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Millimeter Wave Technology for Armament Applications

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ABSTRACT

Use of millimeter wave (MMW) technology in armament systems imposes many restrictions on the size, volume and compactness of these systems in addition to ruggedness and reliable functioning in battlefield environment. This paper discusses the related design and technological issues, particularly in the context of the sensors developed for smart ammunition and active armour protection systems.

1. INTRODUCTION

Until recently, millimeter wave (MMW) technology could not be fully exploited for use in armament systems due to technological problems faced in the fabrication of rugged and reliable components capable of withstanding the severe environmental specifications imposed on them. With the advancement in technology of fabrication of these components and systems, highly compact and reliable systems are available today. The MMW frequencies are best suited for battlefield environment due to their better performance under bad weather, rain and fog conditions compared to the infrared counterparts. Solid state sources are available which can provide medium power levels required for applications like sensors for smart ammunitions and active protection system for tanks.

2. SENSORS FOR SMART AMMUNITION

Key requirements for the MMW sensor for this application are:

(a) Performance under degraded battlefield and adverse weather conditions,

(b) Small size limited by bore size of the carrier shell,

(c) High shock environments (~10000 g),

(d) Low production cost,

(e) Minimum signal processing, and

(f) Low power consumption.

A sensor system is required to perform functions like ranging the ground, target detection/ discrimination and initiating the warhead when a potential target is found or triggering the self-destruction mechanism in case no target is found.

A W-band frequency modulated continuous wave (FMCW) radar is the best option for this application, considering the small size of the antenna, small volume available for the sensor and the range measurement up to almost zero range. W-band FMCW sensor with the following specifications has been developed at the Defence Electronics Applications Laboratory (DEAL), Dehradun, using planar waveguide technology:

Frequency of operation	:	W-band
Type	:	FMCW
Tx power	:	15 mW
Frequency excursion	:	400 MHz
Noise figure	:	12.5 dB

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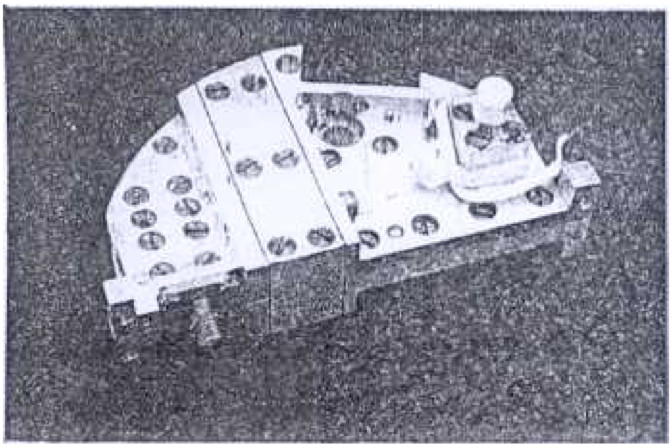

Figure MMW front-end

Modulation frequency	50 kHz
Detection	Clutter limited

Fabrication of MMW front end using planar waveguide technology has the additional advantage of completely avoiding joints and interconnections among the components, as all the components required for the front end are fabricated and integrated into a single plate using three-dimensional CNC milling. This makes the planar waveguide structure rugged and compact, worthy of withstanding high shock levels. The front end developed at DEAL (Fig. 1) has been divided into three blocks to facilitate testing of the integrated components. The power at W-band for Tx and Rx is generated using a 50 mW Gunn oscillator. A part of it is diverted to the mixer for use as LO and about 15 mW of power is transmitted, which is sufficient to detect targets under heavy background clutter up to a distance of 100 m. The mixer has a noise figure of 10 dB. The sensor uses a prime focus fed parabolic reflector of 80 mm diameter as antenna. The liner of the warhead has been shaped parabolic to permit its use as an antenna for the sensor. Lithium sulphur dioxide battery of 15V, 1.5A has been used to power the sensor. Signal processing portion of the sensor performs functions like ranging, detection, adaptive thresholding and self-destruction. The complete SP unit has been hybridised and accommodated on two PCB cards each of diameter 80 mm.

