ROBERT JAMES ALBRIGHT for the M.S. in Electrical Engineering

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Title TWO-INTEGRATOR DETECTOR FOR KNOWN-SIGNAL-IN-NOISE IDENTIFICATION

Abstract approved

This thesis discusses the design and evaluation of an instrument that can detect known signals in noise. This detector uses two integrators to sense a difference in the received signal between half-cycles of the known signal.

The detector is useful for sensing signals in the approximate frequency range of 100 cps to 35 kcps. As an example of the sensitivity of the detector, a 100 cps sine wave can be reliably detected in random noise where the peak signal magnitude is one-fortieth of the rms noise magnitude.

The detector circuit is small and is economical to build. The instrument is quite easy to operate and the results of the detection process are known within one minute once the preliminary adjustments have been made. A complete circuit diagram and a detailed set of operating instructions are given.
TWO-INTEGRATOR DETECTOR FOR
KNOWN-SIGNAL-IN-NOISE IDENTIFICATION

by

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TWO-INTEGRATOR DETECTOR FOR
KNOWN-SIGNAL-IN-NOISE IDENTIFICATION

INTRODUCTION

Electrical engineers are constantly confronted with noise problems of various degrees in the equipment that they design. Sometimes the noise may be much greater than the signal. This problem may arise when a known signal is transmitted through wire, air, or water. Often, the only question to be answered is whether or not the known signal is being received.

Several methods have been used to detect the presence of a known signal in noise. Conventional filters are simple and are useful when the frequency of the noise is considerably different from the frequency of the known signal. However, when the frequency of the noise is in the same range as the frequency of the known signal, the usefulness of filters is limited.

The common techniques presently used to detect a signal in noise are autocorrelation, cross-correlation, and the application of matched filters. These methods give good results but often the equipment needed to implement these methods is quite complicated and expensive (6, p. 413-422).

A different approach will be presented for detecting a known signal in noise. The detector does not sense as small a signal as some of the other methods which have been used (6, p. 422).
However, the detector circuit is quite simple and it gives the results of the detection process within one minute once the preliminary adjustments requiring less than five minutes are made.

The detector may be used to detect a periodic signal of known frequency in the approximate range of 100 cps to 35 kcps. Sinusoidal, square, triangular, and periodic pulse waveforms are examples of this type of signal.

The noise may be any type whose average magnitude above a selected level is independent of time during the detection process. Gaussian noise and a dc voltage are examples of this type of noise.

To demonstrate the effectiveness of the detector, a 100 cps sine wave can be reliably detected in random noise for a peak signal magnitude one-fortieth of the rms noise magnitude.
DETECTION PRINCIPLE

The theoretical basis of the designed detector will be presented in this section. First, a combination of signal and noise waveform will be closely examined for clues of a possible method of detecting a known signal in noise. Once a possible detection method is discovered, the effect of the frequency and phase of the known signal and noise upon the detection principle will be considered.

Received Signal Waveform Characteristics

Suppose that a periodic signal is superimposed on noise. What is the difference in the appearance of the combination signal waveform with respect to the noise waveform? Consider the typical combination of a square wave and noise shown in Figure 1. The noise is shifted each half-cycle by a voltage equal to the peak-to-peak magnitude of the square wave, 2E volts. Now, suppose a positive voltage level, L, is selected as shown in the sketch. The combination signal is above this level for a longer period of time during the more positive half-cycle than during the less positive half-cycle. The magnitude of the combination signal above this level is also larger during the more positive half-cycle than during the less positive half-cycle. Similar reasoning holds for other types of periodic signals. Thus, the presence of a known signal can be sensed by
Figure 1. Typical combination of periodic signal and noise.

noting whether or not such a difference exists between adjacent half-cycles. The level $L$ at which the comparison of the combination signal between adjacent half-cycles is made will be called the "detection level."

