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Smoothing of Impulse Noise by Orthogonal Transform

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Synopsis

Electromagnetic impulse noise which is harmful to signal measurement or transmission of information, is smoothed by the orthogonal transform processor. The idealized impulse noise with infinitesimal duration and Gaussianly-distributed amplitude shows the same spectral characteristics as white Gaussian noise. Optimal correlation detector against such noise is easily realized by the orthogonal transform processor. Photoelectric pulse signals disturbed by the impulse noise from the power supply can be well detected through the Walsh waveform analyzer. Also, orthogonally-synthesized signals can be demodulated with firmly-suppressed impulse noise, where both the statistical and instantaneous SNRs are superior to those in the usual PCM transmission system.

1. Introduction

Electromagnetic impulse noise generally originates from the spark discharge on an electric contact or gap, or from the transient phenomenon in switching.[1] This noise with its high peak power and wide spectrum causes signal processing systems to make errors during operation.

Many physical methods to control the generation and propagation of the noise are adopted. This paper deals with the systematic method to smooth impulse noise for signal detection.

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Real electromagnetic impulse noise may be quite complex.[2] But, here it is treated as the idealized one in order to give a fundamental consideration to filtering. Namely, it is represented by random pulses with infinitesimal duration and Gaussianly-distributed amplitude, and therefore its spectrum is the same as white Gaussian noise's.[3),4)]

For the signal detection in the presence of such impulse noise, the synchronous matched filter is utilized.[3),4)] This works as noise smoother. The filter can be constructed by an orthogonal transform processor. As examples, the method of measuring photoelectric pulse signal by using the Walsh waveform analyzer, and the method of data transmission by the orthogonal transform are discussed.

2. Correlation Detector

Correlation detector is useful for the signal detection under the bad SNR environment. Figure 1 shows a model of correlation detector, and Figure 2 shows typical waveforms of an input signal f(t), input impulse noise g(t), weighting function h(t) and trigger pulse, where input signal, weighting function and trigger pulse are synchronous.

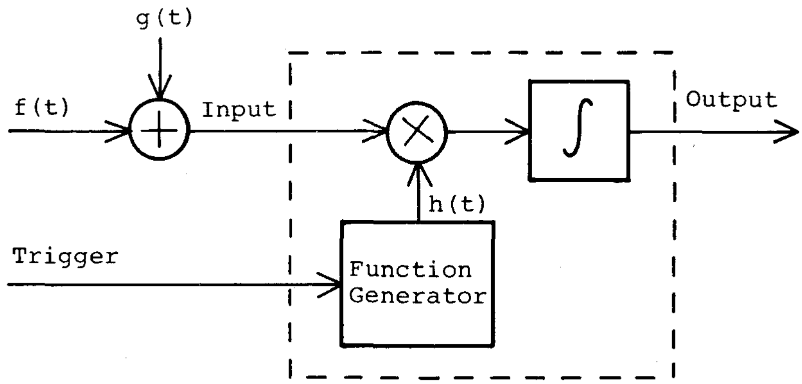

Fig.1 A model of correlation detector.

The value of detector output is given by

$$\frac{1}{T}\int_0^T \{f(t) + g(t)\}h^*(t)\,dt \tag{1}$$

where T is time base and the asterisk denotes complex conjugate for convenience of the spectrum representation later on.

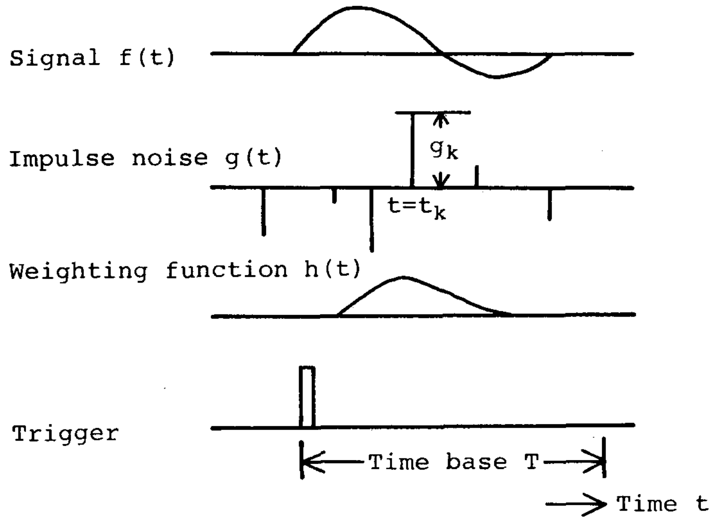

Fig.2 Typical waveforms on the detector.

Now, let an impulse noise consist of numerable square pulses with the infinitesimal duration ε and the pulse height g_k, as shown in Figure 2. This is represented by

$$g(t) = \sum_k g_k\{u(t-t_k) - u(t-t_k-\varepsilon)\} \tag{2}$$

where $u(t)$ is unit step function, and the impulse noise is zero-mean Gaussian and ergodic.[3),4)] White Gaussian noise can be considered to be denumerable sets of such pulses. Therefore, this impulse noise can be treated similarly to white Gaussian noise, and the design of correlation detector becomes easy.

