SOME DIFFERENCES BETWEEN GATED CW AND PULSE RADARS IN RCS AND IMAGING MEASUREMENTS

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ABSTRACT

This paper compares some of the features and capabilities of gated CW and pulse radars for RCS and imaging measurements. At the conceptual level, these two types of radars are very similar. The primary conceptual difference is that a pulse radar has a relatively high bandwidth receiver while a gated CW system has a relatively narrow bandwidth receiver.

The measures of performance of an RCS and imaging system include sensitivity, measurement time, clutter rejection, dynamic range and accuracy. Other considerations such as inter-pulse modulation may be important in some cases.

For some applications, typically where long ranges are involved, a pulse system has significant performance advantages. For many applications, the performance advantage of a pulse system is not significant, particularly when viewed in light of the large difference in cost. This is particularly true of Quality Assurance applications which are normally characterized by both short ranges and lower budgets. Typically, the price of a gated CW system is in the range of 1/4 to 1/2 the price of a comparable pulse system.

This paper discusses general similarities and differences in the fundamental operating characteristics of the two systems. Specific performance measures are discussed including system sensitivity, gate performance, clutter rejection, and measurement times. Other considerations such as pulse modulation are discussed. A summary of the various considerations is presented in order to give the reader an understanding of the applications for which a gated CW system is more appropriate.

Keywords: RCS, Imaging, Instrumentation, Radar, Gated CW, Pulse

1. INTRODUCTION

The selection of the type of instrumentation radar for an RCS measurement facility will significantly impact the performance that can be achieved in the measurement facility. The measures of performance include sensitivity, measurement time, clutter rejection, dynamic range, and accuracy.

On the conceptual level, these two types of radars are very similar with the exception that the pulse radar has a relatively high bandwidth receiver and the gated CW system has a relatively narrow bandwidth receiver. On the implementation level, there are, of course, different implementations and generations of pulse radars and different implementations and generations of gated CW radars. Pulse radar characteristics can vary dramatically from generation to generation and from implementation to implementation. Gated CW characteristics can likewise vary dramatically. For these reasons, specific examples in this paper will be confined to the Scientific-Atlanta Model 2090 Pulse Radar (See Figure 4) and the Scientific-Atlanta Model 2095 Gated CW Radar (See Figure 5).

The next section discusses the fundamental operating character istics of the two types of instrumentation radars.

2. FUNDAMENTAL OPERATING CHARACTERISTICS

In terms of a single frequency measurement, which may involve one or more pulses at that frequency, the objective of the measurement is usually to measure the CW far-field response of the target. The response is usually expressed as a ratio of the response to a known target (e.g., a calibration sphere) and is typically expressed in dBsm.

Both types of radar utilize a pulse as the transmitted waveform in order to determine the CW response. The only real difference, at the conceptual level, between the two types of radars is how they process the received pulse energy.

For a pulse system the transmitted pulse is typically somewhat longer (in nanoseconds) than twice the target length (in feet). A typical transmitted pulse is shown in Figure 1.

Figure 2 shows a simplified version of the return from an extended target (two point scatterers) in a compact range in a chamber. The objective in this idealized case is to obtain the CW sample after any return from the feed and before the return from the back wall. The overlap time between the front edge return and rear edge return is defined as t_s. Typically, a high speed sample is taken near the end of this overlap interval in order to obtain the CW response. The receiver filter bandwidth should be matched to this sampling interval (t_s) to allow the CW response to be maximized when the high speed sample is taken.

