

[54] **REDUCED TIME DELAY AUTO-CORRELATION SIGNAL PROCESSOR**
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[22] Filed: **Dec. 9, 1970**
[21] Appl. No.: **97,450**
[52] U.S. Cl.**235/181, 325/474, 328/165, 333/70 T**
[51] Int. Cl.**G06g 7/19**
[58] Field of Search**235/181, 183; 343/100 CL; 328/166, 167, 165; 325/474**

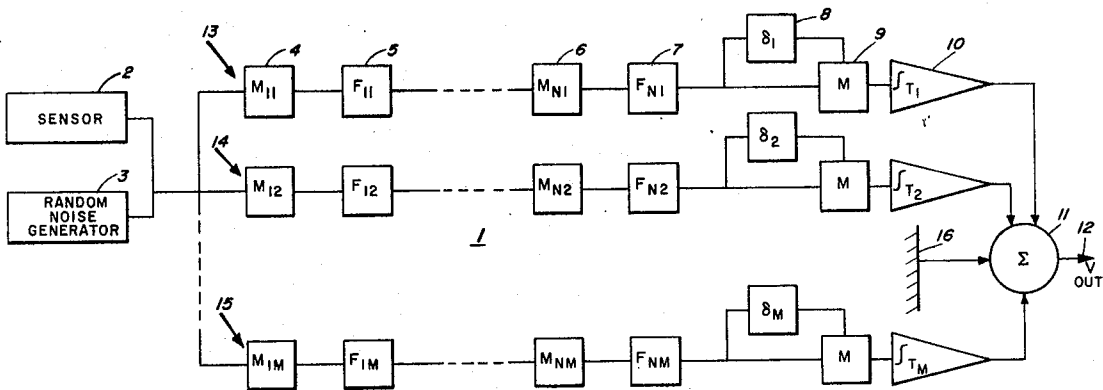
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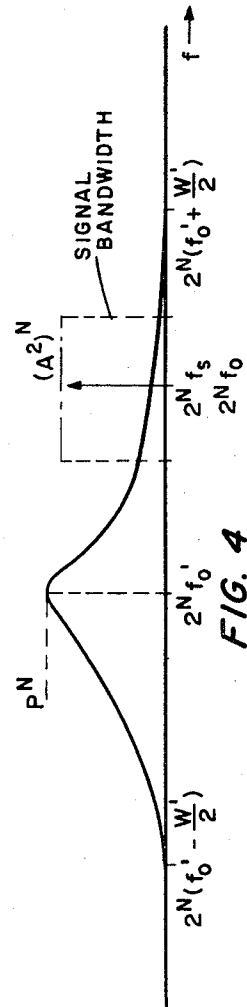
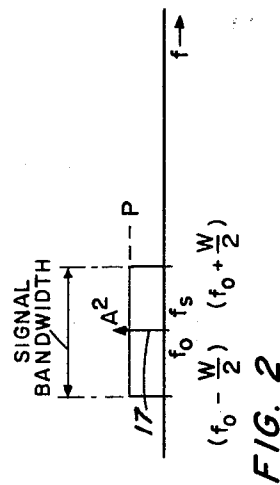
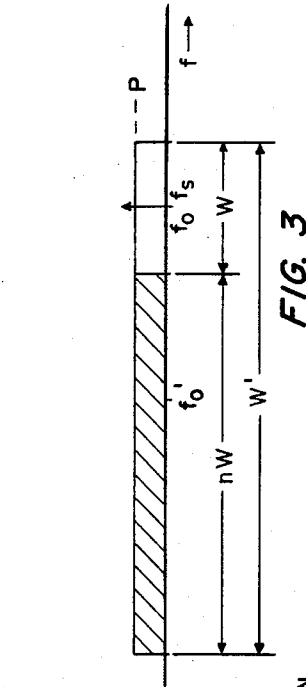
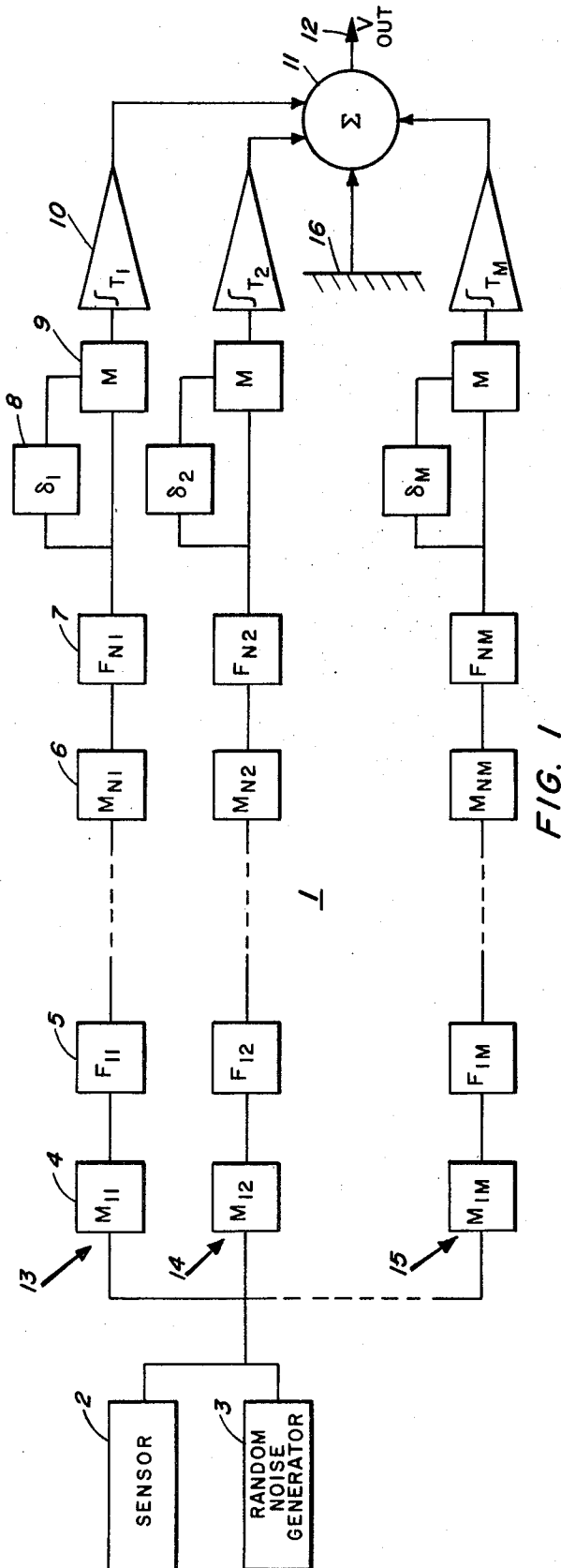
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Primary Examiner—Felix D. Gruber
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[57] **ABSTRACT**
A signal processor utilizing the auto-correlation technique for detecting a signal in the presence of noise. The device reduces both the required time delay and integrating time in conventional auto-correlation processes by the use of a (N) by (M) matrix analog correlator. The device accepts noise and signal which are assumed to be statistically independent and by linearly multiplying both (N) reiterated times and filtering out the d.c. or base band products from each multiplication, forms the final function for correlation. This process of linear multiplication is repeated over (M) parallel paths. The (N) reiterated linear multiplications reduce the required time delay to a small fraction. The (M) parallel paths reduce the required integrating time also to a very small fraction.