The average magnitude of the combination of a square wave and Gaussian noise above the detection level during each half-cycle can be calculated using the probability relations for Gaussian distributions. The ratio of the average magnitude for the more positive half-cycle to the average magnitude for the less positive half-cycle gives an indication of how small a signal can be detected in the noise. The larger the ratio, the easier is the sensing of a difference in the average values above the detection level for each half-cycle. The
equation used for this calculation is given in Appendix I.

Figure 2, obtained with tables of probability functions (2, p. 1-343), gives the ratio of these average magnitudes above various detection levels for different signal strengths. Both the detection levels and the peak signal strengths are given in terms of the rms noise magnitude $\sigma$. The ratio increases for larger signal magnitudes and also for higher detection levels.

To obtain a better indication of whether or not a signal is present in the noise, the average value of the combination of signal and noise above the detection level could be summed over several cycles. Thus, two integrators could be used to sum the average values with one integrator summing during the more positive half-cycle and one integrator summing during the less positive half-cycle. This means that these integrators must be alternately switched on and off at the frequency of the periodic signal.

The integrators could be matched using the noise of the received signal so that the rates at which the average values of the noise accumulate are the same. Then, if a signal is superimposed on this noise, there will be a difference in the rates at which the average values of the combination signal accumulate.

**Frequency and Phase of Known Signal**

The sketches in Figures 3, 4, and 5 show sine waves of
Figure 2. Ratio of the average magnitudes of the combination of signal and noise above the detection level for a square wave superimposed on Gaussian noise.
Integrator No. 1

State
On Off On Off On Off On Off On Off

Voltage

Time

a. Arbitrary phase between signals.

Integrator No. 2

State
Off On Off On Off On Off On Off On

Voltage

Time

Integrator No. 1

State
On Off On Off On Off On Off On Off

Voltage

Time

Integrator No. 2

State
Off On Off On Off On Off On Off On

Voltage

Time

b. Another phase between signals.

Figure 3. Square waves representing integrator states having a higher frequency than a sine wave.
Figure 4. Square waves representing integrator states having a lower frequency than a sine wave.
Integrator No. 1  

<table>
<thead>
<tr>
<th>State</th>
<th>On</th>
<th>Off</th>
<th>On</th>
<th>Off</th>
</tr>
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</table>

Integrator No. 2  

<table>
<thead>
<tr>
<th>State</th>
<th>Off</th>
<th>On</th>
<th>Off</th>
<th>Off</th>
<th>On</th>
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a. Signals with 0 and 180-degree phase shifts.

b. Signals with 45-degree phase shifts.

c. Signals with 90-degree phase shifts.

Figure 5. Square waves representing integrator states having the same frequency as a sine wave.
several frequencies in various phase relations to the square waves representing the on-and-off states of the integrators. These sketches will be used to demonstrate how these important factors, namely, frequency and phase, effect the detection method. It will be assumed that the two integrators are matched. It will also be assumed that the integration extends for enough cycles of the known signal so that both integrators will be in the on-state for approximately the same amount of time. For simplicity the detection level will be assumed to be zero. The integrators will sum only when the sine wave is above the detection level at a time when the integrators are in the on-state.

First, consider the sine waves of Figures 3, 4, and 5 as the received signal in which noise has been omitted for simplicity. However, the principles discussed apply whether or not noise is present. The square waves in the sketches of Figures 3 and 4 are of a different frequency than the sine waves. The rate at which each integrator sums during different cycles of the square wave is not constant as these sketches demonstrate. However, if the integration extends over several cycles of the known signal, there will be only a small difference in the outputs of the integrators. In these cases the phase angle between these two signals has only a small effect on the integrator outputs.

