UWB RADAR FOR GROUND VEHICLE SELF PROTECT

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ABSTRACT

This paper describes a concept to use an impulse radar system to detect, acquire, identify, and track incoming armor piercing rounds which threaten a ground vehicle containing active armor. Data illustrating the ability of a prototype impulse radar to discriminate between different target shapes are presented. The sensitivity of the CFAR receiver used with the system appears to be adequate, but ground clutter poses a serious problem. Techniques for discriminating against ground clutter are being explored.

I. INTRODUCTION

Future military ground vehicles such as tanks may be protected against armor piercing rounds by "smart" munitions, carried by the vehicle, which home in on and engage incoming rounds at a standoff distance of a few to ten meters. Engagement at these distances can drastically reduce the armor piercing capability of the incoming round. For example, the jet from a shaped charge penetrator cannot propagate through this standoff distance in a stable manner. Further, a torque impulse applied to a hypervelocity long rod penetrator (LRP) through collision with a smart munition will cause the rod to rotate, markedly reducing the rod's penetrability. The advantage of this approach to vehicle self-protection is a reduced amount of residual physical armor required on the vehicle, corresponding to a tremendous reduction in mass and volume, with commensurate increases in vehicle mobility, fuel economy, and range. In one concept the vehicle skin is covered with such munitions in the form of tile plates which can be independently initiated in response to the threat of an incoming round. When a real threat is encountered, the appropriate tile must be fired at the appropriate time in order to engage the incoming round at a standoff position which will render it ineffective.

Threat identification and discrimination are necessary for several reasons. Optimum standoff positions for engaging the incoming round may be different for hypervelocity kinetic energy kill devices, whose closing speeds approach 2 km/sec, and the much slower shaped charge warheads, such as the TOW or HELLFIRE. Secondly, not all hypervelocity projectiles constitute an armor piercing threat requiring the expenditure of munitions. The "armor piercing disposable sabot" (APDS) bullet, for example, is a hypervelocity projectile which can, in fact, be stopped by residual armor on tanks, making expenditure of submunitions unnecessary. Thus, a means must be provided for detecting, acquiring, identifying, and tracking real threats. Because of its superior range resolution, simplicity, wide bandwidth, and the potential for fast, hardwired real time signal processing, an ultra-wideband (UWB) radar may provide a cost effective solution to this problem. The objective of the work reported in this paper is to investigate the feasibility of using an impulse UWB radar in this application.

II. UWB RADAR CONCEPT

This concept uses an UWB radar aboard a ground vehicle to identify real threats, track them as they approach the vehicle, and provide timing information for deployment of protective munitions. A repetitively pulsed impulse source shock excites a low gain transmitting antenna, radiating a few cycles of radiation at a center frequency of about 2.7 GHz in pulses approximately 1 ns wide. The current prototype transmitter is based on a Marx generator configuration, shown in Figure 1. The transmitter produces a peak radiated power per pulse of 1 kW at pulse repetition frequencies (PRF's) up to 20 kHz. Reflections from the incoming round are captured by a second antenna connected to a constant false alarm rate (CFAR) impulse receiver which, over a narrow time window corresponding to a specific range gate, senses when any selected part of the target return exceeds a given threshold level and measures the time delay between this return and the "main bang." Details of this CFAR receiver design are

