RECOMMENDATION ITU-R M.1372*

EFFICIENT USE OF THE RADIO SPECTRUM BY RADAR STATIONS IN THE RADIODETERMINATION SERVICE

(Questions ITU-R 35/8 and ITU-R 216/8)

(1998)

Summary

This Recommendation provides some of the methods that can be used to enhance spectrum efficiency of radar systems operating in radiodetermination bands. Several receiver post-detection interference suppression techniques currently used in radionavigation, radiolocation and meteorological radars are addressed along with system performance trade-offs (limitations) associated with the interference suppression techniques.

The ITU Radiocommunication Assembly,

considering

a) that the radio spectrum for use by the radiodetermination service is limited;

b) that the radiodetermination service provides essential functions;

c) that the propagation and target detection characteristics to achieve these functions are optimum in certain frequency bands;

d) that the necessary bandwidth of emissions from radar stations in the radiodetermination service are large compared with emissions from stations in many other services;

e) that efficient use of the radio spectrum by radar stations in the radiodetermination service can be achieved by reducing transmitter spurious emissions and utilizing interference suppression techniques;

f) that methods to reduce spurious emissions of radar stations operating in the 3 GHz and 5 GHz bands are addressed in Recommendation ITU-R M.1314;

g) that the inherent low duty cycle of radar systems permits the use of interference suppression techniques to enable radar stations in close proximity to use the same frequency,

recommends

1 that interference suppression techniques such as, but not limited to, those contained in Annex 1 should be considered in radar stations to enhance efficient use of the spectrum by the radiodetermination service.

ANNEX 1

Interference suppression techniques

1 Introduction

As spectrum demands for radiodetermination bands increases, new radar systems will need to utilize the spectrum more effectively and efficiently. There will be heavily used areas throughout the world where radiodetermination systems will have to operate in high pulse density environments. Therefore, many radar systems may be subjected to pulsed

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* This Recommendation should be brought to the attention of the International Maritime Organization (IMO), the International Civil Aviation Organization (ICAO), the International Maritime Radio Committee (CIRM), and the World Meteorological Organization (WMO).

interference in performing their missions. The incorporation of interference suppression circuitry or software in the design of new radar systems will ensure that system performance requirements can be satisfied in the type of pulsed interference environment anticipated.

Interference suppression techniques, are generally classified into three categories: transmitter, antenna, and receiver. Receiver interference suppression techniques are more widely used. Receiver interference suppression techniques are categorized into predetection, detection and post-detection.

The following is a brief discussion of several receiver post-detection interference suppression techniques currently used in radionavigation, radiolocation and meteorological radars. System performance trade-offs (limitations) are also addressed for each interference suppression technique.

2 Integrator

2.1 Description

The process of summing the echo pulses from a target is called integration. Integrators are generally used in radars for two reasons:

– to enhance weak desired targets for plan position indicator (PPI) display,

– to suppress asynchronous pulsed interference.

The principle of the radar video integrator is that radar signal returns from a point target consist of a series of pulses generated as the radar antenna beam scans past the target, all of which fall in the same range bin in successive periods (synchronous with the radar's transmitted pulses). It is this series of synchronous pulses from a target which permits integration of target returns to enhance the weak signals. The integrator also suppresses asynchronous pulsed interference (pulses that are asynchronous with the radar's transmitted pulses) since the interfering pulses will not be separated in time by the radar period, and thus will not occur in the same range bin in successive periods. Therefore, the asynchronous interference will not add-up and can be suppressed.

Basically two types of integrators have been used in radar systems. The most common type of integrator is the feedback integrator shown in Fig. 1. A binary integrator shown in Fig. 2 has also been used in a few radionavigation radars.