The sketches of Figure 5 show the integrator outputs when
the frequency of the square wave representing the integrator states is the same as the frequency of the known signal. The rate at which each integrator sums during different cycles of the square wave is a constant. Thus, the outputs of the two integrators may be significantly different depending upon the phase angle between the two signals. To obtain the maximum possible difference in the two integrator outputs thus giving the most reliable indication of a signal being present, the integrators must be switched on and off in-phase with the periodic signal as shown in Figure 5a. If the two signals are less than ninety-degrees-out-of-phase as shown in Figure 5b, the integrator outputs will be different but the difference will not be a maximum. No difference in the accumulated average values will be noted, even if a signal is present, if the integrators are switched on and off ninety-degrees-out-of-phase with the periodic signal as shown in Figure 5c. Thus, the phase angle between the states of the integrators and the known signal has an effect on the sensitivity and reliability of the detection method.

In general there will be no information about the phase of the periodic signal. The detection process should be repeated for various phase shifts between the states of the integrators and the known signal. The phase should be varied until a sufficiently large difference in the accumulated average values, if any, is found to give the operator confidence that a signal is present.
**Frequency and Phase of Noise Signal**

Now, consider the sine waves shown in Figures 3, 4, and 5 as noise of a single frequency instead of the known signal. The sine waves in the sketches of Figures 3 and 4 are of different frequencies than the square waves. In these cases the same discussion applies as that given earlier when the sine waves were considered as the known signal. There will be only a small difference in the outputs of the integrators if the integration extends over several cycles of the noise signal. The phase angle between the two signals has only a small effect on the integrator outputs.

Consider the case where the frequency of the noise is the same as the frequency of the waveforms representing the states of the integrators and hence the frequency of the known signal as shown in Figure 5. The integrator outputs may be significantly different depending on the phase angle. Hence, for the special case where the noise is of the same frequency as the known signal, the detector results may be misleading. If no signal is present, the operator may have the impression that a signal is present if the phase angle is varied after the outputs of the integrators are matched using the noise.
DETECTOR BLOCK DIAGRAM

Now that the detection principle has been discussed, the next step is to consider how the principle can be implemented.

The proposed detection method uses two integrators together with a device to switch the combination of signal and noise between the two integrators at the frequency of the known signal. The detection level and the phase angle between the known signal and the square waves representing the states of the integrators should be variable to improve the sensitivity of the detector as discussed earlier. The block diagram of Figure 6 gives the general form of the detection principle.

The received signal, consisting of a possible signal of known frequency superimposed on noise, is passed through a variable delay and a detection level shifter and is then switched between the two integrators at the frequency of the known signal. The outputs of the two integrators are compared and any difference, if any, is noted. This difference information is fed back to the delay circuit to vary the phase between the known signal and the square waves representing the states of the integrators. The feedback may take any one of several forms such as electrical, mechanical, or visual. The detection process is continued for various phase shifts until a sufficiently
large difference, if any, is found to give the operator confidence that a signal is present.
Figure 6. Block diagram of the detection method.
INDIVIDUAL CIRCUITS OF DETECTOR

The block diagram of Figure 7 shows the implemented form of the detector. In this section the individual portions of the detector will be considered in detail. Portions of the detector occur in duplicate except for some variable resistors in place of fixed-value resistors. In these cases a circuit diagram and discussion will be given only for the adjustable unit.

A complete circuit diagram and a component list for the detector are given in Appendices II and III. A detailed set of operating instructions is given in Appendix IV.

A variable delay was not used in the detector which was designed and tested although the sensitivity of the detector should be improved by using one.

Detection Level Shifter

The detection level shifter shown in Figure 8 is used to vary the detection level of the combination of signal and noise and to provide a large input impedance for the detector.

The npn transistor T1 is normally off since the base is connected through the resistors R2 and R3 to -10 volts. The base becomes more negative as the resistor R2 becomes smaller. This transistor will turn on providing a positive voltage to the AND gates.
Figure 7. Block diagram of the implemented detector.
only when the received signal is sufficiently positive to make the base positive. The received signal level at which the transistor T1 begins to conduct is matched to the detection level by varying the resistor R2. The detection level becomes higher as the resistor R2 becomes smaller. As Figure 2 demonstrates, the detection level should be as high as possible to improve the sensitivity of the detector to small signals. Thus, the resistor R2 should be set so that the magnitude of the received signal above the detection level is the minimum voltage needed to turn on the integrators.