10 Claims, 4 Drawing Figures





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REDUCED TIME DELAY AUTO-CORRELATION SIGNAL PROCESSOR

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to devices for detecting a signal in the presence of noise. More particularly to devices known as auto-correlators. Signal processing devices employing the auto-correlation technique having received wide application in the art in detecting a signal in a noise background. The theory behind the auto-correlation technique is well known and will not be discussed herein in detail. The success of detectors employing the auto-correlation technique is due to the fact that the auto-correlation function of random (non-periodic) noise is zero. Further, it can be shown that the auto-correlation function of periodic (time-limited) noise is also zero. On the other hand, it may easily be shown that the auto-correlation function of a signal in the form of a sinusoid is another sinusoid. Further, it is likewise true that a signal in the form of a space-modulated or duration-modulated pulse train will be a function having an appreciable magnitude for relatively small values of delay time. The auto-correlator provides means for obtaining the auto-correlation functions of noise and of the signal simultaneously. The comparison of these functions results in a markedly increased signal-to-noise ratio.

2. Description of the Prior Art

While auto-correlation detectors have been quite successful in improving signal-to-noise ratios, a significant drawback in the use of prior art auto-correlators has been the time delay involved in the auto-correlation process. This time delay results from two factors, the introduced time delay or time lag and the integrating time. The introduced time delay results from the fact that in the auto-correlation process the signal or noise function is multiplied by itself after being delayed in time. This is what is known as the introduced time delay or time lag that is inherent in the auto-correlation process. The other factor involved in the overall time delay of an auto-correlator is the integrating time, i.e., the period of time over which the integration is taken. In theory, this time approaches infinity. However, in practice an integrating time which is very large compared to the introduced time delay or time lag is chosen.