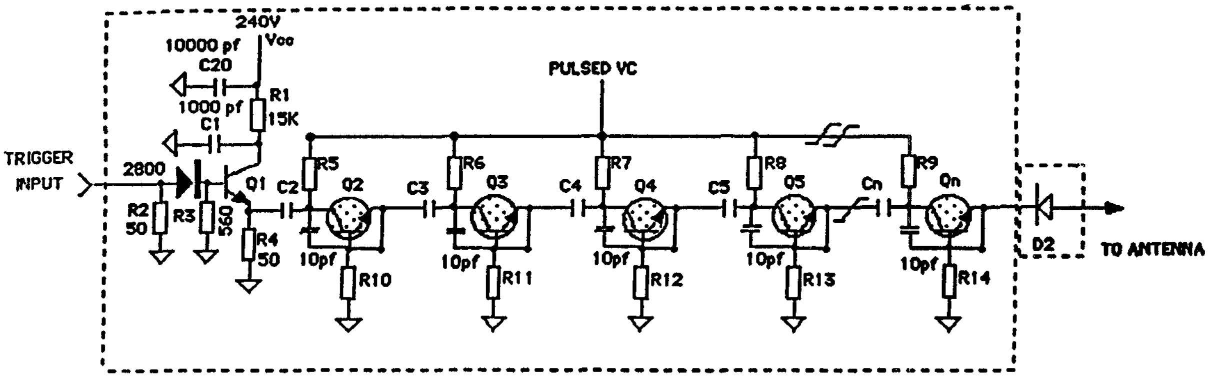

Figure 1. Marx generator configuration for transmitter. Unlabeled resistors are 6.8 kΩ, and unlabeled capacitors are 470 pf. Transistors are Anro special.

found in reference (1). The target range is determined from the time delay between the main bang and the falling edge of the return signal. Angular position, either elevation or azimuth, may be determined by comparing the relative target return arrival times at each of two receivers. The analysis of the angular resolution obtainable with two receivers is analogous to the two-slit interference problem in physical optics. A diagram of the UWB radar system is provided in Figure 2.

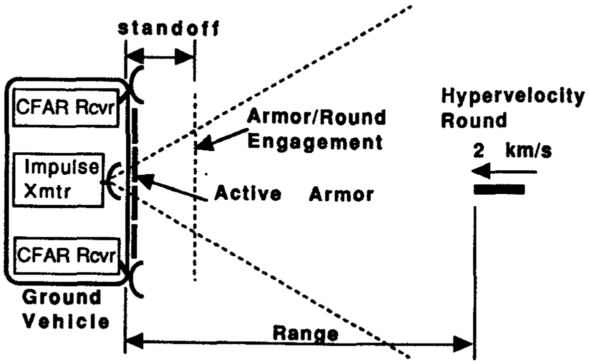

Figure 2. Diagram of UWB radar concept for self protection of ground vehicle with active armor.

The target return signal waveform may contain some information about the shape of the round, particularly its length. Figure 3 shows sampling scope displays of the transmitted impulse waveform and return waveforms from two surrogate targets: a 10 cm APDS bullet and a 30 cm long rod penetrator (LRP). The transmitted waveform consists of about three cycles of a 2.7 GHz carrier with subsequent ringing of much lower amplitude. The target return from end-on illumination of each cylindrical device consists of reflections from front and rear surfaces. The individual returns are separated for the 30 cm long LRP surrogate, but they overlap for the 10 cm APDS bullet, resulting in a broadened return pulse. These differences in shape of the return pulse can be used for threat discrimination.

Once a potential threat is detected its closing speed and trajectory must be determined. Range rate information can be obtained by moving the range gate inward between pulses and measuring the time interval between range gate violations. Multiple receivers can provide angular resolution that will allow division of the threat space into radial sectors.

Once range rate has been determined, one can sequentially move a narrow range gate inward in step with the incoming round. Rounds not aimed directly at the protected vehicle will become more and more "out of step" with the moving range gate as it is pulled in toward the vehicle and can be ignored.

III. IMPULSE RADAR PERFORMANCE REQUIREMENTS

The data shown in Figure 3 were obtained in the laboratory with targets located approximately one meter from the transmitting and receiving antennas. For the ground vehicle self-protect application, however, incoming rounds must be detected at ranges of 50m or more. Preliminary measurements of the sensitivity of the CFAR receiver indicate that it should be able to detect peak signals as low as 40μV. Assuming that the transmitter power can be increased to 16kW peak and that transmitting and receiving antenna gains are 3 dB, the maximum range for the system should be about 70m, assuming it is limited only by the receiver sensitivity. Detection of a 2 km/s round at a range of 70 meters would allow about 35 ms to process the radar information and decide whether or not to expend a submunition, and launch the submunition. Processing, therefore, must be very rapid.