As discussed earlier, the outputs of the integrators are matched when only the noise is present. The detection level must be selected before the integrator outputs are matched to avoid upsetting the matched outputs. A shift in the detection level varies the output
voltage of the detection level shifter which is an input voltage to the
two AND gates. This change in the input voltage to the AND gates
changes the output voltages of the AND gates which are inputs to the
integrators. However, the two AND gates and the two integrators do
not remain matched for these voltage changes because of differences
in the characteristics of the transistors.

The received signal may need to be amplified before entering
the detector if it is too small in magnitude to turn on the integrators.

**Multivibrator**

The astable multivibrator (3, p. 138) shown in Figure 9 is
used to provide square wave signals to switch the combination of
known signal and noise between the two integrators at the frequency
of the known signal.

![Multivibrator circuit diagram](image)

*Figure 9. Astable multivibrator.*
The collector-to-emitter voltage from one multivibrator transistor controls one integrator while the collector-to-emitter voltage from the other multivibrator transistor controls the other integrator. One of these positive multivibrator outputs is an input to one AND gate while the other positive multivibrator output is an input to the second AND gate. Identical square waves, except for a 180-degree phase shift, are thus inputs to two AND gates.

Control over the symmetry and frequency of the multivibrator output square waves is attained by varying the base resistors R8 and R10. However, major changes in the frequency of the multivibrator outputs are made by varying the capacitors C3 and C4. The frequency of the multivibrator square waves must be the same as the frequency of the known signal as discussed earlier.

**AND Gates**

The AND gate shown in Figure 10, obtained by modifying an inverter NAND gate (1, p. 183), is used to switch the combination of signal and noise between the two integrators. The AND gate provides a negative voltage turning on the integrator only when the two inputs are both positive as demonstrated in Figure 11. The npn transistors of the AND gate are on when one or neither of the two inputs are positive and are off when both of the inputs are positive. One of the AND gate inputs, which is a multivibrator output square wave
Figure 10. AND gate.
Received signal (noise neglected for simplicity).

AND gate input from multivibrator.

AND gate input from detection level shifter.

AND gate output.

Figure 11. AND gate signals.
corresponding to states of a multivibrator transistor, is either of two values except for the short transient state. However, the other AND gate input, which is the output of the detection level shifter, has a varying magnitude.

**Integrators**

The integrators must be of such a nature that the integrator outputs can be matched when only the noise is present as mentioned previously. The integrator shown in Figure 12 was selected because (1) the output is quite linear due to the constant current source T8 and the large capacitor C7 and (2) the outputs of the two integrators are quite easy to match. This integrator is a portion of another integrator (5, p. 101) about which much of the detector design was centered.

![Integrator Diagram](image)

*Figure 12. Integrator.*
Transistor T8 of the integrator is normally off and turns on only when the AND gate is turned off. When transistor T8 conducts the capacitor C7 begins to charge until limited by the supply voltage. Once the capacitor C7 is charged it remains charged until the integrator is reset or until it slowly discharges through the adjacent circuitry.

Typical integrator outputs are shown in Figures 13 and 14. Before the integrator outputs are matched, the outputs appear as shown in Figure 13. The variable resistor R23 between the capacitor C7 and one of the oscilloscope inputs is used to match the magnitudes of the integrator outputs. The variable resistors R19 and R20 in the one integrator are used to match the rates of integration of the two integrators. The coarse adjustment is R19 and the fine adjustment is R20.