3. Spectrum Expression of Matched Filter

Correlation detector becomes the matched filter under a certain matching condition. Here, the matched filter is explained using the orthogonal transform.[5)]

Using the first N orthonormal functions $\{\phi(i,t)\}$, the signal, the impulse noise, and the weighting function are respectively expanded in a series as

$$f(t) \simeq \sum_{i=0}^{N-1} a_i \phi(i,t) \tag{3}$$

$$g(t) \simeq \sum_{i=0}^{N-1} b_i \phi(i,t) \tag{4}$$

$$h(t) \simeq \sum_{i=0}^{N-1} c_i \phi(i,t) \tag{5}$$

where a_i, b_i and c_i are the amplitude spectra and the impulse noise spectrum b_i holds zero-mean Gaussian. Then the spectrum expression of the detector output becomes

$$\sum_{i=0}^{N-1} (a_i+b_i) c_i^* \ . \tag{6}$$

Figure 3 shows the correlation detector using a waveform analyzer, such as a Walsh or Fourier transform processor. Here the summing amplifier follows the analyzer and gives the output according to Equation (6).

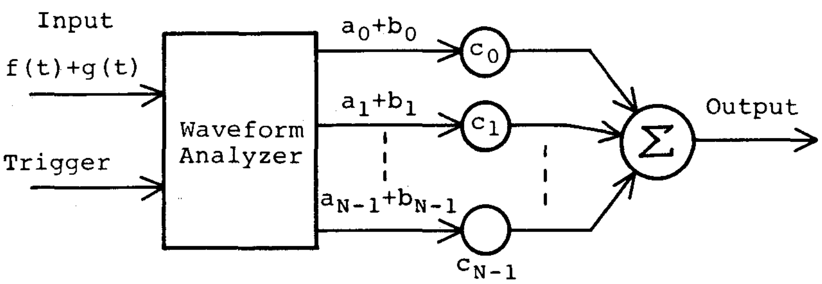

Fig.3 Correlation detector using waveform analyzer.

This method without generating the weighting function is convenient for construction of the matched filter as below.

The matched filter in this case satisfies the matching condition that the weighting function should present the same waveform as the input signal ($h(t)=Kf(t)$, $c_i=Ka_i$). The output SNR of this matched filter becomes

$$\frac{\sum_{i=0}^{N-1} |a_i|^2}{\overline{|b_i|^2}} \simeq N \cdot \frac{\frac{1}{T}\int_0^T f^2(t)\,dt}{\frac{1}{T}\int_0^T \overline{g^2(t)}\,dt} \tag{7}$$

where the noise power is uniformly spread over the spectrum.

Another matched filter that the weighting function is one of the orthogonal functions as $h(t)=\phi(i,t)$, is to be called the orthogonal matched filter and useful for data transmission. Its output SNR becomes

$$\frac{|a_i|^2}{\overline{|b_i|^2}} \simeq N \cdot \frac{|a_i|^2}{\frac{1}{T}\int_0^T \overline{g^2(t)}\,dt} \quad . \tag{8}$$

4. Pulse Signal Measurement by Walsh Waveform Analyzer

Here, the matched filter for pulse signal measurement is constructed by the Walsh waveform analyzer.[6)]

The analyzer transforms a solitary waveform of 16 microseconds into parallel 16 amplitude spectra using $\{wal(i,t/T)\}$ functions. In the application of this analyzer to the matched filter, input impulse noise must not exceed its allowable input range of -1 to +1 volt. Therefore, a linear-time-invariant pre-filter as given by

$$\{u(t) - u(t-\Delta t)\}/\tau \tag{9}$$

should be followed by the analyzer, where Δt=1μs and τ=constant.

Figure 4 shows the block diagram of the system to measure the pulse laser-light signals. The input signal and the trigger are derived from the light of the pulsed laser. The input noise consists of the additive impulse noise leaking from the laser power supply and of the white Gaussian noise from the electronic circuits.

The matched filter output is quantized by the analog to digital converter and transferred into the personal computer, which accumulates the output data for the better SNR.

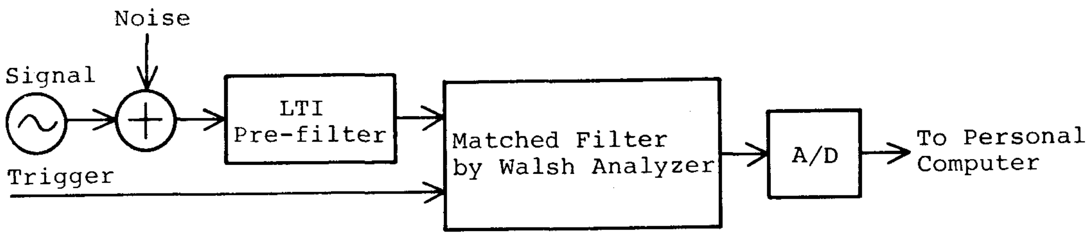

Fig.4 The system to measure the pulsed-laser light signals.