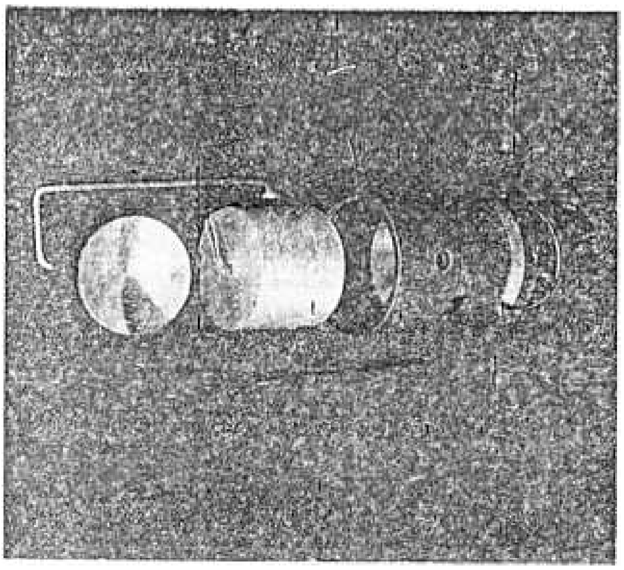

Figure 2. MMW sensor with parabolic liner and battery pack

The sensor unit with feed, parabolic reflector and the battery pack for the sensor is shown in Fig. 2. These sensors have been successfully tested at a shock of 10,000 g for their full functional performance. A number of sensors have been produced and test fired, thus confirming the advantages of planar waveguide fabrication technology for such applications.

3. SENSORS FOR ACTIVE ARMOUR

Due to rapid advancements in various areas of battlefield technologies, the modern battle scenario has undergone a lot of changes. Presently, the protection of tanks and infantry combat vehicles (ICV) is provided entirely by passive systems which rely on various types of steel armour, aluminium alloy and composite materials to defeat chemical and kinetic energy threat. Exception to this is the explosive reactive armour, which reacts to the threat. But it is not a truly active protection system. To improve the survivability of tanks in future battlefields against antitank guided weapon and unguided infantry antitank weapons, there is a need to develop an active defence system

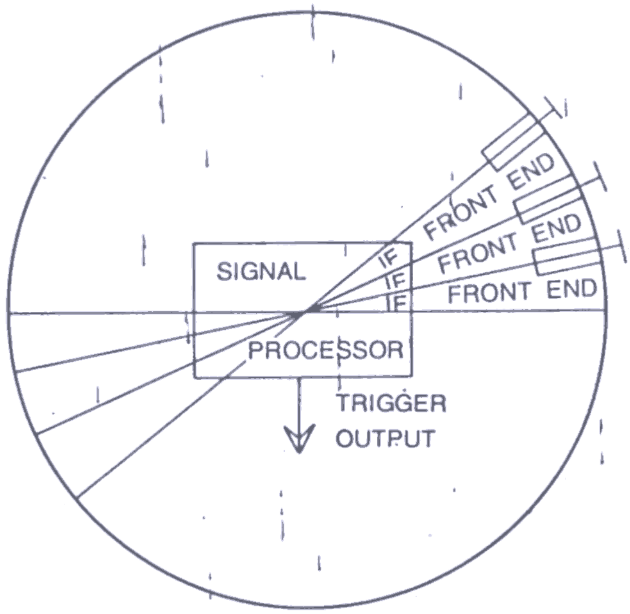

Figure 3. Active armour conceptual diagram

sometimes referred to as 'active armour' to be installed on MBTs or ICVs. The distinguishing features of the active protection system are as follows:

Automatic operation

- Extremely short reaction time (τ 0.05 s)
- Azimuth coverage of the radar ~ $\pm$ 90 °
- Range for detection ~ 100 m
- Expected incoming missile speeds, 70 to 700 m/s
- Mounted on the roof of MBT constraint)
- High accuracy and kill probability.

