Recent Trends in Antennas for Electronic Warfare Applications

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1. INTRODUCTION

Electronic warfare (EW) is a military technology which facilitates prevention of effective exploitation of electromagnetic spectrum by an adversary, while ensuring its friendly use. It provides early warning of threats and generates Electronic Order of Battle and thereby helps our Forces in planning appropriate response. Hence, EW is a vital component of the Nation’s security. DLRL has developed technologies and acquired technical competence and capability for configuring the EW Systems to meet the state-of-the-art requirement of armed forces in Communication and Non-Communication segments. Non-com EW is electronic warfare in the context of electronic sensor systems, particularly radar while Com EW concerns with battlefield communications systems that support the command-and-control process.

The heart of the system in both Com and Non-com segments of EW is the antenna which provides the necessary interface between the transmitter/receiver system and free space. EW Antenna research and development is propelled by the demand for new, high performing electronic systems for electronic support (ES) as well as electronic attack (EA) in both communication and radar frequency bands. To meet this demand, DLRL has successfully designed and developed various types of antenna systems working over frequency range of 1.5 MHz up to 40 GHz. The activity is not only confined to only defence field. Due to band congestion and the need for frequency spectrum management, attention is focused on new technology areas like smart antenna systems, conformal mounting for low RCS, antenna / electronics integration. Micro electro mechanical systems (MEMS) are used in realization of state-of-the-art reconfigurable electromagnetic structures to perform multiple functions. Computer controlled smart antennas and advances in core technologies such as microelectronics are miniaturizing systems in weight and volume covering a wide frequency range. Present interest in the area of smart structures have led many researchers to find new and promising application of new smart film materials. In addition, some of the latest trends in the field of antennas like smart antennas, fractal, photonic, multi function shared aperture antennas, Rotman Lens fed planar array and tactical HF antennas, small size omni antennas in VHF/UHF frequency band are also discussed.

2. ANTENNAS AND ANTENNA SYSTEMS DEVELOPED FOR EW APPLICATIONS

2.1 Omni -Directional Antennas

For effective and accurate jamming of hostile signals, high gain reflector antennas with fine bearing auto track horns have been developed and employed to handle one target at a time. To counter multi attack warfare scenario, DLRL has successfully developed state-of-the-art Rotman Lens fed multi-beam array antenna which can handle multiple threats.

DLRL has developed a large variety of communication antennas covering 1.5 MHz - 3 GHz. Electronic beam switching cylindrical array antenna for point-to-multipoint communication is one such example. Different types of monopole, sleeve, discone, log periodic antennas etc. are in use for communication EW applications. These antennas have been designed keeping in view the portability factor also.

The present key research in antenna technology includes high performance, low-cost, compact size, lightweight, conformal mounting for low RCS, antenna / electronics integration. Micro electro mechanical systems (MEMS) are used in realization of state-of-the-art reconfigurable electromagnetic structures to perform multiple functions. Computer controlled smart antennas and advances in core technologies such as microelectronics are miniaturizing systems in weight and volume covering a wide frequency range. Present interest in the area of smart structures have led many researchers to find new and promising application of new smart film materials. In addition, some of the latest trends in the field of antennas like smart antennas, fractal, photonic, multi function shared aperture antennas, Rotman Lens fed planar array and tactical HF antennas, small size omni antennas in VHF/UHF frequency band are also discussed.
45° polarisers, conical log spirals, discone, blade antennas, etc., have been designed, developed and productionised successfully.

2.2 Wideband Directional Antennas for DF Applications

Directional antennas are basic building blocks for any DF system. These antennas are cavity backed spiral, equiangular spiral, pyramidal log periodic, ridged horns, printed circuit antennas such as patch, tapered slot antennas etc. have been designed and developed to meet the DF system requirements over multi octave frequency bandwidth. Using these antennas as radiating elements, DF systems like Amplitude Comparison DF, Phase comparison DF system i.e. Base Line Interferometric DF system, DBD (Digital Bearing Discriminator) DF systems and Rotary DF systems have been developed.