FIGURE 1

Feedback integrator block diagram

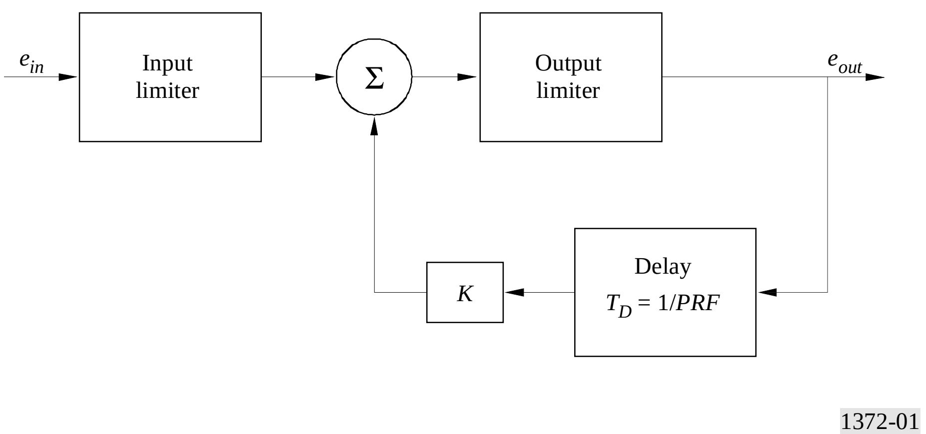


FIGURE 2

Binary integrator block diagram

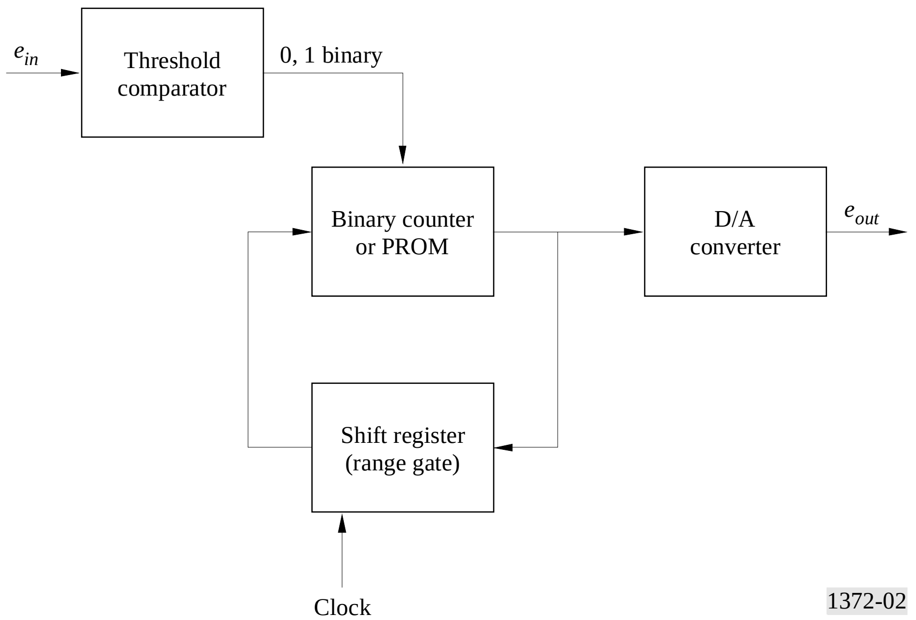


Figure 3 shows a simulated output for a desired target return (pulse width = 0.6 µs, pulse repetition frequency (PRF) = 1 000) without integration for a signal-to-noise ratio, *S*/*N*, of 15 dB. Fig. 4 shows a simulated output of radar without integration in the presence of the desired signal and three interference sources (interferer 1, pulse width = 1.0 µs, PRF = 1 177 ; interferer 2, pulse width = 0.8 µs, PRF = 900; interferer 3, pulse width = 2.0 µs, PRF = 280) with interference-to-noise ratios (*I*/*N*) of 10, 15 and 20 dB, respectively.

