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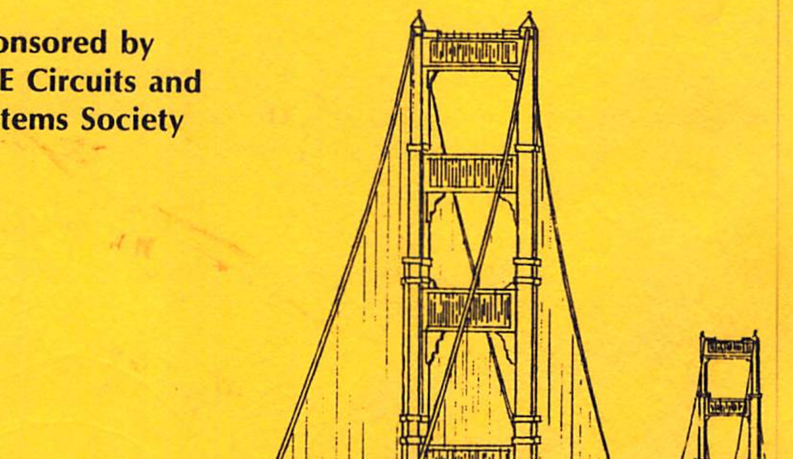

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ON AUTOMATED RECOGNITION OF FAMILIES OF SWEPT-FREQUENCY TRANSIENT SIGNALS

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Abstract

Of the several currently available techniques for recognition of swept-frequency transient signals, most are fundamentally limited in their ability to detect the occurrence of signals with a high sweep rate relative to the frequency band of interest. In addition, common techniques such as Phase Lock Loops (PLL) and Voltage Tunable Filters are not inherently immune to very high noise with the result that they can be easily unlocked with a variety of types of noise.

A scheme is presented which has the capability of detecting fast, swept-frequency transient signals in the presence of most disturbances within the frequency range of the sweep. The disturbances tolerated are not completely without restriction, however, and are affected by the relation of their power spectra to factors of filter bandwidths and resonant frequencies, signal sweep rate, noise amplitude, and other elements. With a slight modification which is incorporated in the circuit realization, it is also possible to cope with continuously varying amplitudes of the swept signal.

I. INTRODUCTION

This paper is concerned with a detector of families of swept-frequency transient signals. It provides an output at the time of occurrence of a swept-frequency transient signal of known characteristics that is buried in a noisy background. The basic class of signals of interest here are those in which its frequency content is shifting rapidly in a monotonic fashion. An example is a doppler-shifted signal in which the rate of displacement is high.

The detection system desired might have been an ideal PLL that has the capability of acquiring the rapidly changing signal. However, it can be shown that for a second order example this approach cannot be implemented where the normalized rate of frequency deviation is high. A novel technique for detecting signals having a high sweep rate relative to the frequency band of interest is described. The noise immunity properties of this technique are then discussed and an example circuit realization is given. In the final section, several practical applications of this technique are suggested.

II. FUNDAMENTALS OF SEQUENTIAL TRANSIENT FILTERING [1]

The method proposed is a piecewise approximation to filtered time domain characteristics of the signal and is describable as a form of signature detection. A conceptual block diagram is presented in Figure 1.

The input signal is processed through N relatively narrow, fixed band-pass filters that are arranged in parallel but with the distinction that they are sequentially related through logic networks. By maintaining equal bandwidths in all of the filters two important results are obtained. First, the output envelope from the filter closest to the instantaneous frequency of the signal rises more rapidly than the output envelopes from the other filters and second for the case of constant rate of frequency deviation, the amplitudes of all output envelopes are the same. The analysis which leads to these results is given in the next section.

The output of the first responding filter (the Kth filter where the transient of interest is deviating upwards in frequency) is monitored by an output interrogator and used to enable sequentially the next responding filter ((K+1)th) output interrogator after a time set by the corresponding "enable" delay. If an appropriate output is present within the time set by the corresponding "disable" delay, the process continues. An output from the Nth filter's interrogator indicates that a swept event has occurred. By establishing controlled delays as shown, it is possible to detect nonlinearly sweeping events as well.