Typical matched integrator outputs are given in Figure 14a in which both outputs lie directly on each other. If a signal is superimposed on the noise, the two integrator outputs will no longer be matched as shown in Figure 14b. The smaller the known signal, the smaller the difference between the two integrator outputs. Hence, the better the integrator outputs can be matched, the smaller the signal that can be detected in the noise.
Figure 13. Typical integrator outputs before being matched. Multivibrator frequency is 1 kcps. Random noise has an upper frequency limit of 20 kcps. Ordinate 1 volt per cm. Abscissa 0.5 second per cm.
Figure 14. Typical integrator outputs after being matched. Signal frequency is 1 kcps. Random noise has an upper frequency limit of 20 kcps. Ordinate 1 volt per cm. Abscissa 0.5 second per cm.
The integrators are reset by closing the switch of the integrator reset of Figure 15. This switch contains a spring to return it to the open position once it is released. When this switch is closed, the transistor T11 turns on causing capacitor C7 to discharge. The idea for this integrator reset evolved from another integrator reset (5, p. 101).

**Difference Indicator**

A Tektronix Dual-trace Oscilloscope was used to indicate the difference between the two integrator outputs. Since the capacitor C7 of Figure 12 charges when a signal is applied to the detector input,
the output of the integrator decreases toward zero. However, it was found that the observer's eyes could follow the two integrator outputs easier if the outputs rose instead of decayed. Thus, the oscilloscope inputs were placed on "inverted" so that the integrator outputs appeared to rise.

It was also found that the oscilloscope sweep rate had an effect on the observer's ability to compare the two integrator outputs. The sweep rate should be slow enough so that the voltage excursions of the integrator outputs occur during one sweep across the oscilloscope screen. However, the sweep rate should be fast enough so that the integrator outputs rise during as much of one sweep cycle as possible. Then, the integrator outputs appear on the screen as two dots rising simultaneously along approximately 45-degree curves. The photographs of Figures 13 and 14 show typical paths of these dots. A sweep rate of 0.5 seconds per cm or 1 second per cm usually satisfies these conditions. The integrator outputs appear as two dots rising essentially vertically for a very slow sweep and as two essentially horizontal lines rising for a fast sweep.
TEST RESULTS

Now that the detector has been designed and built, the next step is to test the circuit. The effectiveness of the detector in sensing signals of different frequencies together with the effects of component changes will be discussed.

Detector Sensitivity

The sensitivity of the detector circuit shown in Appendix II was determined for a sine wave superimposed on random noise. Figure 16 gives the test results. The known signal was obtained

<table>
<thead>
<tr>
<th>Signal Frequency, cps</th>
<th>Signal-to-Noise Ratio</th>
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<tbody>
<tr>
<td>100</td>
<td>1/40</td>
</tr>
<tr>
<td>1 k</td>
<td>1/37</td>
</tr>
<tr>
<td>5 k</td>
<td>1/24</td>
</tr>
<tr>
<td>10 k</td>
<td>1/6</td>
</tr>
<tr>
<td>25 k</td>
<td>6/10</td>
</tr>
<tr>
<td>50 k</td>
<td>14/10</td>
</tr>
</tbody>
</table>

Note: Above ratios were obtained using peak signal magnitudes and rms noise magnitudes.

Figure 16. Minimum signal-to-noise ratio at which a sine wave can be reliably detected in random noise.

with a conventional generator. The noise, having an upper frequency limit of 20 kcps, was generated using a Type 1390-B General Radio Company Random Noise Generator. The frequency of the
multivibrator was varied by changing the capacitors C3 and C4 and
the base resistors R8 and R10.

Useful Frequency Range

The useful signal frequency range of the detector is approximately 100 cps-35 kcps. At frequencies below approximately 100 cps, the amount of time that each integrator is in one state before changing to the opposite state is a significant portion of the total integration time. Thus, the outputs of the integrators appear as staircase curves to the oscilloscope observer as shown in Figure 17. In these cases the outputs of the integrators are difficult to match when only the noise is present. It is also difficult to match the frequency of the multivibrator to the frequency of the known signal for frequencies less than about 100 cps.