2.3 Amplitude Comparison DF Antenna

In this approach generally 4 antennas, 6 antennas or 8 antennas are used to determine the direction of arrival (DOA) of unknown signal. This type of system covers 360° and provides 100% of probability of intercept (POI). Using this concept, cavity backed spiral and pyramidal log periodic antenna covering 1-18 GHz & 2-18 GHz have been used and measured accuracies are 5° rms for 6 or 8 antenna system and 7° rms for 4 antenna system. However these accuracies can be improved by calibration methods. The 4 antenna system is preferred where space, size, weight and cost are of prime importance for example for airborne application.

2.4 Base Line Interferometric and Digital Bearing Discriminator

This technique works on phase comparison method on linear array geometry. offers 2° rms accuracy over multi octave frequency band with 100% probability of intercept. Usually four wide band phase matched antennas are employed to get DF over 90° sector and using four such units, 360° coverage is achieved. Sixteen phase matched spirals covering 2-8, 8-18 GHz have been developed and integrated with the system and DF accuracy of 2° rms is achieved.

DBD works on circular array geometry based on mode theory to achieve the DF accuracy of 2° rms with 100% probability of intercept covering complete 360°. The higher order modes of circular array offer better accuracy while lower order modes resolve ambiguity. Inter element spacing and number of elements decide phase purity of the array and simulation studies reveal that 16 elements covering 0.5-8.0 GHz (two bands) and 32 elements for 8-18 GHz with spacing of 0.5λ is the optimum choice.

2.5 Rotating DF Antennas

In some application like ELINT, high sensitivity is the prime requirement which is met by rotating narrow beam and the high gain antenna and deriving the accurate direction of threat emitter through the narrow beam pattern of antenna. Cylindrical parabolic reflector type antennas are optimum choice for RDF application which offer narrow beam in one plane and wide beam in other plane. RDF antennas have been developed in 2 -18, 18-40 GHz band realizing DF accuracy of the order of 1°. Due to size restriction the additional frequency coverage of 0.5 – 2.0 GHz is covered by mounting two antennas generating sum and difference patterns and hence offer high DF accuracy of the order 2°.

2.6 ECM Antenna Systems

Once the threat is detected, identified and prioritized for jamming action, high ERP in the threat direction can be generated either by high RF power source with moderate gain of antenna or comparatively low power with high gain antenna such as parabolic reflector. The latter is preferred as low RF power generation provides better reliability, less electrical power consumption and lesser space. High gain of antenna leads to reduced beamwidth of the order of 2° which demands DF accuracy better than 1° in both the planes. Wide open DF systems offer 5° to 3° rms which makes the narrow beam (1°) jammer antenna ineffective for this application. The problem is solved by using two sets of auto track antennas which work on amplitude comparison technique in azimuth and elevation planes. Their crossover is aligned to the main jammer antenna boresight within the accuracy of ±0.25° for effective jamming. Using this concept, ECM antennas with fine bearing antenna system have been designed and developed in the frequency range of 2 to 40 GHz.

2.7 Multiple Beam Jammer Antenna System

Present war scenario requires an ECM system capable of handling multiple simultaneous threats which cannot be handled by above described servo based ECM system as it requires more reaction time. In order to overcome this problem, multiple beam generation with high E.R.P. is the solution. There are various technique but multiple beam generation using Rotman Lens fed array is the state-of-art system[1]. The Rotman lens is the heart of multiple beam system. Rotman lens beam ports are connected to switching matrix for selection of beam and array ports are connected to gain and phase matched low power TWTs to get high E.R.P through space combination of the power. Rotman lens technique is capable of generating simultaneous beams which is not possible in conventional phased array. Rotman lens using 15 beam ports and 16 array port has been designed, developed and integrated with 16 element linear array, over X-Ku band frequency for ±45° scan sector. The scanning patterns for 15 beams over ± 45° scanning have been measured over the band and it is in good agreement with theory over 8-18 GHz frequency band. The Rotman lens integrated with linear array is shown in Fig.1.

3. FUTURE TRENDS-ANTENNA TECHNOLOGY

3.1 Shared Aperture Antennas

A shared aperture is a broadband phased array antenna that could provide multifunction such as Electronic Warfare,
radar, missile warning, IFF and communication on a time shared basis. New Technologies and advanced integration concepts can reduce the cost and provide better mission flexibility. Common aperture installed for the above functions in an aircraft would interface with the different payloads to provide a wide range of missionised performance.

