ULTRAWIDEBAND RADAR

James D. Taylor, P.E.
Lt Colonel USAF

AFSC Electronic Systems Division
Hanscom AFB Massachusetts

ABSTRACT

Ultrawideband radars use signal bandwidths greater than 25 percent of center frequency. Conventional radio and radar signal bandwidths are generally less than 1 percent of center frequency. Using ultrawideband signals gives a range resolution smaller than most military targets. Ultrawideband impulse signals can provide a capability for target imaging and identification through resonance characteristics. The added capabilities gained through ultrawideband signals are balanced by needs for complex receivers and signal processing. This paper discusses ultrawideband radar and makes qualitative comparisons with narrowband systems.

INTRODUCTION

Ultrawideband radar systems have instantaneous signal bandwidths greater than 25 percent of center frequency. Ultrawideband radar draws on applicable technologies from electromagnetic pulse, electronic warfare, lasers and nuclear energy. This article is an introduction to the technical issues of ultrawideband radar.

DEFINITIONS AND TERMS

Ultrawideband is a new electronics term. To understand the meaning, we need introduce the concepts of absolute and percentage bandwidth.

Absolute Bandwidth: When we talk about an electromagnetic wave, we want to know its center (or assigned) frequency, and how much the signal deviates from the center frequency. The signal deviation from center frequency indicates how much information it can carry, and is called bandwidth.

Percentage Bandwidth: Another way to indicate bandwidth is as percentage of center frequency. This method is found in antenna theory and circuit design. Equation 1 defines percentage bandwidth.

$$BW(\%) = \frac{(f_h - f_l)}{((f_h + f_l)/2)} X100 \qquad (1)$$

Where f_h and f_h are the highest and lowest frequencies of interest, not the half power point (-3 dB) frequencies used in resonant circuit and filter design. The percentage bandwidth concept defines narrowband, wideband and ultrawideband signals.The time and frequency domains are two ways to think about electromagnetic waves:

Time domain: If we study a waveform and want to know its value at any given instant, then we are in the time domain. When signals have a short duration, then circuits will have a transient and the steady state response.

Frequency domain: If a waveform has long duration and does not The frequency range tells us how antennas, circuits, cavities, and components will work under steady state conditions.

The frequency domain is the conventional way to describe circuits and signals. Most commonly encountered signals are narrowband and long duration and steady state conditions are the designers primary concern.

ULTRAWIDEBAND WAVEFORMS

Figure 1 shows some typical ultrawideband waveforms. These have one of two characteristics: they have a short duration; or they have complicated waveforms with many frequency components.

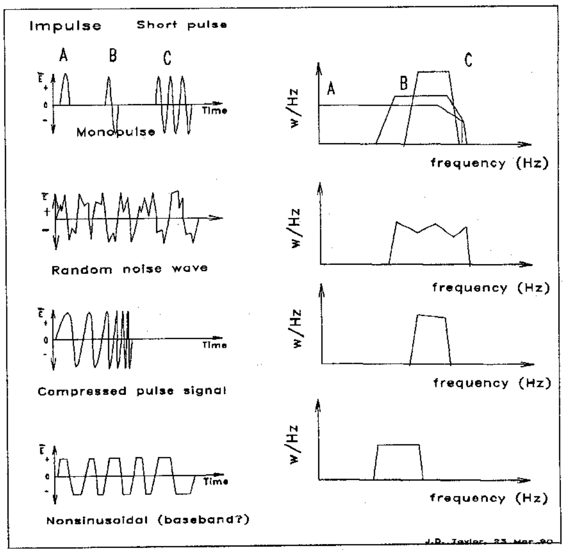

Figure 1: Typical ultrawideband waveforms showing time domain and notional power density spectra.

ULTRAWIDEBAND RADAR

Analyzing ultrawideband radar means looking at directed electromagnetic energy, the interaction of waves and objects, and communications theory. Figure 2 shows the principal parts of a radar system.