Based on these considerations, an active protection system for tanks can be visualised as a close-range anti-missile/anti-warhead defence system that creates an active protection area at a safe distance around the vehicle. As the range of detection is small, and also there is size and weight constraint, since it has to be mounted around the turret, and the system should have all-weather capability, the MMW system is the only choice which can meet the requirement of an active armour system.

The conceptual diagram of the active armour system using MMW front end is shown in Fig. 3 and the block schematic is shown in Fig. 4.

The active armour system consists of a number of MMW sensors to be mounted at a suitable place around the turret. The armoured radar head will not rotate; rather, it will have 36 small flat face antennas each covering a sector of 10 ° in azimuth and 60 ° in elevation. The detection of an incoming missile or rocket will automatically provide a trigger to activate the active defence mechanism,

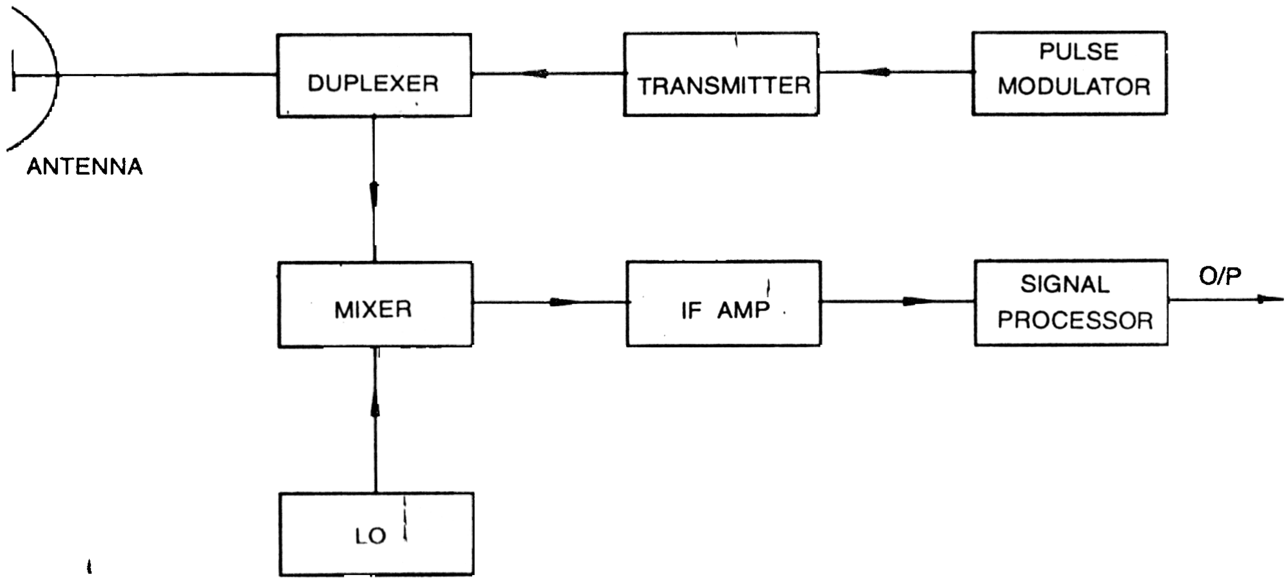

Figure 4. Active armour block diagram

with an overall reaction time of less than 50 ms. Each sector will have a complete independent radio frequency (RF) front-end consisting of antenna, transmitter, receiver and intermediate frequency (IF) amplifier. In all, one full system will have 36 such front ends covering each sector. At a particular time, only two sectors will be transmitting the RF energy. All the sectors will be scanned electronically within a very short span of time of about 20 ms. The system will consist of three subsystems: (i) antenna, (ii) RF front-end, and (iii) signal processing and control.

The details of these subsystems are given below:

3.1 Antenna

The objective of the present system is to cover the whole 360 ° in azimuth and a sector of 60 ° in the elevation plane. Such a wide coverage is not possible with a single antenna. So, it is proposed to use a number of antennas to cover the whole azimuth, so that reasonable antenna gain and thereby range is obtained. It has been decided to use antennas which can cover 60 ° in elevation and 10 ° in azimuth. Thus, the system requires 36 antennas to cover the whole azimuth. It is further proposed to connect dedicated transmitter and receiver to each antenna.