FIGURE 3

Simulated output of radar without integrator for
***S*/*N* = 15 dB**

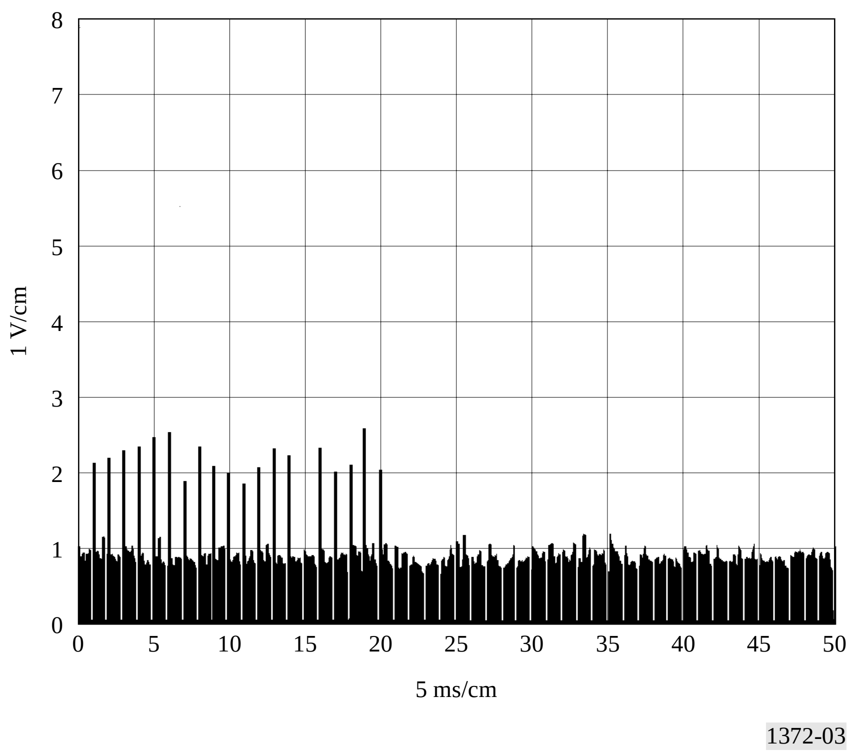
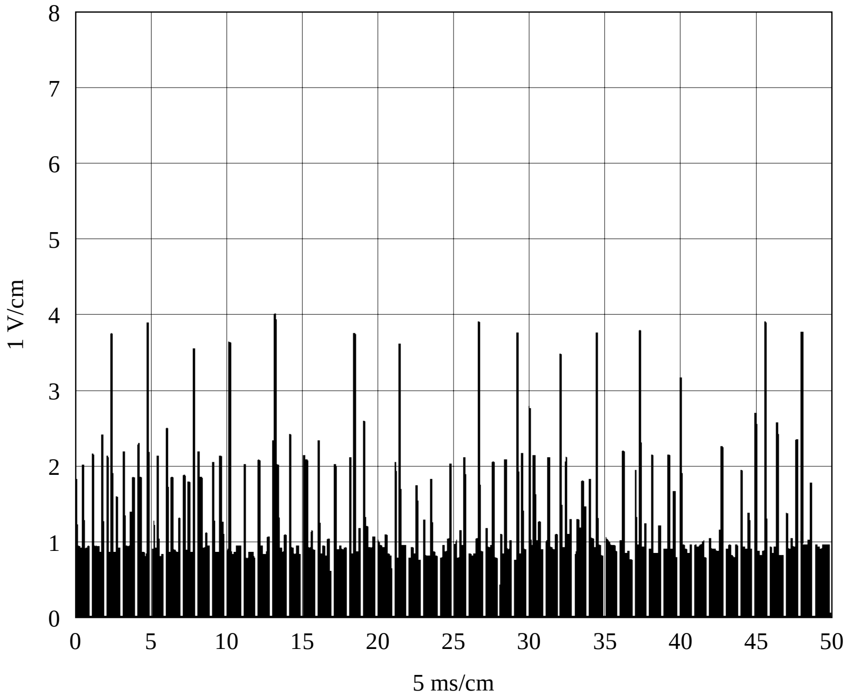


FIGURE 4

Simulated output of radar without integrator in presence of interference



Desired S/N = 15 dB
Interferer 1 I/N = 10 dB
Interferer 2 I/N = 15 dB
Interferer 3 I/N = 20 dB