Thus an input signal belonging to a particular family of swept frequency events is detected by a sweep rate window generator yielding a digital signal. Depending on the requirement, the system can be armed either synchronously via an external trigger or asynchronously via a monostable triggered by a combination of either an intermediate output interrogator or the Nth output interrogator.

III. SEQUENTIAL TRANSIENT FILTER ANALYSIS

In order to provide for a flexible prototype circuit, each fourth-order filter channel is composed of a cascade of second-order stages that are identically tuned. Thus, in the calculations below, the dependent parameter BW, is the bandwidth (3db) of the second-order filter. Because of the linear relationship between the effective bandwidth of the cascade (approximately equal to .643BW) and BW, all conclusions made with respect to the second-order filter will apply equally as well to the resultant fourth-order filter. As it is desired to obtain analytical results, a Laplace Transform analysis is attempted subsequently.

The general form of the previously described fourth-order filter is given by:

$$H(s) = \frac{s^2}{[s + (2\pi BW)s + \omega_o{}^2]^2}$$

From this the impulse response, h(t), can be calculated as:

$$h(t) = \left(\frac{\frac{1}{4Q^2} + 1}{2\omega_o} - \frac{t}{2Q}\right)\left(e^{-\frac{BWt}{2}} \sin \omega_o t\right) - \left(\frac{\frac{1}{4Q^2} - 1}{2}\right)\left(te^{-\frac{BWt}{2}} \cos \omega_o t\right)$$

where

$$BW = \frac{\omega_o}{2\pi Q}$$

This is plotted in Figure 2 for various values of equal BW. The important conclusion to be drawn here is that equal BWs yield coincident peaks in the envelope of the signal. Essentially, it is these coincident peaks that provide the transient noise immunity by allowing the delay enabling configuration of Figure 1 to inhibit detection on simultaneous filter outputs.

Using a linearly sweeping signal of the form,

$$x(t) = \sin(t^2)$$

its Laplace Transform is found to be

$$X(s) = \sqrt{\frac{\pi}{2}}\left\{\left[\frac{1}{2} - C\left(\frac{s^2}{4}\right)\right] \cos\frac{s^2}{4} + \left[\frac{1}{2} - S\left(\frac{s^2}{4}\right)\right] \sin\frac{s^2}{4}\right\}$$

where C(p) and S(p) are the respective Fresnal Integral Functions:

$$C(p) = \frac{1}{\sqrt{2\pi}} \int_o^p \frac{\cos\mu}{\sqrt{\mu}}\, d\mu$$

$$S(p) = \frac{1}{\sqrt{2\pi}} \int_o^p \frac{\sin\mu}{\sqrt{\mu}}\, d\mu$$

Once X(s) is determined, the output Y(s) can be formed as

$$Y(s) = H(s)X(s)$$

Taking the Inverse Laplace Transform of Y(s) appears rather formidable and other methods of solution will be pursued.

One possibility is that of modelling the differential equations of the system using a state-variable approach and iterating a numerical solution. By using suitably cascaded second-order analog computer networks, the desired function can be realized. The results of two filters at 400 and 800 Hertz with several values of both equal and unequal BWs are shown in Figure 3.

Two important conclusions can be made from these plots. Firstly, as expected, it can be seen that narrower BW filters respond more slowly than those with wider BWs and different amplitudes are obtained for filters with different BWs. Secondly and most importantly, in the two cases of equal BW, there is a time delay between the peak of the envelope of the two filters which provides a characteristic that can be detected. By unbalancing the BWs, it is possible to change this delay for any given sweep rate. However, the respective amplitudes will change as well. From a practical point of view, it is more desirable to have equal amplitude signals merely delayed in time and to maintain coincident peaks for transient inhibition as previously mentioned.