To make the system light and low profile, it has been decided to use patch array.

3.2 Radio Frequency Front-End

The transmitter will consist of a solid state source at Kaband using high power impact diodes. The source will feed the antenna through a duplexer. The return received from the incoming threat will be fed to the mixer via the duplexer. A continuous wave (CW) source will be used as local oscillator for the mixer. The mixer and the local oscillator will convert the RF signal to IF. The IF will be suitably amplified and fed to a signal processor. All the receiver outputs of various sectors will be fed to a signal processor serially with a switching mechanism.

3.3 Signal Processing

The processing of a pulsed radar return to indicate the presence of a target of highly reduced cross-section in the appropriate sector is the objective of signal processing for active armour. Since the return is from a target of highly reduced cross-section and at a considerably large distance, the return signal-to-noise ratio (SNR) is very low. The SNR is typically below unity. This mandates improvement of the SNR by means of pulse integration or frequency chirp processing. The returns from all sectors are available as a time multiplexed sequence of pulses and these need to be adaptively thresholded and processed for different scenarios by appropriate identification of the sector from which the return is obtained.

The return is then to be dynamically conditioned and digitised. The digitised signal is to be integrated with appropriate sector information and trigger is to be generated for initiation of the appropriate countermeasures.

Further processing is application-dependent and will be software-based. Adaptive thresholding is to be used for identification of the targets of small radar cross-section (RCS) in the appropriate scenario. Generation and formatting of the trigger can be better attempted once familiarity is gained with the type of countermeasures to be employed.

4. CONCLUSION

Planar waveguide technology has made it possible to develop rugged, compact and reliable MMW sensors for smart ammunition which can withstand 10,000 g shock. These sensors can find various armament applications like active protection system for tanks and ICVs, off-route mines, etc.

Contributors

Dr AS Bains obtained his MSc (Engg) and PhD both from University of London. He joined DRDO at the Defence Research & Development Laboratory (DRDL), Hyderabad, in 1984 as Head, Electromagnetic Guidance Group. At DRDL, he was responsible for the development and integration of various systems for *Nag, Akash* and *Trishul* missiles. In 1987, he joined Defence Electronics Applications Laboratory (DEAL), Dehradun, and is presently its Director. He has outstanding contributions in the areas of millimeter wave communications, radio relays, missile seeker heads and top-attack smart munitions. Before joining DRDO, he worked as Senior Scientist at Marconi Space and Defence Systems, Stanmore, UK, for about eight years on the development of front-ends for missile seeker heads. He is a corporate member of the Institute of Electrical Engineers, UK and a fellow of the Institute of Electronics & Telecommunication Engineers (India). He is recepient of the *DRDO Scientist of the Year award* (1993) in recognition of his significant contributions in the field of electronics.

Dr Deepak Singh did his MTech from Birla Institute of Technology & Science (BITS), Pilani, and PhD (Engg) from University of Wales, Cardiff, UK, under Commonwealth fellowship scheme. He joined DRDO in 1979 at DEAL, Dehradun. Currently, he is heading RF System Group. His areas of research include design and development of microwave and millimeter wave components and systems for radar and communication applications. He is a fellow of the Institute of Electronics & Telecommunication Engineers (India). He has published more than 50 research papers in national/international journals.

Mr RP Dixit obtained his MSc (Electronics) from Garhwal University in 1978. He joined DRDO in 1981 at DEAL, Dehradun. He has been working on the design and development of active and passive microwave and millimeter wave components like slotted array antennas, printed antennas, circulators, hybrids, impact oscillators, etc. He has designed and developed a compact FMCW sensor at W-band for use in smart ammunition. Presently, he is engaged in the development of millimeterwave seekers and sensors for military applications. He has contributed more than 20 technical papers in national/international journals.