Waveforms: Start with the radar waveform for a surveillance pulse radar, as shown in Figure 4. The range resolution ΔR depends on the pulse length, τ in seconds, and the velocity of light, c. The radar signal bandwidth depends on the pulse length and any additional modulation or shaping of the pulse. If a the radar signal during the pulse is a simple sine wave, then the time bandwidth product is 1. This brings us to two important points about radar waveforms:

(1) Range resolution is inversely proportional to bandwidth.

(2) Minimum range resolution is one wave length, therefore the radar signal frequency sets a minimum limit. For example, an L-band radar operating at 1.0 gHz has a minimum resolution of 0.15 meters, or about

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0.5 foot.

If we want to get fine range resolution with a long pulse length τ, then we can use:

(1) Pulse compression wave forms which frequency modulate the radar pulse to get range resolution better than $1/\tau$. The receiver uses matched filtering to detect the signal. Resolution is smaller than $1/\tau$, but greater than the smallest wavelength (highest frequency) in the pulse. Pulse compression is also called chirped pulse.

(2) Spread spectrum wave forms which widen the radar signal spectrum and give range resolution at the smallest modulating signal wavelength. The receiver uses correlation detection of the received against the transmitted signal to get fine range resolution. Correlation detection requires more processing than matched filtering. Noise and pseudonoise waveforms are typical spread spectrum signals. Spread spectrum brings a feature called processing gain which permits extraction of signals from below the noise level. However, processing gain also takes time and adds processing complexity.

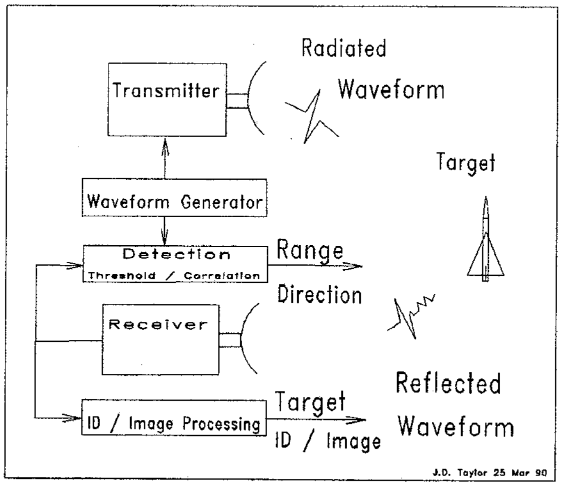

Figure 2: Radar subsystems include a waveform generator, a transmitter and antenna, the target, the receiver antenna and signal processing.

Impulse waveforms: The impulse waveform, which uses only a few cycles of a sine wave, is another approach to fine range resolution. The typical impulse signal approximates a single cycle of a sine wave. If T is the period of the sine wave of frequency f, then $\tau = NT$ or N/f. Thus we get one class of ultrawideband waveforms by using very short length pulse lengths. Transmitter and antenna design follows waveform and center frequency of the signal. The conventional experience is that narrowband waveforms are easy to generate, transmit and receive.

Energy is a primary consideration in radar signal design. The real design issue is how much energy is transmitted, reflected and detectable by a receiver. As the pulse length decreases, power must increase to get an equivalent energy on the target. In electromagnetics, power means electric field strength. Gas breakdown is problem at high field strength levels. Gases break down between 10^5 and 10^8 volts per meter depending on the gas, pressure and other conditions. However, it takes time to form a plasma, and we can have high field strengths by using short pulses. Figure 4 shows the plot of electric field times pressure vs the time pressure product.

TRANSMITTERS AND ANTENNAS

Ultrawideband Sources Generating a high power impulse is easy, generating many uniform impulses and controlling them will be another matter. This section describes typical ultrawideband sources for both pseudonoise and impulse sources.

Random noise ultrawideband sources: The random noise signal is an old form of ultrawideband signal. When the signal bandwidth is considerably larger than the information bandwidth, then we have a spread spectrum signal. The noise source can be a natural random noise source, or a computer generated pseudorandom code. The radar set keeps a sample of the source for correlation with returned energy. The advantage of random noise sources is that they use long pulse lengths which means that lower power levels can give higher energy levels. Correlation can give short range resolution and processing gain which permits extracting signals from below the noise level.