From a detection viewpoint it is advantageous to detect the output before the peak of the envelope. By doing this, two benefits are achieved. Firstly, the two outputs are spaced farther apart in time at this portion of the transient and secondly, this allows for compensation of the errors in detection of the beginning of the sweep because of finite rise time.

IV. NOISE IMMUNITY

To demonstrate some properties of noise immunity of this scheme, consider the result of a delta impulse excitation by reference to Figure 1. Theoretically, the impulse has a constant frequency spectrum and would excite the entire bank of filters simultaneously. The output from the first filter would then initiate its enabling delay 1. At the end of this delay, the output from the second filter is interrogated. If its output is present (examined on a comparative amplitude basis), then the detection cycle is disabled for the following reason. In order that the transient be classified as a member of the specified family of swept frequency events, the filter must not respond until an interval of time has elapsed which includes both the "enable" delay of the previous filter plus a further period characteristic of the transient of interest. Without too much difficulty, one can examine various other types of input signals and conclude that they too will not be falsely detected as swept events.

It has been empirically determined that for a linear frequency ramp beginning at 50 hz and sweeping to 1200 hz in 5 milliseconds the maximum signal to noise ratio required for detection is 16 db with a 300 hz noise bandwidth. This falls off as the bandwidth of the Gaussian noise is varied and becomes less than 0 db required signal to noise ratio with a 2 decade increase in noise bandwidth.

V. CIRCUIT REALIZATION

Referring to Figure 4, the system was first implemented using the minimum number of bandpass filters - namely two. These are formed from IC1-IC3 and IC4-IC6. This state-variable configuration of equal-bandwidth fourth-order filters allows for independent adjustment of filter bandwidth and resonant frequency.

The output interrogator for the first filter (lower resonant frequency) is comprised of IC9A, IC10, and IC11A. These form an envelope detector, an exponential peak detector, and a comparator, respectively. With this configuration it is possible to determine when the envelope of the present signal is greater than a percentage of the previous signal. By utilizing an exponentially decaying peak detector, the system can adjust to varying input amplitudes. In addition, the finite rise time of the transient response of the bandpass filters is compensated for by detecting the signal before the peak in the envelope of the filter response. Potentiometer, P1, then can effect several tradeoffs between noise immunity, amplitude variation, and accurate swept frequency detection.

The output (F) initiates "enable" delay 1 which consists basically of IC13A and B and IC15B. The second output interrogator is composed of IC9B, IC12, and IC9C. Its output (H) is stored in IC15B and the digital output signal is present as a level transition (C).

Enabling of the second filter is accomplished by an operational transconductance amplifier using the bias terminal as an enable function. In addition IC9A and B are also operational transconductance amplifiers to provide a means for synchronous operation if required.

VI. APPLICATIONS

The present system is currently being used as a part of specified instrumentation that detects the opening of cardiac valves. Using a doppler technique, a signal is obtained which contains a frequency sweep deviation corresponding to valve velocity. By detecting the occurrence of this ramp of frequency, it is possible to determine the opening time of a heart valve in a manner suitable for clinical use.

Other applications for this scheme include establishing time parameters for intonation curves in linguistics, obtaining time of occurrence of resonance in mechanical elements using a suitable transducer, and determining the onset of turbulence in high speed flow mechanisms. It is also possible to form a bank of units each with N filters in order to perform "spectral" analysis of rate-of-frequency deviation versus time.

The technique is quite general in nature and has the capacity to detect a wide variety of swept-frequency signals.

REFERENCE

[1] A.J. Cousin, "A Bioengineering Investigation of Valvular Events of the Heart: Evolution of a Real Time Cardiac Pre-ejection Period Monitor", M.A.Sc. Thesis, Department of Electrical Engineering, University of Toronto, January 1973.