Shared aperture antenna eventually will be the dominant technique as the real estate available for sensors on a platform such as aircraft becomes more precious. This technique also reduces the radar back scatter cross section of the platform. Shared aperture as reported in\(^2\) is the technique that everybody wants today. The shared aperture and new integration concepts can be extended to ship defence as well as ground base application and is shown in Fig. 2.

### 3.2 Smart Antennas

Smart or intelligent antennas\(^3\) mean different things to different people. Basically, smart antennas increase the spectral efficiency of a communication system by using arrays of antennas to shape RF signals in particular dimensions.

Three main categories of smart antennas may be defined based on how they produce their response namely switched beam, direction finding and optimum combining. The switched beam method employs a grid of beams and usually chooses the beam which gives the best SNR. For DF technique, all the processing is focussed on the acquisition and users. With optimum combining the output signal-to-interference-plus-noise ratio (SINR) is the parameter optimized.

Currently smart antenna systems are widely used in wireless mobile communication and low-earth-orbit satellite communication systems. Fig. 3 shows the concept of adaptive array where nulls are steered in the direction of interferences / jammers and beams with good gain in the desired direction.

### 3.3 Fractal Antennas

Most fractal objects have self-similar shapes, which means that some of their parts have the same shape as the whole object but at a different scale. Fig. 4 shows the fractal antenna geometries. The construction of many ideal fractal shapes is usually carried out by applying an infinite number of times an iterative algorithm.

In such iterative procedure, an initial structure called generator is replicated many times at different scales, positions and directions, to grow the final fractal structure. The concept of fractal as discussed in ref [4] is recently applied.

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**Figure 1.** Rotman less integrated with linear array.

**Figure 2.** Shared aperture antenna.

**Figure 3.** Adaptive array concept.
to antennas to obtain multi-band frequency operation. This type of antennas are attractive candidates for personal communication systems, small satellite communication terminals and other wireless applications.

The general concepts of fractals can be applied to develop various antenna elements and arrays. Applying fractal to antenna elements allows for smaller, resonant antennas that are multiband/broadband and may be optimized for gain. Applying fractals to antenna arrays develops multiband/broadband arrays. The fact that most fractals have infinite complexity and detail can be used to reduce antenna size and develop low profile antennas.

3.4 Photonic Array Antennas

In recent years there has been a growing interest in applying the photonic technology to phased arrays [5]. Significant progress has been made in the reduction of RF to optics conversion loss. The areas that will benefit from this new technology include RF signal distribution, beam forming and the remote control of the antenna. The unique features of an optically-fed array are wide instantaneous bandwidth, low transmission loss for data remoting and reduction in size and weight as a long term goal.

A photonic array generally consists of a number of sub arrays, which will be controlled by RF and digital fiber optic links from a remote site. On transmit, a laser light will be modulated by the RF source and transmitted through the fiber to the antenna site. The RF signal will be photo detected, amplified and then will be applied to the each sub array.

3.5 Rotman Lens-Fed Planar Arrays

Lens fed Arrays provide a set of high gain antenna beams all existing simultaneously with each beam possesses the full gain of array aperture. A linear array fed by single Rotman lens provides a cluster of simultaneous conical fan beams. For pencil beam applications, a two dimensional array as discussed in [6] is required. To feed the two dimensional planar array, a stack of vertical and horizontal lenses as shown in fig. 5 are required. Elements in each column of the array are connected to vertical Rotman lens to provide focusing in the elevation plane and an orthogonal stack of lenses are cascaded with the first to provide focussing in azimuth plane. Each beam port of the second. Lens stack thus corresponds to a pencil beam in space.

Planar lens fed arrays can be used for both offensive and defensive electronic warfare. This technique can be used for remotely piloted vehicle systems for multiple drone control and broadband data retrieval links. The multiple beam array is an ideal antenna choice for this type of application.

4. ANTENNAS FOR COMMUNICATION EW SYSTEMS

The communication EW systems use the frequency spectrum from 1.5 MHz to 3 GHz spanning the frequency bands: HF, VHF and UHF. Wide variety of antennas are required for meeting the operational requirements of strategic and tactical systems for various platforms like ground based, airborne, UAV, Aerostat, Ship-borne and Submarines. The latest trends in the development of Communication EW antennas are highlighted below.