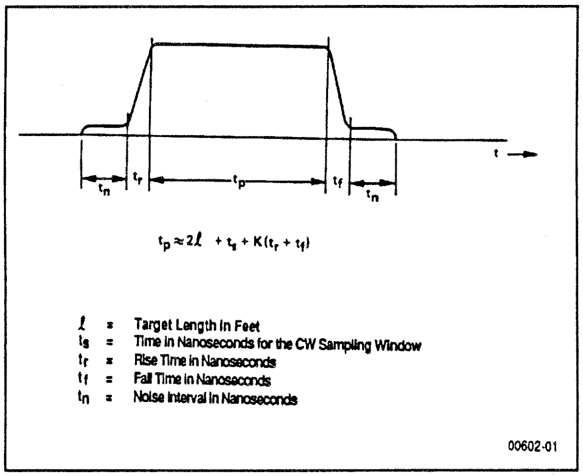

Figure 1: Transmitted Pulse

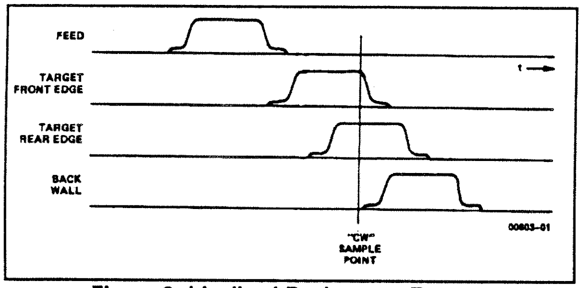

Figure 2: Idealized Backscatter Returns

For a pulse system, most of the received spectral energy is passed to the final I.F. stage which is on the order of 1.5 GHz. There the signal is filtered and converted to I (in-phase) and Q (quadrature) components which are converted to baseband and then sampled at the appropriate time with high speed sample and hold circuits. These sampled I and Q signals are then converted to digital form with A/D converters and are then transmitted to a computer for processing and storage.

A gated CW system processes the received energy in a different manner. After limiting and low noise amplification, the received energy is gated to eliminate as much undesired energy (e.g., clutter) as possible and still be consistent with other requirements of the measurement scencerio. This energy is then processed by a relatively low bandwidth receiver. This narrow band detection process deals only with one of the spectral lines (the center one) in the frequency spectrum of the pulse train. An example of the frequency spectrum of a pulse train is shown in Figure 3. The duty cycle in this example is .2 and the pulse width is τ.

Since the detection time of the receiver is inversely proportional to its effective bandwidth, there may be hundreds of pulses integrated by the receiver. The effective noise bandwidth over the processing interval of the 2095 receiver is approximately 6.6 KHz. This detected signal includes, both I and Q components which, are then converted to digital form for processing and storage.

In summary, although it is somewhat of an oversimplification, the fundamental difference between a gated CW system and a pulse system is that the former uses a narrow band detection process and the latter uses a wideband detection process. In practice there are many different implementation possibilities. The performance can be greatly affected by the specific implementation chosen.

3. SYSTEM SENSITIVITIES

A limit on sensitivity is placed by physical laws based on the power placed on the target and the measurement time. Further limits are imposed because in most cases it is not desirable to receive and process all of the energy returned from the target (e.g., in order to reduce the effect of returns other than target returns). In order to have some basis for comparison consider the case of equal measure-ment times, equal PRF's and equal receive aperture times ("receive pulse widths").

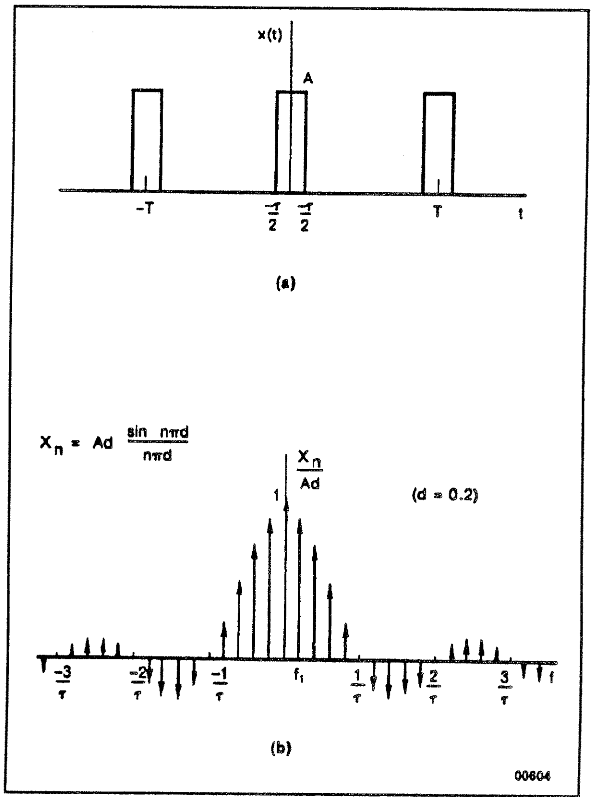

Figure 3: Periodic Pulse Train and Its Spectrum (d = 0.2)