1372-04

2.2 Feedback integrator

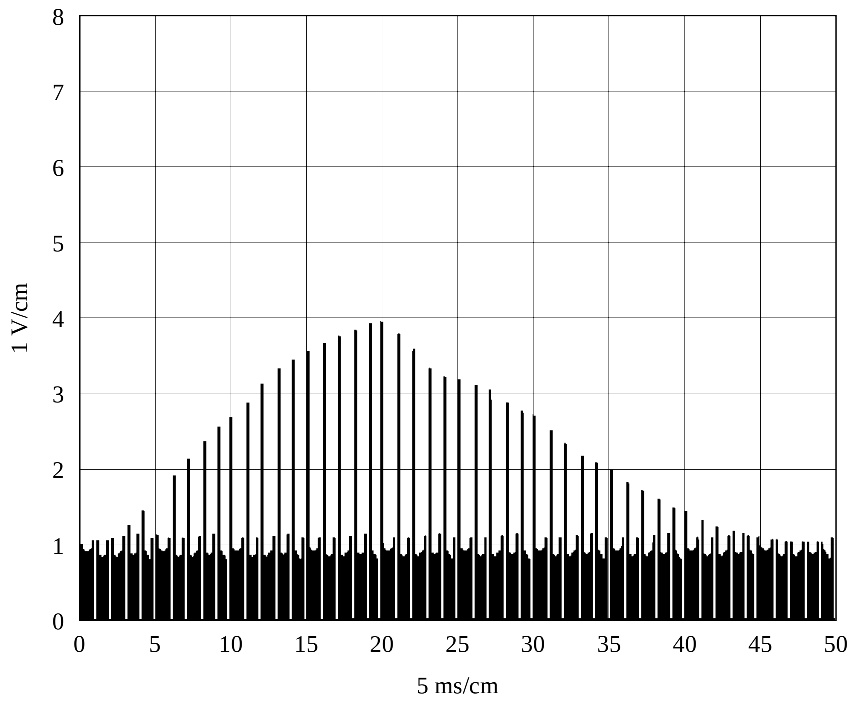
The feedback integrator shown in Fig. 1 consists of an input limiter, an adder, and a feedback loop with an output limiter and a delay equal to the time between transmitter pulses (1/PRF) in radars using non-staggered pulse trains. The overall gain, K, of the feedback loop is less than unity to prevent instability. The input limiter serves as a video clipping circuit to provide constant level input pulses to the feedback integrator, and is a necessary integrator circuitry element to suppress asynchronous pulsed interference. The input limiter limit level is usually adjustable, and controls the transfer properties of the feedback integrator. Fig. 5 shows the radar output for the same interference condition shown in Fig. 4 with feedback integration for an input limit level setting of 0.34 V. The asynchronous interference has been suppressed by the feedback integrator.

2.3 Binary integrator

The binary integrator shown in Fig. 2 consists of a threshold detector or comparator, binary counter or programmable read-only-memory (PROM) logic (adder/subtractor circuit), a multi-bit shift register memory, and a digital-to-analogue (D/A) converter. Each inter-pulse period is divided into range bins. Each time a pulse of a target return, noise, and/or interference exceeds the comparator threshold level, the binary counter or PROM is bumped up to the next level or . For this simulation, a PROM logic with non-linear state progressions of 1, 2, 4, 8, 16, 31 was used. If the successive pulses of the target return pulse train continue above the comparator threshold in the given range bin, the PROM is advance to the next highest programmed state until a maximum integrator level of 31 is reached. If in any PRF period the signal fails to exceed the comparator threshold, the PROM logic is bumped down to the next lowest programmed state until a state level of zero is reached. The subtraction provides the target return pulse train signal decay required after the antenna beam has passed the target, and also enables the suppression of asynchronous interfering signals. The voltage amplitude at the integrator D/A converter output is determined by the binary counter or PROM level (0 to 31) for the particular range bin times 0.125 V. Therefore, for a binary counter level of 31, the maximum enhancer output voltage would be 3.875 V (31×0.125). Fig. 6 shows the radar output for the same interference condition shown in Fig. 4 after binary integration. The asynchronous interference has been suppressed by the binary integrator.