For frequencies above approximately 35 kcps, a smaller signal can be detected by observing the combination of signal and noise on an oscilloscope than can be sensed with the detector. Thus, the detector is not needed to detect signals of frequencies greater than approximately 35 kcps.

The first step in estimating the upper limit of the useful frequency range was to connect a random noise signal directly to an oscilloscope. This noise signal is shown in Figure 18. Next, a 25 kcps sine wave was superimposed on this noise. The magnitude of this known signal was increased until its presence could be noted
Figure 17. Typical unmatched integrator outputs for signal frequencies less than approximately 100 cps. Multivibrator frequency is 50 cps. Random noise has an upper frequency limit of 20 kcps. Ordinate 1 volt per cm. Abscissa 0.5 seconds per cm.

Figure 18. Random noise having an upper frequency limit of 20 kcps. Noise rms voltage is 5 volts. Ordinate 5 volts per cm. Abscissa 10 µsec per cm.
on the oscilloscope. The signal could be reliably detected visually for a peak sine wave magnitude approximately equal to the rms noise magnitude as shown in Figure 19a. However, the detector could sense a 25 kcps sine wave with a peak magnitude of about 6/10 times the rms noise magnitude.

A 50 kcps sine wave was then superimposed on the random noise shown in Figure 18. The magnitude of this known signal was increased until its presence could be noted on the oscilloscope. The signal could be reliably detected visually for a peak sine wave magnitude of approximately 8/10 times the rms noise magnitude as shown in Figure 19b. The minimum signal-to-noise ratio at which this 50 kcps sine wave could be sensed with the detector was approximately 14/10. The upper limit of the useful frequency range is the frequency at which the sensitivity of the detector is the same as the sensitivity of the oscilloscope-eye method. This frequency is between 25 kcps and 50 kcps and is estimated as 35 kcps.

Component Tolerances

The transistor types used in the detector circuit are not critical. The transistors were replaced with other types of transistors and the detector performance was not noticeably changed. Variations of a factor of 2.5 can be tolerated in the dc and ac forward-current-transfer ratios. Some of the possible replacement transistors
a. A 25 kcps sine wave superimposed on random noise. Peak sine wave voltage is 5 volts.

b. A 50 kcps sine wave superimposed on random noise. Peak sine wave voltage is 4 volts.

Figure 19. Sine waves which can be visually detected in random noise. Noise has an upper frequency limit of 20 kcps. Noise rms voltage is 5 volts. Ordinate 5 volts per cm. Abscissa 10 μsec per cm.
are given in the component list of Appendix III.

Five-percent-tolerance resistors can be used in the circuit.

The variable resistors compensate for variations in the other resistors of the circuit.

Capacitor tolerances are of concern only for the integrator capacitors C7 and C8. Since these capacitors affect the linearity of the integrator outputs, the tolerances should be five percent or less.
DETECTOR ADVANTAGES AND DISADVANTAGES

Now that the detector has been built and tested, the main advantages and disadvantages of the detector can be compiled.

Detector Advantages

1. Reliable results can be obtained for a peak signal magnitude one-fortieth the rms noise magnitude in the case of a 100 cps sine wave.
2. The useful frequency range is approximately 100 cps-35 kcps.
3. Signals of different frequencies can be detected by changing the capacitors in the multivibrator.
4. The results of the detection process are known within one minute once the preliminary adjustments requiring less than five minutes are made.
5. The detector is quite easy to operate.
6. The detector can be built and operated economically.
7. The detector circuit is small.

Detector Disadvantages

1. The detector is not useful for frequencies less than about 100 cps or greater than approximately 35 kcps.
2. It is difficult to judge whether or not a small signal is present
by noting a visual difference between two nearly identical curves on an oscilloscope.

3. The integrators must be matched on the noise in which the known signal will be superimposed.

4. The two integrators must be rematched for changes in the noise voltage and for changes in the detection level.

5. The frequency of the signal must be known.

6. The detection process should be repeated for various phase shifts between the combination of signal and noise and the output square waves of the multivibrator.