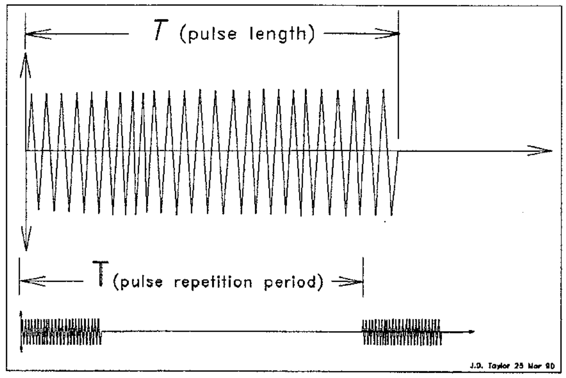

Figure 3: The radar signal pulse length τ determines the minimum range resolution ΔR. The pulse repetition interval T determines the unambiguous range.

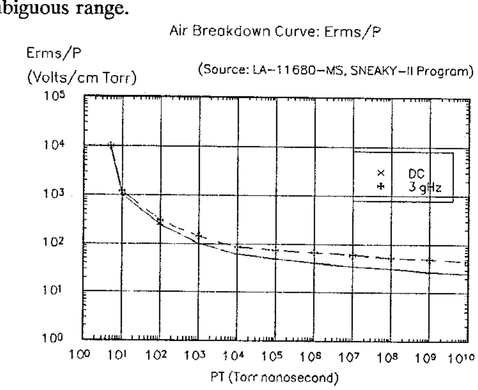

Figure 4: Air breakdown curves for dc and microwave frequencies. By using short pulse lengths, we can get higher field strengths. (1 Torr = 1 mm Hg)

Impulse sources: Ultrawideband impulse sources are generally some variation of the frozen Hertzian generator, shown in Figure 5 or the Marx bank generator. There should be some advantage in combining the antenna and transmitter into one element for generating ultrawideband signals. The transmitter problem is providing high energy electrical signals. The antenna problem is to couple the ultrawideband signal into space and to direct the energy.

Ultrawideband Emitter Design:

Source and reflector: High energy source and reflectors offer simplicity of design. However, the impulse signals and reflectors introduce a problem called time sidelobes. Long interval ultrawideband signals may have a diffraction pattern side lobe problem, and impulse signals may have a related time side lobe problem. Figure 6 shows the diffraction and time side lobe antenna problem.

Arrays: Arrays of ultrawideband emitters controlled in time are a second approach to high power and directivity. Figure 7 shows an impulse array with its main and side lobes caused by reinforcement of successive impulse wave fronts.

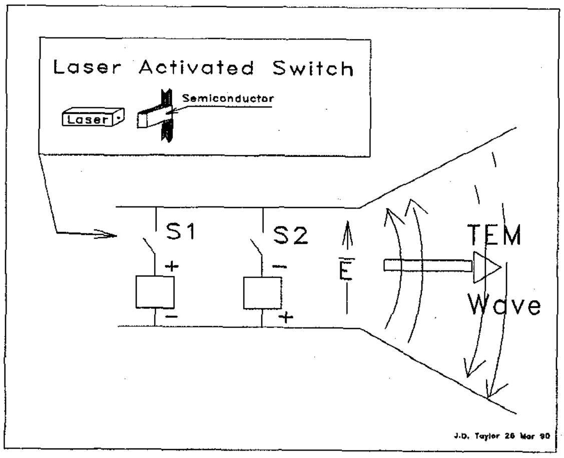

Figure 5: Frozen Hertzian generators provide a way to convert high voltages directly into ultrawideband electromagnetic waves. A laser pulse created charge carriers in the semiconductor switch.

TARGETS AND ULTRAWIDEBAND WAVEFORMS

The target is part of our radar system. If we build a radar for some practical application, then we have a set of performance priorities:

Target Detection: The radar must indicate the presence of a class of target at some specified range with a given probability of detection and false alarm.

Target Tracking: The radar must detect and continuously display the target position.