The equation for determining system sensitivity is:

$$\sigma = \frac{(S/N)kTB_nL_TL_R(NF)(4\pi)^3R^4}{P_tG^2\lambda^2(N\beta)}$$

where:

σ	=	RCS
S/N	=	Signal-to-Noise Ratio
kT	=	Thermal Noise Power Density (-174 dBm/Hz)
B_n	=	Noise Bandwidth of Receiver Filter
L_T	=	Transmitter Front-end Losses
L_R	=	Receiver Front-end Losses
NF	=	Receiver Noise Figure
R	=	Range
P_T	=	Transmitter Peak Power
G	=	Effective Feed/Antenna Gain
λ	=	Wavelength
N	=	Number of Pulses Coherently Integrated
β	=	Coherent Integration Efficiency

If we assume that L_T, L_R, and NF are the same for both systems then the ratio of the sensitivities σ_p/σ_g is:

$$\frac{Bnp}{(N\beta)BngLg}$$

where:

Bnp	=	Pulse System Receive Noise Bandwidth
$N\beta=N$	=	Number of Pulses Integrated (Assume $\beta = 1$)
Bng	=	Gated System Receive Noise Bandwidth
Lg	=	Gating Loss
	=	$1/d^2$
d	=	Duty Cycle = PRF * RPW
RPW	=	Receive Pulse Width

Now if t is the measurement interval:

N	=	PRF * t
Bng	~	1/t
Bnp	~	1/RPW (Matched Filter)

therefore:

$$\frac{\sigma_P}{\sigma_S} = \frac{(1/RPW)}{PRF * t(\frac{1}{t})(1/d^2)}$$

$$= d$$

This means that under equal measurement intervals and the other assumptions stated above, the ratio of the sensitivities of the two systems is d. Thus for a duty cycle of .1, a pulse system would be ten times more sensitive. Or viewed another way, the same sensitivity can be achieved by the pulse system in one tenth of the time required for a gated CW system.

It is important to understand that the above conclusions apply only under the above assumptions. One cannot generalize the conclusions to conclude that a given pulse system is x times faster or x times more sensitive than a given gated CW system. Such comparisons are very dependent on the specific implementations (e.g., losses, noise figures, leakage, etc.), the desired sensitivities, and the measurement scenario. For example, the measurement scenario might be limited by frequency switching speed or target handling time. These scenarios are discussed later.

Furthermore, Scientific-Atlanta has developed in the Model 2095 gated CW system ways of improving the sensitivity over that derived above.

4. GATE PERFORMANCE AND CLUTTER REJECTION

Gate performance is composed of gate speed and gate isolation. The gate speed determines how close clutter and other undesired returns can be to the target and still be rejected. The gate isolation determines the maximum suppression of unwanted signals (e.g., transmitted signal coupling and feed or backwall returns) even if these undesired signals are widely separated in time from the target return. Thus gate speed and gate isolation together determine how high and how close to the target unwanted returns can be and still be sufficiently suppressed.

High gate isolation requires very careful attention to design, packaging, and switch performance. There is no fundamental reason why the gate performance of a gated CW system cannot be as good as the gate performance of a pulse system. Specifically the gate performance of the Model 2095 is comparable to the gate performance of the Model 2090 pulse radar. For the 2095 system the gate rise and fall times are less than two nanoseconds. The isolation is better than 140 dB.

Therefore, it can be concluded that comparable clutter rejection can be achieved with a gated CW system. For this to occur the receive gate must be similar in width to the receive gate of the pulse system. However, this is not the way a gated CW system is typically operated. One rule of thumb is that the receive gate width should be 2.5 times the target length plus the transmitted pulse length. When hardware gating of clutter is important, the receive gate width can be narrowed down to only cover the overlap area (See Figure 2) where returns are received from both the front and rear of the target.

Of course, there is a penalty (sometimes unacceptably severe) to pay in making the receive gate narrow. It reduces the duty cycle (d) and thus the sensitivity per unit time is reduced. However, the clutter rejection would be comparable to the pulse system.