5. Data Transmission by Orthogonal Matched Filters

The orthogonal matched filters are effectively applied to the following data transmission system.

Figure 5 shows a typical model of the system. Here, the noise is assumed to be the impulse noise. The signal on the transmission channel is assumed to be the orthogonal synthesis signal, given by

$$f(t) = \sum_{i=0}^{N-1} a_i \phi(i,t) \tag{10}$$

whose spectrum a_i is analog or digital datum. At the receiver, the waveform analyzer which forms the N synchronous matched filters, gives the estimate of the transmitted data.

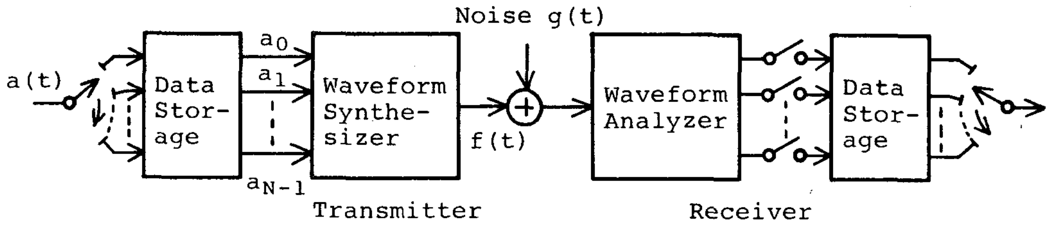

Fig.5 Data transmission system using orthogonal transform.

Now, let us consider the SNR in the data transmission system using the block-pulse train, where the received signal is the PAM signal given by

$$\sum_{i=0}^{N-1} \sqrt{N}\, a_i [u(t-i\Delta t) - u\{t-(i+1)\Delta t\}] \quad ; \; \Delta t = T/N \qquad (11)$$

whose power is equal to that of the orthogonal synthesis signal.

The statistical SNR in receiving the i-th datum in both systems becomes

$$N|a_i|^2/\ \overline{g^2(t)}\ . \qquad (12)$$

On the other hand, in case an impulse noise has the power g^2 only at the i-th time slot, the short time SNRs become

$$(\text{SNR})\text{orth} = \frac{N|a_i|^2}{g^2 \frac{1}{T}\int_{i\Delta t}^{(i+1)\Delta t} |\phi(i,t)|^2 dt} \qquad (13)$$

for the orthogonal transmmission and

$$(\text{SNR})_{\text{PAM}} = N|a_i|^2/\ g^2 \qquad (14)$$

for the PAM transmission. If $\phi(i,t)$ is a Walsh function, the SNR value in the orthogonal transmission takes N times as much as in the PAM transmission, since the noise power spreads over each spectrum.

Figures 6(a) and 6(b) show respectively a Walsh-synthesis multi-level signal and a PCM dipolar signal on the digital data transmission channel, where $a_1=a_4=a_7=-E$ and others = +E, and N=8, and $\phi(i,t)=\text{wal}(i, t/T)$. Both signal powers are constant and the Walsh synthesis signal is easily amplified if $a_0=0$.

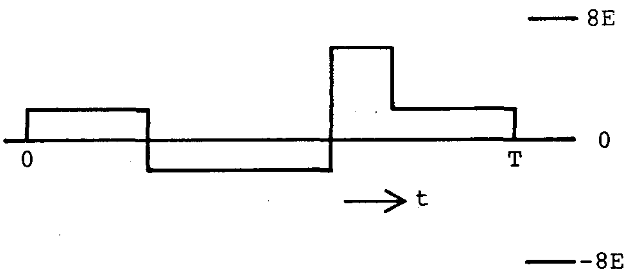

Fig.6 (a) Walsh synthesis multi-level signal.

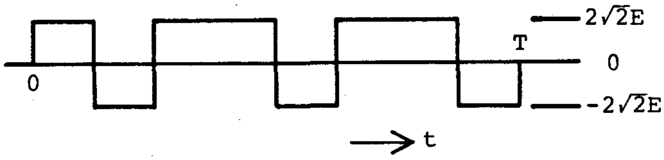

Fig.6 (b) PCM dipolar signal.

6. Conclusion

Electromagnetic impulse noise is idealized to be a finite set of random pulses with infinitesimal duration and Gaussianly-distributed amplitude. It is shown that the synchronous matched filter against impulse noise can be constructed by an orthogonal transform processor. As the first example, the matched filter using the Walsh waveform analyzer is effectively applied to photo-electric pulse signals. As the second example, the orthogonal matched filter in data transmission is effective in suppression of impulse noise. In each example, impulse noise power is smoothed through matched filtering and spectrum decomposition.

For strict processing of real impulse noise, the model of impulse noise and the method of filtering might have to be modified to some extent.

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