7. A dual-trace oscilloscope is needed.
CONCLUSIONS

A relatively simple detector has been designed and built which senses known signals in noise quickly and easily. The useful frequency range of the detector is approximately 100 cps - 35 kcps. As an example of the sensitivity of the detector, a 100 cps sine wave can be reliably detected in noise where the peak signal magnitude is one-fortieth of the rms noise magnitude.
BIBLIOGRAPHY


APPENDIX I

A derivation of the ratio of the average values of the combination signal above the detection level for each half-cycle of a square wave follows. Figure 2 is a plot of this ratio.

Consider the square wave superimposed on noise shown in Figure 1. The difference between the detection level and the square wave voltage during the more positive half-cycle will be designated as $D_1$. The difference between the detection level and the square wave voltage during the less positive half-cycle will be represented by $D_2$. If the square wave magnitude is $E$, then from Figure 1

$$D_2 = D_1 + 2E$$  \hspace{1cm} (1)

The probability that the combination signal is above the detection level during the more positive half-cycle is the same as the probability that the noise is greater than $D_1$. This probability is given by

$$\int_{D_1}^{\infty} p(v) \, dv$$  \hspace{1cm} (2)

where $p(v)$ is the probability density function (4, p. 376-377, 382).

The average value of the combination signal that is above the detection level with respect to the square wave voltage for the more positive half-cycle is given by
Then, the average value of the combination signal that is above the detection level with respect to the detection level for the more positive half-cycle is given by

\[
\left( \frac{\int_{D_1}^{\infty} v \, p(v) \, dv}{\int_{D_1}^{\infty} p(v) \, dv} \right) - D_1.
\]  

(4)

However, the averages given by relations (3) and (4) do not include the instances during the more positive half-cycle when the combination signal is less than the detection level. To obtain averages over the entire positive half-cycle, the relations (3) and (4) must be multiplied by the fraction of the more positive half-cycle that the combination signal is above the detection level. This fraction is given by relation (2).

Thus, the average value of the combination signal above the detection level for the more positive half-cycle is given by

\[
\left( \int_{D_1}^{\infty} p(v) \, dv \right) \left( \frac{\int_{D_1}^{\infty} v \, p(v) \, dv}{\int_{D_1}^{\infty} p(v) \, dv} \right) - D_1.
\]  

(5)

Similarly, the corresponding equation for the less positive half-cycle is given by
Then, the ratio $R$ of the average values of the combination signal above the detection level for each half-cycle is given by

$$R = \left( \frac{\int_{D_1}^{\infty} v \, p(v) \, dv}{\int_{D_1}^{\infty} p(v) \, dv} \right) - D_1 \right) \left( \frac{\int_{D_2}^{\infty} v \, p(v) \, dv}{\int_{D_2}^{\infty} p(v) \, dv} \right) \left( \frac{\int_{D_2}^{\infty} v \, p(v) \, dv}{\int_{D_2}^{\infty} p(v) \, dv} \right) \left( \frac{\int_{D_2}^{\infty} p(v) \, dv}{\int_{D_2}^{\infty} p(v) \, dv} \right) .$$

If the noise is Gaussian, the probability density function, $p(v)$, is given by

$$p(v) = \frac{1}{\sqrt{2\pi} \sigma} e^{-\frac{v^2}{2\sigma^2}} \quad (4, \ p. \ 376-377) .$$
Figure 20. Detector circuit diagram.
APPENDIX III