SUMMARY OF THE INVENTION

The invention consists of what may be described as an (N) by (M) matrix analog auto-correlator which is effective to reduce the required time delay or time lag of a conventional auto-correlator to a small fraction (of order $[2^N]^{-1}$) and the required integrating time to a small fraction (of order M^{-1}). The invention accepts an input, consisting of a signal containing information and noise which are assumed to be statistically independent, and by linearly multiplying both (N) reiterated times and filtering the product for each multiplication

by high pass filters forms the final function for auto-correlation. This process is repeated over (M) parallel paths, thereby reducing the integrating time required in the auto-correlation process. The device further reduces the introduced time delay or time lag of an auto-correlator by the addition of random noise to the signal to be processed. This results in an increased in the bandwidth of the signal to be processed; increasing the bandwidth of the signal will result in a decrease of the time delay or time lag of an auto-correlator.

OBJECTS OF THE INVENTION

An object of the present invention is to provide means for increasing the signal-to-noise ratio of very low signals in a random (non-periodic) or periodic (time-limited) noise background.

Another object is to provide a new and improved auto-correlation detector circuit.

A further object of the invention is to reduce the time required in conventional auto-correlation processes.

Other objects, advantages, and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a preferred embodiment of the invention;

FIG. 2 shows on a frequency spectrum a signal to be detected with accompanying noise background;

FIG. 3 illustrates the addition of random noise to the received signal; and

FIG 4 depicts the signal being processed after (N) linear multiplications.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG 1 illustrates a preferred embodiment of the auto-correlation circuit of the instant invention. In FIG 1, a signal to be processed is introduced in the detector circuit by means of a sensor 2. The sensor may take the form of a number of devices, for example, an antenna or, as would be the case in Sonar applications, a transducer. Random noise from a random noise generator 3 is added to this received signal, thereby increasing the bandwidth of the signal to be processed by the auto-correlation detection system circuit 1. In being processed, this signal undergoes (N) linear multiplications over each of (M) parallel paths. The (N) by (M) matrix of the instant invention may be referred to as an "averager."

The signal to be processed first is multiplied by itself, for example, along path 13, by multiplier 4. The multiplied signal is then filtered by filter 5, which constitutes a high-pass filter and eliminates the d.c. or base band products from each multiplication. This multiplication and filtering is repeated (N) times along each linear path. After the Nth multiplication and filtering, the signal is applied directly to multiplier 9. It is also applied to delay means 8 which produces a delayed signal and applied it to multiplier 9. This delay means represents the introduced time delay or time lag of the

auto-correlator. The signal from the multiplier 9 is then integrated by the integrator 10 over a period of T_1 . The resulting signal passes to the summer 11. This process is repeated in the ensemble averager over (M) parallel paths. The symbol designated 16 in FIG 1 represents the inputs from the (M-3) parallel paths into the summer 11. The resulting signal appearing at the output terminal 12 of the summer 11 will exhibit a markedly increased signal-to-noise ratio over the input signal from the sensor 2.

The main features of the invention will be explained with reference to FIGS 2 through 4. The signal derived from sensor 2 of FIG 1 is graphically represented in FIG 2. The continuous signal to be detected of frequency f_s and power level A^2 is represented by arrow 17 in FIG 2. The accompanying noise background is also shown in figure 2 and has a bandwidth of W, coincident with the signal bandwidth, extending from $(f_o - W/2)$ to $(f_o + W/2)$ and a power level designated by P. FIG 3 illustrates the addition of random noise from the random noise generator 3 to the signal from the sensor 2. FIG 3 clearly shows the increased bandwidth of the signal to be processed by the circuit of FIG 1. Note in FIG 3 the transposition of the center frequency of the noise background from f_o to f_o' . This transposition results in an increased spreading effect that will be further explained with reference to FIG 4. It should be noted that the bandwidth of the added noise in FIG 3 is designated nW where W is the original noise band width. For purposes of the instant invention, n may be, but is not required to be, a positive integer. FIG 4 represents the signal as it appears, for example, along linear path 13, after undergoing the Nth multiplication and before the final filtering by filter 7. As can be seen, the form of the processed signal of figure 4 departs radically from the form of the signal illustrated in FIG 2 or FIG 3 since the (N) multiplications disperse the signal frequency f_s from the center of the noise band f_o' by the factor 2^N ($f_s - f_o'$). It is further evident from FIG 4 that the signal-to-noise ratio of the signal to be detected is greatly enhanced merely by the (N) multiplications. It is apparent that the level of noise within the signal band of the signal in FIG 4 is much lower than the level of noise in the signal band of the signal in FIG 2. Thus, the signal-to-noise ratio that results from the simultaneous auto-correlation of the noise and signal functions appearing within the signal bandwidth as shown in FIG 4, resulting from the (N) linear multiplications, will be much improved over the ratio that would result from the auto-correlation of the signal shown in FIG 1 as occurs in prior art auto-correlators. The time delay or time lag 8 required by the auto-correlator of FIG 1 is inversely proportional to $2^N w'$. Thus, the required time delay or time lag may be made vanishingly small by choosing a large number of linear multipliers along each of the (M) paths or by significantly increasing the noise bandwidth of the received signal by the addition of random noise. This reduction in time delay or time lag is critically important because, for example, it permits an information channel to be utilized at an increased efficiency. That is, by reducing the required time delay, less transmitted redundancy will be required for signal detection. Finally, the integrating time of the auto-correlator of FIG 1 is inversely proportional to (M). Thus, by choosing (M) large enough the