Target Identification: Identification becomes important in military applications. When a radar detects and tracks a target, the next question is what is the target? Identification can take several forms.

-Cooperative identification, such as the Identification Friend/Foe (IFF) systems, work with radar interrogators and aircraft transponders. However IFF means adding an extra system to the radar. In war, IFF can become the victim of electronic combat or deception, or transponder failure.

-Position Correlation: If friendly aircraft positions are known, then indicated position can indicate friend or foe status. This requires an extensive tracking and reporting system.

-Noncooperative Target Recognition: Noncooperative target recognition systems determine target identity from the radar return signal characteristics.

Ultrawideband target returns: The difference between narrowband and ultrawideband radar is range resolution. At microwave frequencies used for long range radars, narrowband radar range resolution is greater than the target size. Ultrawideband radar range resolution is smaller, say less than one tenth target size. The combination of fine spatial resolution and wide frequency spectrum gives two radar return characteristics for target identification.

-Multiple time shifted returns from the target scattering centers, as shown in Figure 8. We get a series of returns instead of the lumped return of a narrowband radar. The returns taken over a series of different angles could form a target image by inverse synthetic aperture processing. Identification may be possible if the image has enough detail to differentiate between similar aircraft types.

Both target imaging and resonance extraction from ultrawideband signals assume that the target is detectable and:

-The target return signal is strong enough that the resonance response signals are well above the noise level. Note that the frequency range of the resonance response will be higher than the frequency range of ultrawideband radar signal. This implies wide receiver dynamic and frequency ranges. Any analog to digital conversion of signals must be fast enough to accurately reproduce the highest resonance mode signal.

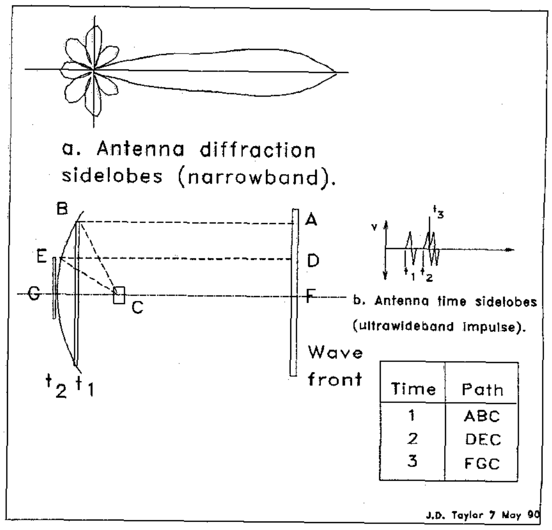

Figure 6: Antenna sidelobes: *a.* Diffraction sidelobes of a narrowband antenna caused by phase reinforcement. *b.* Time sidelobes from an impulse source and reflector.

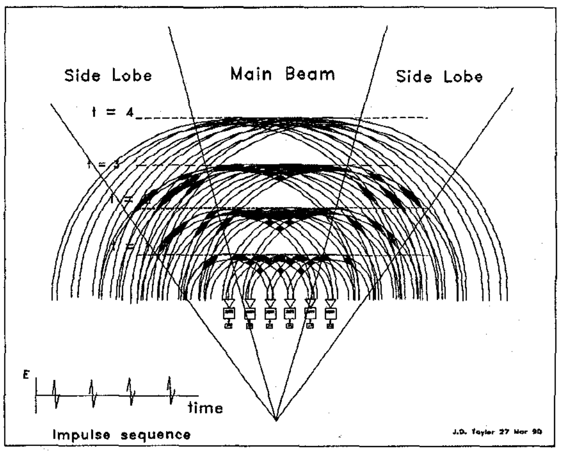

Figure 7: Impulse array antenna pattern. An array of emitters driven by an impulse sequence with along period between impulses. Sidelobes disappear as the interval between impulses increases.

-Target resonance returns are another ultrawideband target effect. The ultrawideband signal will have frequencies that are close to the target natural resonance modes. As shown in Figure 9.a. the target response contains a physical optics and resonance response. Excitation of natural resonators on the target produce the resonance response. Processing the resonance returns can give a set of poles in the complex plane, as shown in Figure 9.b. called singularity expansion modes.