5. MEASUREMENT TIMES

5.1 OUTDOOR EXAMPLE

For outdoor applications where the range to the target is relatively long, the gated CW system is usually not in contention because of the low duty cycles involved. As an example consider a 2000 feet outdoor range and a 25 feet target. Typically, the receive gate width is set to minimize the reception of target interactions with the ground. One commonly used gate width is approximately 25% of twice the target length. In this case that would indicate a receive pulse width of approximately 13 nanoseconds. Even with a maximum PRF (unambiguous) of about 250 KHz, the duty cycle would be only about .003 (13/4000).

This duty cycle could provide an intolerable degradation in sensitivity and/or measurement time when compared with a pulse system. In general, if relatively high quality measurements are required, a gated CW system may not be appropriate for long range lengths.

5.2 INDOOR EXAMPLE

A typical compact range geometry for measuring targets up to 12 feet in length would involve a chamber length of approximately 72 feet. The distance from the feed to the reflector and then to the back wall would in this case be about 96 feet. The maximum distance between the back of a 12 feet target and the back wall would be on the order of 12 to 18 feet (with the target center of rotation somewhere between 48 and 54 feet from the front wall).

This imposes absolute maximum receive gate widths of between 24 and 36 nanoseconds in order to gate out the backwall return. In order to be specific and allow for gate fall times, we will assume the target at the furthest practical distance from the backwall and that a receive gate width of 24 nanoseconds is used.

We will further assume that a PRF of 4 MHz (1/250) can be used in order to provide about 50 nanoseconds of margin over the approximately 200 nanosecond round trip time. This PRF along with the 24 nanosecond receive pulse width will provide a duty cycle of about .1. With this duty cycle a gated CW system could be attractive since it is less costly.

5.3 OTHER CONSIDERATIONS IN MEASUREMENT TIMES

The conclusion that the relative sensitivity for equal measurement times (or the relative measurement time for equal sensitivities) is proportional to the duty cycle depends on the previously stated assumptions. The conclusion is directly applicable to single frequency measurements.

For imaging applications and other multi-frequency applications, there may be some scenarios where the limiting factor may be how many frequencies per unit time can be handled by each system. These limitations go beyond the fundamental differences between gated CW and pulse systems. Considerations such as synthesizer speed, settling times, processor bottlenecks, and storage bottlenecks enter the picture. In principle a pulse system should be able to handle many more frequencies per second since it doesn't have to integrate perhaps hundreds of pulses per frequency. However, in practice, there may typically be only a factor of two or less between a fast gated CW system (the Model 2095) and a pulse system in terms of effective frequency switching speed.

There may be measurement scenarios (although rare) where the measurement time is limited by the target rotation rate. Clearly, for those scenarios the gated CW system would be as fast as the pulse system. However, in these cases, it is likely that the pulse system would be used to acquire more data or more sensitive data.

As a final note on measurement times, one must consider total measurement time when comparing measurement times. The total time includes such steps as target handling, range setup, and calibration and verification.

6. OTHER CONSIDERATIONS

There may be other capabilities, not previously discussed, which may enter into a decision to use either a pulse or gated CW system. One such capability would be the capability to measure high doppler rates (e.g., full scale engine modulation or helicopter blade modulation). The pulse system will typically allow much higher doppler rates to be measured. There is a factor of 20 difference in the maximum doppler rates that can be measured on the Model 2090 and those that can be measured on the Model 2095.

Another capability might be inter-pulse modulation which may be useful in some cases to enhance clutter rejection. Although there is not a fundamental reason why a gated CW system could not have this capability, it has not typically been implemented on gated cw systems in the past.

Reliability is a very important consideration. In general, a gated CW system is less complex and thus, in principle, should be more reliable. However, a more important consideration for reliability is the quality of the design and the manufacturing process. Reliability is likely to be higher for a system from a company that has standard radar measurement products, has a long history of producing quality instrumentation, has a relatively large customer base for the system and related subsystems, and has the capability and reputation for servicing its products.

7. SUMMARY

A pulse system and a gated CW system process the received pulse waveform in a different way. The pulse system uses a wideband process and the gated CW system uses a narrowband process (after gating).