FIGURE 5

Simulated output of radar with feedback integrator in presence of interference

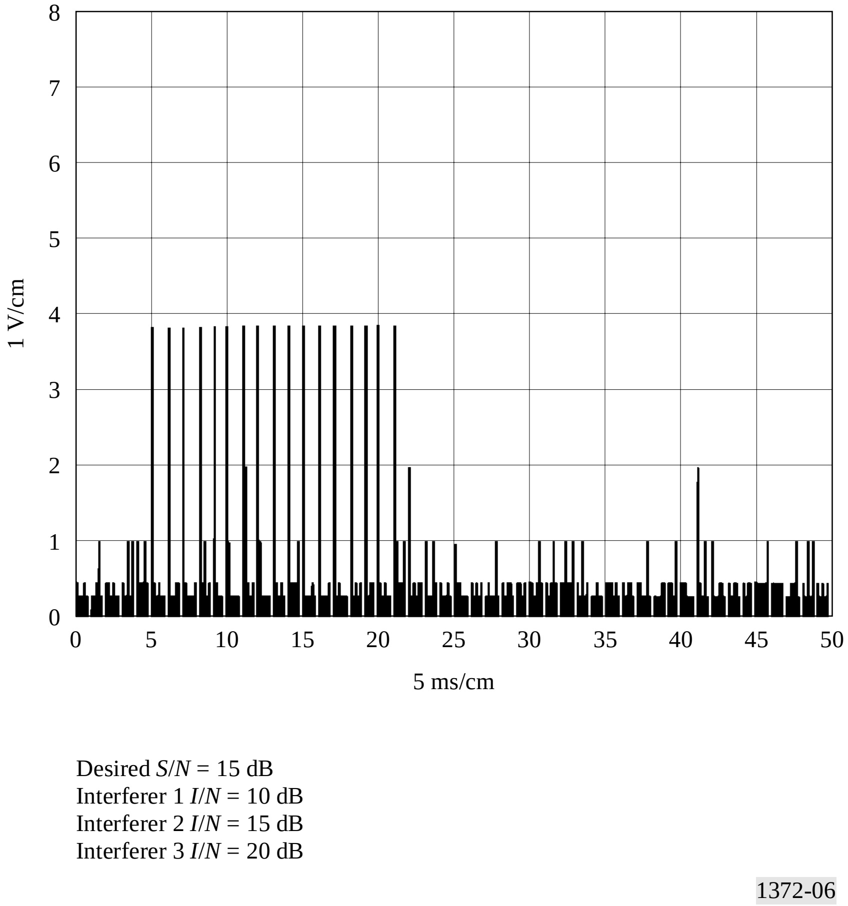


Desired S/N = 15 dB
Interferer 1 I/N = 10 dB
Interferer 2 I/N = 15 dB
Interferer 3 I/N = 20 dB

1372-05

FIGURE 6

Simulated output of radar with binary integrator in presence of interference



2.4 Trade-offs

Target azimuth shift:	0.9°	(0.7 beamwidth) for feedback integrator
	0.2°	(0.2 beamwidth) for binary integrator
Angular Resolution:	1.2°	(0.9 beamwidth) for feedback integrator
	0°	(0 beamwidth) for binary integrator

2.5 Desired signal sensitivity

Approximately 1 dB decreases when the integrator is adjusted to suppress pulsed interference with the normal video mode and with moving target indicator (MTI) mode in the 2 and 3 pulse canceller mode without feedback. However, in the MTI mode with feedback, the sensitivity loss can approach 2 dB due to the need to adjust the integrator input limiter to limit the interference level below the receiver inherent noise level.