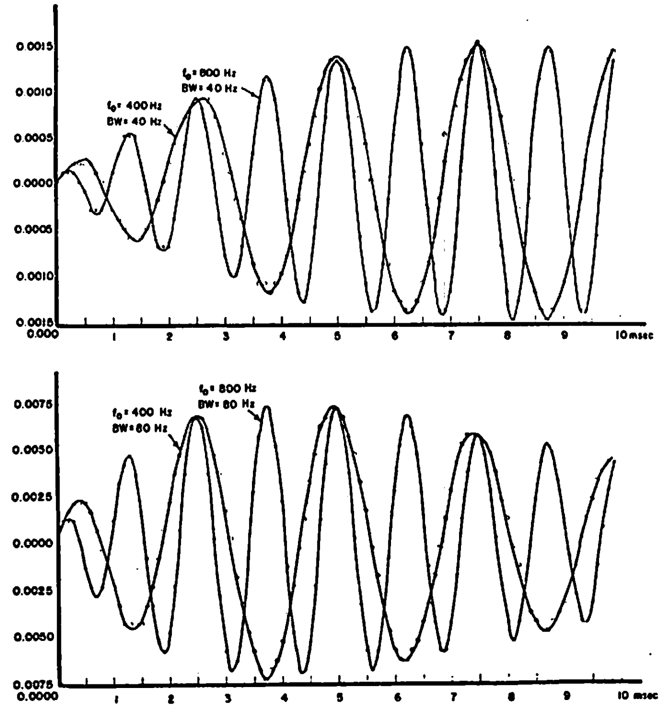

Figure 2

Impulse Response of Equal BW Bandpass Filters

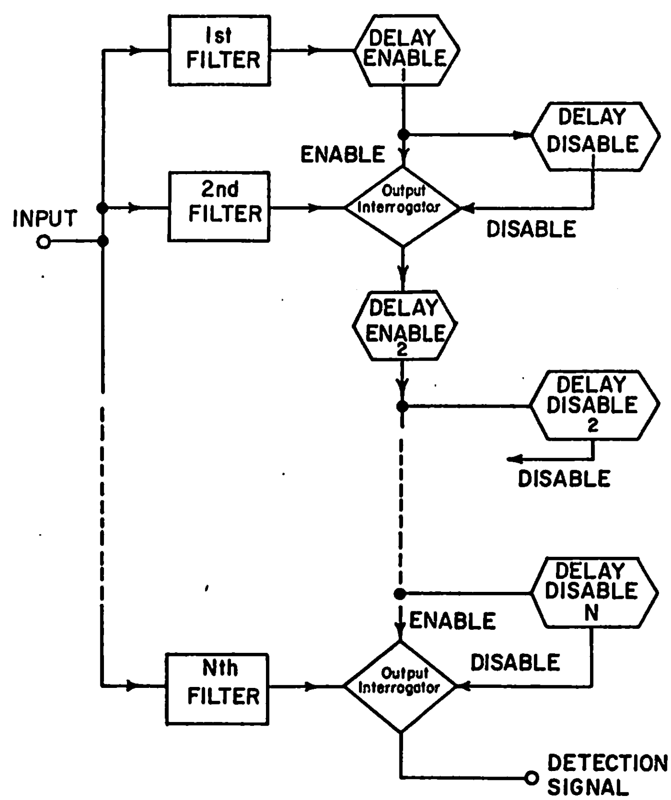

FIGURE I

BLOCK DIAGRAM OF SEQUENTIAL TRANSIENT FILTERING TECHNIQUE

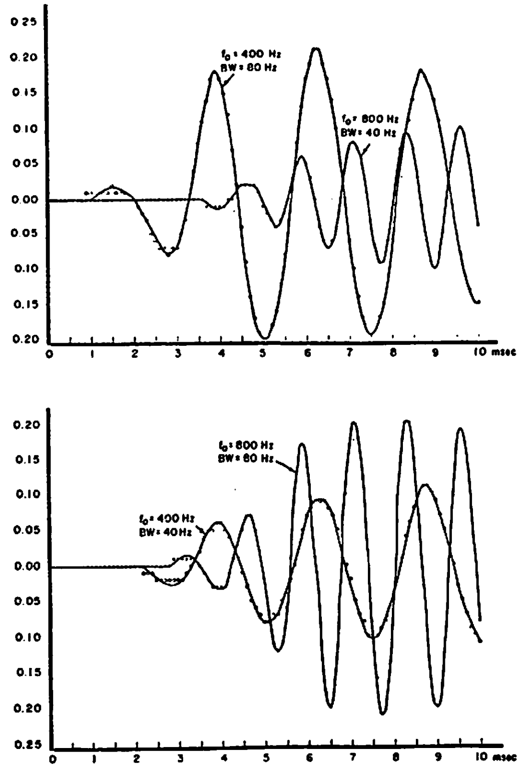