It has been shown that, under certain assumptions, the pulse system is faster by a factor of the duty cycle if equal sensitivity is desired. In general, the pulse system may be desirable for outdoor (long) ranges. For indoor ranges, where the range length is shorter, a gated CW system may be the appropriate choice depending on such factors as measurement scenarios, measurement volume, and instrumentation budget.

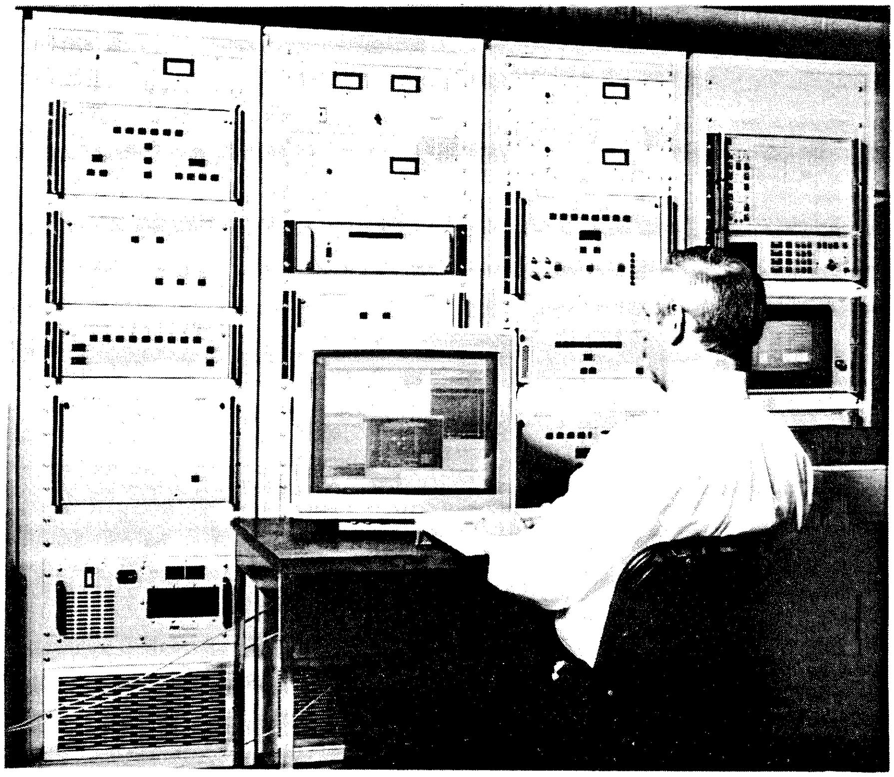

Figure 4: Scientific-Atlanta 2090 Pulse Radar

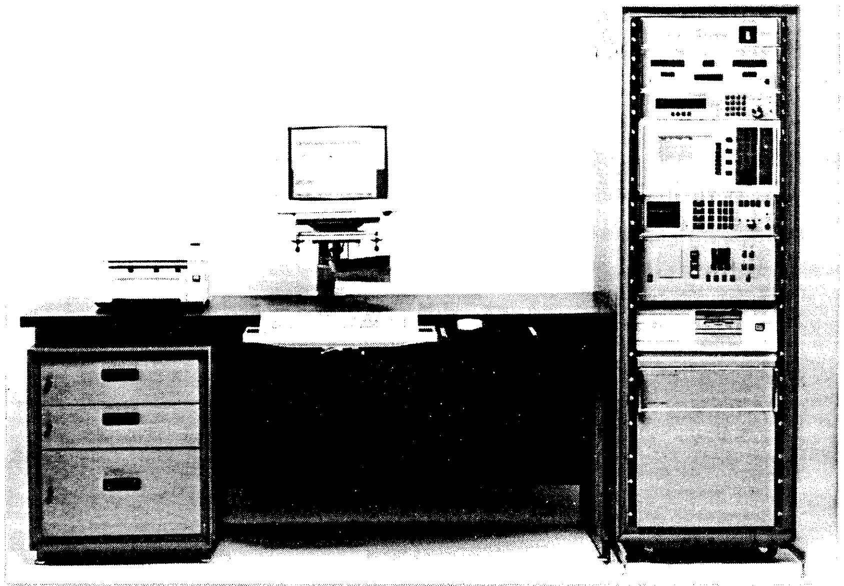

Figure 5: Scientific-Atlanta Model 2095 Gated CW Radar

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