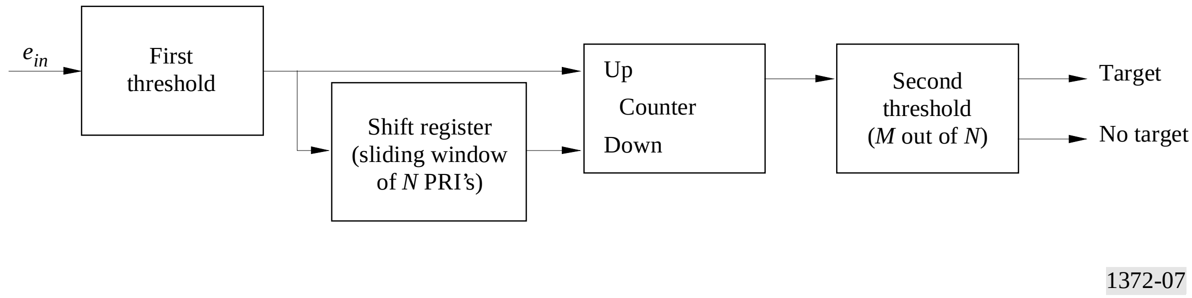
3 Double-threshold detection

3.1 Description

The double-threshold detector is a post detection signal processing technique used in radionavigation and search radars. The function of the double-threshold detection circuit is to extract or identify targets from radar target pulse returns. However, the double-threshold method of detection also has an inherent capability to suppress false alarms caused by asynchronous pulsed interference. Fig. 7 shows a simplified block diagram of a double-threshold detector.

FIGURE 7

Double-threshold detector block diagram



The "double-threshold" detector consists of establishing a bias level, *T*, the "first threshold", at the output of the radar, and then counting the number of pulses whose amplitude exceeds the bias level, *T*, in a "sliding time window". The sliding window consists of *N* successive repetition periods in a given range bin. Where *N* is approximately equal to the number of pulses emitted as the beam scans through an angle equal to the half–power antenna beamwidth. If in any given range bin the number of pulses exceeding *T* in the sliding window is greater than or equal to a preassigned number *M*, the "second threshold", a target is declared to be present in that range bin. The values of the first threshold, *T*, and second threshold, *M*, are chosen to meet a particular probability of false alarm, P_{fa}, and probability of detection, P_d.

There are also more complex double threshold detection criteria than discussed above. For example, a fixed window size with separate leading and trailing edge first threshold levels can be used. Also, a variable window size with separate leading and trailing edge first threshold levels can be used.

Intuitively, the double-threshold technique should be useful in reducing the effects of asynchronous pulsed interference. Target echoes received as the beam scans past a target will occur in the same range bin. However, interfering pulses, occurring at random in the repetition period, will be unlikely to occur in any given range bin more than a few times in N repetition periods, unless the interfering pulse density is extremely high.

3.2 Trade-offs

The double threshold detector has a slightly poorer target probability of detection performance than the integrators which sum the target return pulses. The performance (P_d and P_{fa}) of the double threshold detector in suppressing asynchronous pulse interference depends on both the first and second thresholds.

4. PRF discriminator

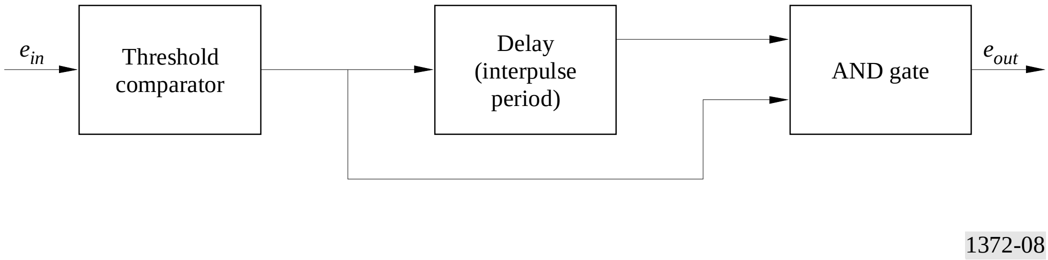
Fig. 8 shows a simplified block diagram of PRF discriminator. The PRF discriminator utilizes a threshold comparator, delay (shift register) and a coincidence circuit (AND gate) to suppress asynchronous interfering pulses that do not have the same PRF (interpulse period) as the desired signal. The discriminator usually operates at video, target pulses above the threshold are passed by the comparator; one pulse repetition period later, a second target pulse arrives at the input to the coincidence circuit just as the first leaves the shift register. In this scheme, all except the first pulse in the target return pulse train are processed. The threshold level of the comparator is generally set at a 6 to 8 dB threshold-to-noise ratio. More complex PRF discriminators can be designed to suppress multiples of the desired signal PRF.