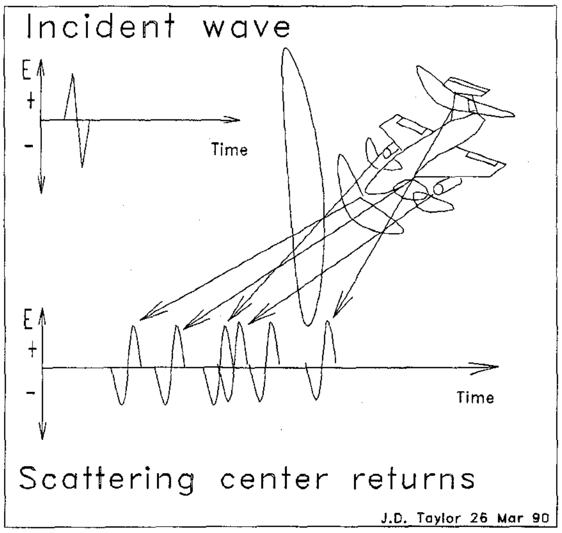

Figure 8: Ultrawideband radar target response from multiple scattering centers when range resolution is smaller than target size.

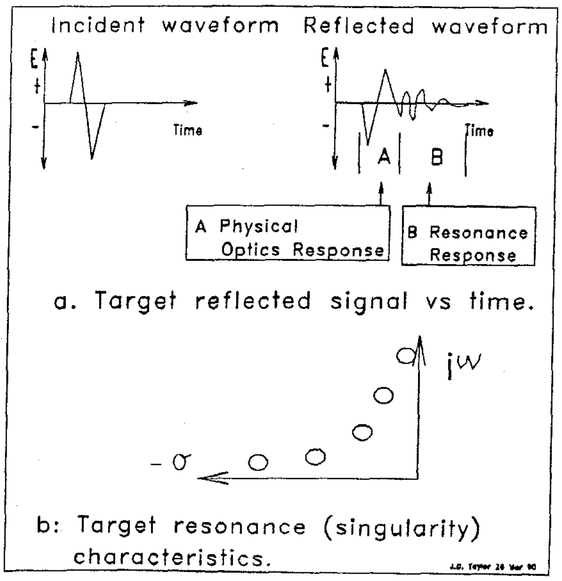

Figure 9: *a.* Ultrawideband radar target physical optics and resonance response. *b.* Processing the resonance response to give the singularity expansion mode plot may provide target identification.

-The receiver signal processing is adequate to detect and process many signal returns. Digital and optical analog are two forms of processing that seem to hold some promise. An analog to digital converter must satisfy Shannon's sampling theorem for the highest frequency of interest. The receiver front end must pass the signal frequency and the resonance frequencies.

-There will be enough time to detect and process the target returns. If an identification process requires a strong signal return, and by implication, ranges shorter than detection range, then will it be useful? Radar performance sets radar employment. How you plan to use the radar answers this question.

ULTRAWIDEBAND RECEIVERS

Generating and sending an ultrawideband signal is easy. Receiving and processing an ultrawideband signal presents some technical challenges. If we know the frequency content of the transmitted signal, then the receiver must cover the frequency band plus enough extra to include target resonances and multiple returns. A set of multiple impulse returns closely spaced may have a different frequency content from the original signal. The problem is to receive the ultrawideband signal and then recognize it by some correlation technique. Up to now, ultrawideband impulse experiments and ground probing radars have used sampling oscilloscopes connected to antennas to collect return signals. Oscilloscopes are adequate for experimental work. A practical military radar will use the same principles, but will be more complex. The receiver designer may have to go back to some fundamental physics and design for instantaneous wideband field detection.

CONCLUSIONS

Ultrawideband radar is just one application of ultrawideband technology. Communications and electronic warfare are other potential ultrawideband applications. Ultrawideband radar is still a developmental technology and must compete with narrowband radar before we'll see widespread use. Any proposed ultrawideband radar must pass the test of cost vs utility for a given purpose.

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