Figure 3

Bandpass Response to Frequency Ramp Signal

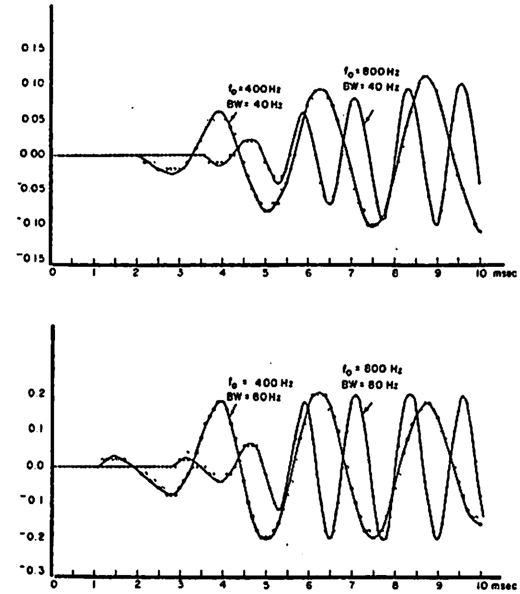

Figure 3 (Cont'd)

Bandpass Response to Frequency Ramp Signal

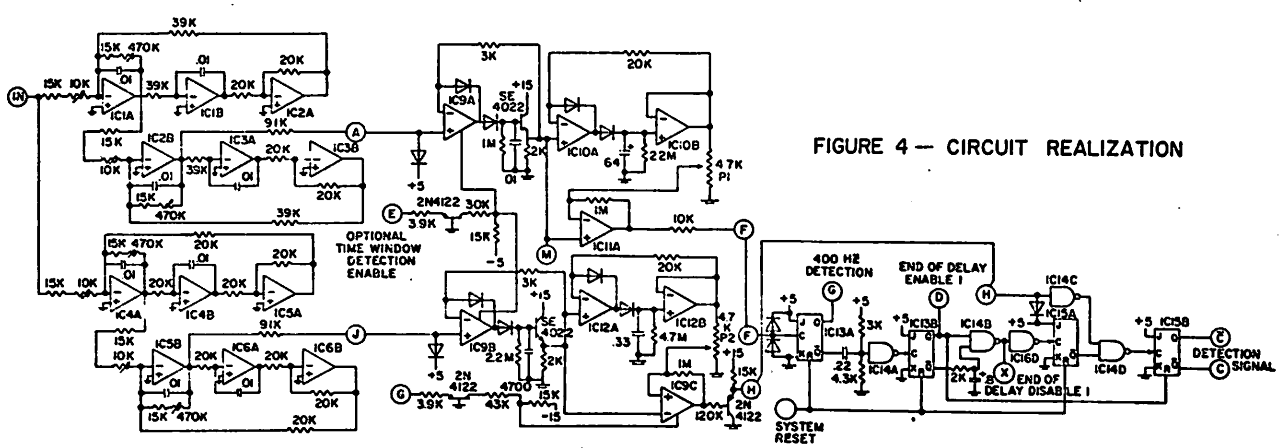

FIGURE 4 — CIRCUIT REALIZATION