4.1 Trade-offs

The PRF discriminator does not enhance the desired signal as the feedback and binary integrator circuits. Also there is a loss in desired signal sensitivity which is a function of the comparator threshold setting.

FIGURE 8

PRF discriminator block diagram



5 Pulse width discriminator

If the pulse width of the interference differs from that of the victim radar, it may be used to provide a means for discrimination. One method of implementing a pulse width discriminator is shown in Fig. 9. The input pulse is differentiated and split into two channels. In one channel the differentiated pulse is delayed a time corresponding to the width of the desired pulse τ, while in the other channel the differentiated pulse is inverted. If the input pulse were of width τ, the differentiated trailing edge inverted pulse would coincide in time with the leading edge pulse delayed in time τ. The coincidence circuit permits signals in the two channels to pass only if they are in exact time coincidence. If the input pulse were not of width τ, the two spikes would not be coincident in time and the pulse would be rejected.

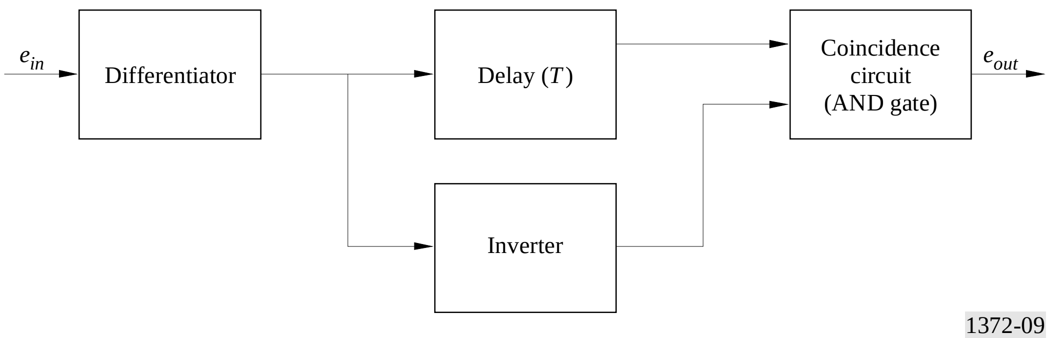
Pulse width discriminators are generally not effective against off-tuned interference due to the inherent receiver IF output impulse response on the leading and trailing edge of an off-tuned pulsed signal. The leading and trailing edge impulse response of an off-tuned pulsed signal are each typically similar to the desired signal full pulse width because of the matched radar IF filter.

5.1 Trade-offs

The utilization of pulse-width discriminators generally results in reduced receiver sensitivity and probability of detection.

FIGURE 9

Pulse width discriminator block diagram



6 Pulse amplitude discrimination

6.1 Description

Pulse amplitude discrimination can be used to suppress asynchronous pulsed interference if the interfering signal levels are several dB above the receiver noise or clutter level. In one pulse amplitude discrimination technique, the signal level in the same range bin is added for several consecutive radar pulse periods. The voltage magnitude is then stored and the average voltage computed. The voltage in each range bin is then compared with 4 or 5 times the average. If any range bin exceeds this number, it is replaced by the average of the range bins. When there is interference in only one of the range bins and noise only in the other range bins, asynchronous pulsed interference with a peak I/N greater than 12 to 14 dB (depending on the criteria of 4 or 5 times the average) will be eliminated from further processing in the radar.

Many different algorithms can be developed to suppress asynchronous pulsed interferences based on pulse amplitude discrimination. The radar mission and type of radar signal processing must be taken into consideration in determining an appropriate pulse-amplitude discrimination algorithm.

6.2 Trade-offs

Desired signal trade-offs should be minimal with proper choice of algorithms. Pulse amplitude discriminators do not suppress weak interfering signals, and they do not work well in the presence of strong clutter unless they include additional features.