Component List

<table>
<thead>
<tr>
<th>Transistors</th>
<th>Capacitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 GE 2N1304</td>
<td>C1 500 pf</td>
</tr>
<tr>
<td>T2 GE 2N1304</td>
<td>C2 500 pf</td>
</tr>
<tr>
<td>T3 GE 2N1304</td>
<td>*C3 400 pf - 0.2 μf</td>
</tr>
<tr>
<td>T4 GE 2N395</td>
<td>*C4 400 pf - 0.2 μf</td>
</tr>
<tr>
<td>T5 GE 2N395</td>
<td>C5 500 pf</td>
</tr>
<tr>
<td>T6 GE 2N395</td>
<td>C6 500 pf</td>
</tr>
<tr>
<td>T7 GE 2N395</td>
<td>C7 50 μf, 25 volts, tantalum</td>
</tr>
<tr>
<td>T8 TI 2N706</td>
<td>C8 50 μf, 25 volts, tantalum</td>
</tr>
<tr>
<td>T9 TI 2N706</td>
<td>C9 0.01 μf</td>
</tr>
<tr>
<td>T10 GE 2N332</td>
<td>C10 0.01 μf</td>
</tr>
<tr>
<td>T11 GE 2N332</td>
<td></td>
</tr>
</tbody>
</table>

*Size depends on frequency of known signal.

Some possible replacement transistors:

1. Detection Level Shifter and Multivibrator; T1, T2, T3.
   T1 2N119, GE 2N332, for GE 2N1304
   GE 2N706, TI 2N1565

2. AND Gates; T4, T5, T6, T7.
   GE 2N394, GE 2N1305 for GE 2N395

3. Integrators; T8, T9.
   TI 2N119, GE 2N332, for TI 2N706
   TI 2N1565

4. Integrator Reset; T10, T11.
   TI 2N119, GE 2N706, for GE 2N332
   TI 2N1565
Resistors in ohms. All resistors have five percent tolerances, 1/2 watt ratings.

<table>
<thead>
<tr>
<th>Resistor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
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<tr>
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<td>R11</td>
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<td>100 k</td>
</tr>
<tr>
<td>R24</td>
<td>1 k</td>
</tr>
</tbody>
</table>

*Variable resistors
APPENDIX IV

Operating Instructions

1. Turn on the dual-trace oscilloscope allowing sufficient time to warm.

2. Suggested oscilloscope settings:
   a. Inputs on dc.
   b. Inputs on inverted.
   c. Vertical sensitivity for both inputs on about 1 volt per cm or 2 volts per cm.
   d. Horizontal sweep on about 0.5 seconds per cm or 1 second per cm.
   e. Use an external trigger obtained from the integrator reset.

3. Turn on the dc power supplies to provide +10 volts and -10 volts.

4. Connect a signal of the same frequency as the signal to be detected to the detector input. This test signal, which may be obtained from a signal generator, must be of sufficient magnitude to turn on the integrators. Adjust the multivibrator frequency by varying the capacitors C3 and C4 and/or the base resistors R8 and R10 of the multivibrator until it is the same as the signal frequency. A clue as to when these two frequencies are nearly matched is when the two integrator outputs both rise but rise in a choppy manner as shown in
Figure 21a. These frequencies will be the same when the output of one integrator rises while the output of the other integrator remains stationary as shown in Figure 21b. The integrators must be reset after each attempt of matching these two frequencies.

5. Remove the signal generator and connect the received signal containing only noise to the detector input. Adjust the detection level by varying resistor R2 so that the outputs of the integrators rise in approximately five to ten seconds. The received signal may need to be amplified before entering the detector if it is too small in magnitude to turn on the integrators.

6. Vary resistor R23 until the magnitudes of the two integrator outputs are the same.

7. Vary resistor R19, the coarse adjustment, and resistor R20, the fine adjustment, until the two integrator outputs are the same over the voltage excursion. The more carefully these outputs are matched, the more sensitive will be the detector. The integrators must be reset after each attempt of matching the integrators.

8. If more than about five minutes passes after the adjustments are made before the detector is used, the adjustments should be rechecked. In particular, check the outputs of the integrators
when only noise is present to make sure they are still matched.
Figure 21. Typical integrator outputs when the multivibrator frequency is being matched to the known signal frequency. Ordinate 1 volt per cm. Abscissa 0.5 second per cm.