integrating time may be also made vanishingly small. In order, however, to truncate the integrating time by the factor M^{-1} and achieve statistically acceptable results, the integrating time and delay time along each of the (M) paths of FIG 1, for example path 13, should be chosen to be distinct from the integrating times and delay times along each of the other (M) paths, for example paths 14 and 15. Thus, the invention provides a method and a means for detecting the presence of a signal in a noise background at a markedly increased signal-to-noise ratio over conventional auto-correlators without sacrificing either information capacity or processing time.

It is obvious that each of the above features of the invention may be employed either singly or in combination to provide an improved auto-correlation process. For example, by merely increasing the bandwidth of the noise as shown in FIG 3, the time delay or time lag of conventional auto-correlators can be reduced. Further, by providing (M) parallel paths the required integrating time of conventional auto-correlators can be reduced by a factor of M^{-1} . Finally, the mere addition of (N) linear multipliers to the circuit of a conventional auto-correlator can reduce the required time delay or time lag by a factor of $(2^N)^{-1}$.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. For example, it is obvious from FIG 4 that a signal processor comprising merely a sensor 2, random noise generator 3, (N) multipliers and associated filters would be quite effective in increasing a signal-to-noise ratio. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise and as specifically described.

What is claimed is:

1. An autocorrelation signal processor comprising:
 - a means for receiving a signal containing information and noise and for producing an electrical output signal representative of the received signal;
 - a random noise generator having its output connected to said electrical output signal, said electrical signal and said random noise together comprising the signal to be processed;
 - means for multiplying the signal to be processed by itself N successive time along M parallel paths, where N is an integer equal to or greater than 1 and M is an integer greater than 1;
 - means for filtering individually each product of a multiplication; and
 - means for autocorrelating said signal to be processed after the N multiplications and filterings.
2. A device as recited in claim 1 in which the receiving means comprises a transducer.
3. A device as recited in claim 1 in which the receiving means comprises an antenna.
4. A device as recited in claim 1 in which the filtering means comprises N high-pass filters.
5. A device as recited in claim 1 wherein the autocorrelating means comprises:
 - a. M means for delaying said signal to be processed after N multiplications and filterings;
 - b. M means for multiplying said signal to be processed after N multiplications and filterings by said delayed signal;
 - c. M means for integrating the products of said M multiplications;

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wherein one of each said means recited in (a), (b) and (c) is connected in each of the M parallel paths; and,

means for summing the outputs of the integrating means,

6. A device as defined in claim 5 in which the time delay associated with each of the M parallel paths is distinct from the time delays associated with the remaining M-1 parallel paths and in which the time period for integration associated with each of the M parallel paths is distinct from the time periods for integration associated with the remaining M-1 parallel paths.

7. A device for reducing the time period for integration in an autocorrelation processor comprising:

means for receiving a signal to be processed;

M parallel paths, where M is an integer greater than 1, each path being connected to the receiving means so that the signal to be processed is applied simultaneously to each path;

wherein each of the M parallel paths includes:

means for delaying said signal to be processed;

means for multiplying said signal to be processed by the delayed signal; and,

means for integrating the product of the multiplication; and,

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means for summing the outputs of the integrating means.

8. A device for increasing the signal-to-noise ratio of a received signal thereby reducing the delay time inherent in the auto-correlation process comprising:

means for receiving the received signal;

a random noise generator connected to the receiving means, the received signal and the random noise comprising the signal to be processed;

means for multiplying the signal to be processed by itself N successive times, where N is an integer equal to or greater than 1; and,

means for filtering individually each product of a multiplication.

9. The device as recited in claim 8 wherein:

the received signal has a determinable bandwidth;

the random noise has a determinable bandwidth; and,

the bandwidth of the random noise occupies a frequency spectrum which is lower than and adjacent to the frequency spectrum of the signal bandwidth.

10. The device as recited in claim 9 wherein the filtering means comprise high pass filters.

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