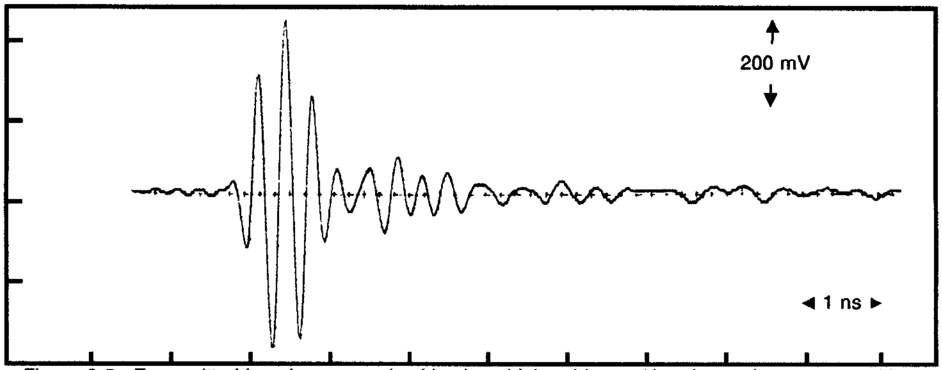

Figure 2-5. Transmitted impulse as received by the wideband horn. Horn located at target position.

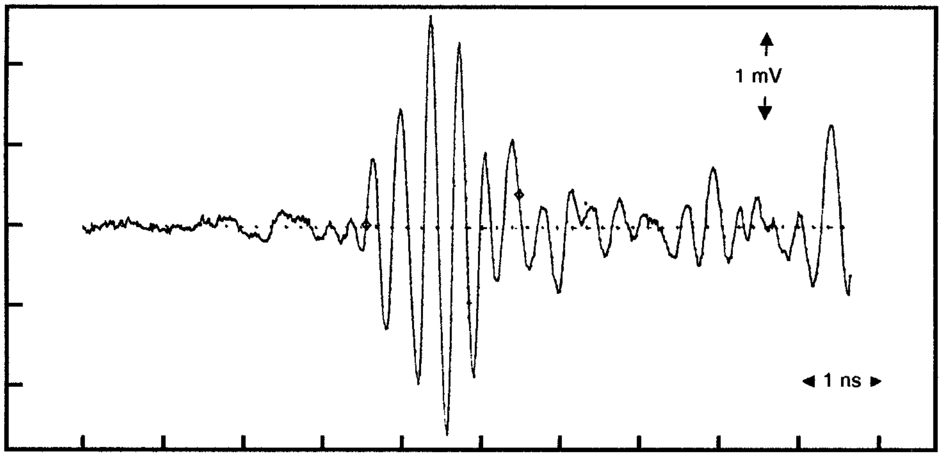

Figure 2-6. Target return from 10 cm long surrogate APDS bullet.

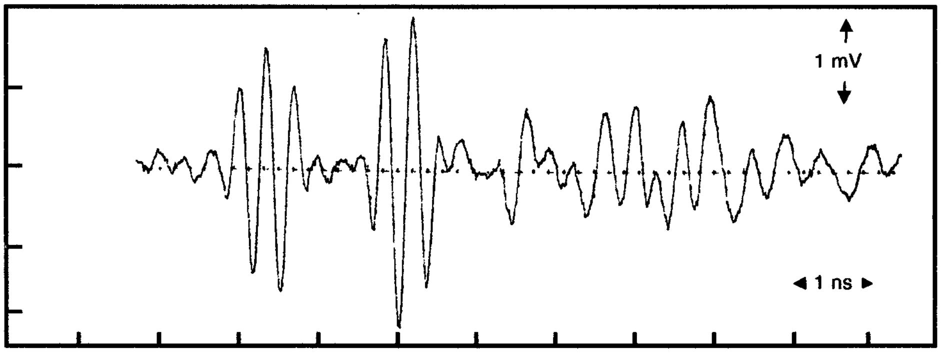

Figure 3. Typical impulse radar transmitted pulse (upper trace), target return from 10 cm long APDS bullet surrogate (middle trace), and target return from 30 cm long LRP surrogate (lower trace).