4.1 Tactical HF Antennas

Full size conventional HF antennas have very long dimensions and demand large real estate for antenna farm, typically of the order of few acres. Such antennas are generally installed when adequate space is available and used for strategic applications. Tactical applications demand reduced size and mobile / semi-mobile antenna configurations for quick role at the cost of degraded antenna performance. These requirements are met by exploring novel size reduced antenna designs.

A brief of HF antennas used for EW applications is given below.

- Log periodic dipole and monopole arrays, moncone antenna, Rhombic antenna, wire dipole / monopole antennas or its variants for Fixed site applications.
- Steerable (mechanically) log periodic dipole and monopole
• Reduced size Log Periodic dipole arrays using novel concept of travelling wave antenna and log periodic dipole antenna is used for realizing compact directional antenna for ground wave and long range sky wave communications. DLRL has designed, developed and productionised a field expedient HF Zigzag tactical antenna for ground wave reception and jamming applications (1.5 kW (CW)). This antenna is successfully tested for interception of ground wave signal up to 20 km. The photograph of this antenna is shown in Fig. 6.

• Broadband reduced size dipole antennas with specially designed broadband matching networks and broadband baluns are widely used for state of the art high accuracy phase comparison Direction Finding systems. DLRL has designed and developed broad dipole antennas in 20-160 MHz and 160-500 MHz and broadband Diconical antenna covering 500-300 MHz for ground based DF system. Fig. 8 shows antenna sub-system for ground based DF system covering 20-3000 MHz.

• Broadband blade monopole antennas are used in airborne systems for signal interception, DF and monitoring applications as shown in Fig. 9. These antennas are the state of the art antennas employing wideband matching circuits, static charge protection and aerodynamically shaped radome. DLRL has designed and developed blade antennas in several frequency

• Conventional HF omni-directional antennas covering 1.5-30 MHz have height of the order of 30 in to 50 m, which are not suitable for tactical applications as they demand small size, minimum erection / dismantling time with minimum manpower. Dielectric-loaded monopole antennas, trap-loaded monopole antennas with specially designed wide band matching networks are being explored to meet this challenging requirement.

• DLRL has designed and developed two novel types of HF omni-directional antennas covering 1.5-30 MHz for tactical roles. They are folded monopole antenna and kite antenna, shown in Fig. 7. Folded monopole antenna is a trap-loaded folded monopole antenna with a height of 10.9 m. Kite monopole antenna is a trap loaded inverted cone antenna with a height of 12.2 m. The antenna is implemented using only wire sections to simulate the conical geometry, thus reducing the weight of the antenna drastically.

4.2 V/UHF Antennas

Dipole and monopole antenna variants are most preferred antennas owing to their simple geometry, small size, and being light weight products.

V/UHF antennas used for EW applications are given below.

• Log Periodic dipole and monopole arrays for directional coverage. This wideband antenna covering multi-octave frequency band is widely used for interception, monitoring and jamming applications.

• Broadband blade monopole antennas are used in airborne systems for signal interception, DF and monitoring applications as shown in Fig. 9. These antennas are the state of the art antennas employing wideband matching circuits, static charge protection and aerodynamically shaped radome. DLRL has designed and developed blade antennas in several frequency
bands: 20-500 MHz, 500-1000 MHz and 20-1500 MHz for ongoing and futuristic Projects. The productionisation and qualification of these antennas is under progress.

- Electrically short broadband active antennas covering wide bandwidth are being used in applications like mobile DF stations and submarine COMINT systems.
- Conformal printed circuit antennas are being designed and developed for use in man portable systems.

5. CONCLUSION

A wide variety of broad band antennas in the freq. Range of 1.5 MHz – 40 GHz such as Zigzag, folded monopole and kite antennas in HF band, Broadband omni directional hand antennas in VHF and UHF bands for DF, log-periodic antenna, spiral antenna, conical log-spiral antenna, slant polarised biconical antenna, tapered slot antenna, reflector type antenna etc., have been developed successfully. The unidirectional antennas have been used for amplitude and phase comparison technique DF system in the required frequency band. A wide variety of state-of-the-art radomes for airborne, shipborne, submarineborne and ground based applications have been developed and obtained type approval for their installation successfully. The multiple beam jammer array antenna with Rotman lens is a unique development which will be used for handling multiple threats simultaneously in X - Ku bands. Beam Switching Cylindrical Arrays have been developed for point to multi-point communication and have been used in the system. The new type antennas are being explored for future needs.

REFERENCES