A geometric cross section of 10 cm^2 for the LRP and ADPS surrogate targets was assumed as an upper bound to the UWB scattering cross section in the previous sensitivity calculation. The actual UWB cross sections are not known at this time and may be quite different from the geometric cross section. Cross sections are usually defined in terms of narrowband excitations and often are sensitive functions of frequency. Therefore, one must be careful in defining cross sections when using impulsive UWB waveforms. Appropriately defined cross sections of the LRP and ADPS surrogates are being determined for the UWB transmitter waveforms, and results will be reported at the meeting.

For low elevation-angle threats, ground clutter is perhaps a more serious problem than receiver sensitivity. The nature of the problem is such that for incoming rounds traveling horizontally along trajectories within a few meters of the ground the target return signal is likely to be contaminated with ground clutter. We have made some open-field measurements of target return signal-to-clutter ratio and its variation with range using our UWB transmitter and a variety of targets. The gently rolling terrain was unbroken, but with rocky soil. Grasses and shrubs comprised the predominant vegetation.

In theory, the signal-to-clutter ratio for radar returns from within a fixed-width range gate diminish inversely with range(2). However, this result is strictly correct only if the radar signal is narrow band and if the clutter return scales linearly with the area illuminated by the radar. Our field measurements yielded signal-to-clutter ratios that fell off much more slowly than linearly with increasing range. Clutter is highly variable, however, and one should not necessarily expect this kind of behavior in arbitrary clutter environments.

From measurements on targets of known geometric and narrowband radar cross-section, and comparison of these measurements with similar measurements on ADPS and LRP surrogates, we have determined that signal-to-clutter ratios for targets of interest should be of order 0 dB over the range of concern for ground vehicle self-protect applications. Thus clutter, rather than receiver noise, will dominate detection sensitivity for moderate ranges at low elevation angles. Since the clutter is stationary and the target is moving, it is possible, in principle, to detect a target in a comparable amplitude clutter background by means of moving target indication (MTI) techniques. The nature of the UWB radar has made it difficult to apply the more conventional MTI techniques, such as delay-line cancellers, to this problem. The interpulse period is long because the targets are relatively slow, and delay line requirements are difficult to meet.

At present, we are investigating several less-conventional MTI concepts, and the results will be discussed at the meeting. So far, we have observed several dB of clutter rejection with one concept, but more rejection is needed. Alternatives are the use of clutter and return signal shadowing techniques.

We note in closing that the clutter problem is a sensitive function of the terrain, elevation angle, and height of the target. For certain threat scenarios, e.g. hypervelocity rounds fired from a helicopter, the impulse radar will be pointed above the horizon as it tracks the incoming round. The clutter problem for this scenario would be considerably less severe than for rounds fired near ground level.

IV. CONCLUSION

We have described a concept to use an UWB radar system to detect, acquire, identify, and track incoming armor piercing rounds threatening a ground vehicle. Data illustrating the ability of a prototype impulse radar to discriminate between different target shapes were presented. The sensitivity of the CFAR receiver appears to be adequate, but ground clutter poses a serious problem. Techniques for discriminating against ground clutter are being explored in conjunction with several threat scenarios and will be discussed at the meeting.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

1. C. L. Bennett and G. F. Ross, "Time Domain Electromagnetics and Its Applications," Proc. IEEE, Vol 66, No. 3, p 299, March, 1978.
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