Radar Antenna and Transmitter Technologies

To meet the system requirements of range, coverage and resolutions, radar antenna needs to generate different types of beams of desired pattern characteristics in terms of beam shape, beam width, sidelobe level and directivity with an ability to steer the beam in desired directions. Antenna technology has gone through several changes commensurate with the evolution of complex radar systems for various military applications. The development of antenna systems has been categorised based on how the antenna beam of the required beam-width, sidelobe level, gain and other antenna characteristics are steered to give the required volumetric coverage of the radar. DRDO has developed the following radar antenna technologies:

Mechanically Scanned Doubly Curved Reflector Antenna System-I

To meet the requirement for detecting targets flying at a very low altitude to a high altitude, without scanning the antenna beam in elevation, a doubly curved reflector antenna system, has been developed to produce a very narrow pencil beam in azimuth and shaped beam in elevation. It has high gain antenna with fairly low sidelobe levels using efficient corrugated horn which supports dual polarisation.

Mechanically Scanned Doubly Curved Reflector Antenna System-II

To meet the radar beam width requirement of about 5° in azimuth plane and a shaped beam in the elevation plane and to meet the detection requirements of targets flying close to ground level and up to 6000 m in altitude, a doubly curved reflector antenna has been designed and developed. Instead of a monolithic structure, the antenna is made out of small segments, which can be quickly dismantled into packages to facilitate quick installation and relocation in mountainous terrain.
To meet the stringent electrical and mechanical requirements for various airborne radars, DRDO has developed a design methodology based on extensive electromagnetic modelling using Method of Moments (MoM) and Finite Element Methods Techniques, which offers high degree of accuracy. A computer-aided design (CAD) tool, followed by computer controlled slot machining and fabrication methodologies have been developed. Besides, various critical joining processes like dip brazing, vacuum brazing, adhesive bonding, etc., to join up to four layers of antenna have also been developed.

The technology has made the country fully self-reliant in the field of slotted waveguide arrays. The product out of this technology has not only being used for various airborne/missile radars developed by DRDO but also exported.

**Flat Plate Antenna System for Multi-mode Radar**

*Salient Features*

- X band
- Vertically polarised

**Horizontally Polarised Slotted Waveguide Antenna for Maritime Patrol Radars**

*Salient Features*

- X band
- Horizontally polarised

**Mechanically Scanned Slotted Waveguide Array Antenna for Airborne Radars**

- Sub-arraying and multi-layer feed network for enhancing the bandwidth
- Two plane mono-pulse capability
- Integrated IFF and guard
- Fabrication through the use of precision machining and dip-brazing
Sub-arraying and multi-layer feed network for enhancing the bandwidth
Az plane mono-pulse capability
Fabrication using precision machining and adhesive bonding
Gain: > 30 dB
Power handling: 10 kW (peak)
Size: 1200 x 250 mm, weight: 3 kg

Mono-pulse Array Antenna for Missile Seeker Head

Salient Features
- Ku band
- Non-standard reduced height waveguides for compactness and lightweight
- Mono-pulse comparator using planar magic tees
- Fabrication using precision machining and adhesive bonding

Mechanically Scanned Multi-beam Antenna System

The multi-beam antenna (MBA), developed for 3D surveillance radar for navy, has capability to form many beams in different directions from a single aperture. MBA is capable of forming a very low sidelobe narrow beam in azimuth, shaped beam in elevation during transmit mode of operation for the required elevation coverage, and multiple low sidelobe beams of varying beam widths simultaneously in elevation during receive from a single aperture. A planar array of air-dielectric strip-line fed tri-plate dipole arrays for a very low sidelobe pencil beam in azimuth, a shaped beam forming network to produce a near cosecant squared pattern in elevation during transmit mode of operation, and a Blass beam forming network to produce typically six to eight beams simultaneously in elevation during receive mode of operation have been designed and developed.

Simultaneous, multi-beam formation from an array plays an important role in height finding radar. A comprehensive CAD approach to realise an ultra low sidelobe multi beam tri-plate Dipole array antenna system for long range 3D surveillance radar has been developed.

The technology has been successfully implemented in indigenous multi-beam antenna systems for 3D radar, for providing elevation coverage of 40° with a shaped transmit beam and stack of seven multiple beams (3D surveillance radar for air force) of 50° with a stack of eight to nine multiple beams (3D surveillance radar for navy) and more than 50° of coverage with a stack of nine multiple beams (3D-TCR).
Ultra Low Sidelobe Tri-plate Dipole Array

A linear array, using air-dielectric strip-line feed network integrated with 48 tri-plate dipoles as radiating element, has been realised using CAD. Special design methods and unsymmetrical topology of feed network design have been evolved to achieve low SLL. The whole network is a combination of sub-networks, consisting of T-junctions and modified hybrid ring power dividers.

Teflon supports, used as support for the strip-line, and all mechanical tolerances, have been taken into consideration in design for efficient manufacture. Thirty-two such linear arrays have been used to make a planar array of 1.6 m x 4 m. Suitable radome has been developed for environmental sealing of the planar array.

The antenna array has peak power handling capability of more than 15 kW with a very low peak sidelobe level of the order of –35 dB or less for a very wide band of operation. The array has been fabricated using precision machining and EDM wire cutting technologies to achieve the tolerances. It has been tested in near-field test range.

Shaped Beam Forming Network

DRDO has designed, fabricated and evaluated compact, lightweight, high power shaped beam antenna feed network based on non-standard, reduced height waveguide unequal power divider network, with integrated high power cables. The entire beam former has been realised by machining the waveguide channels from a single aluminium block.

Blass Multi-receive Beam Forming Network

The receive beam former has been designed and developed using Blass matrix to generate seven to eight low sidelobe beams of different beam widths in pre-fixed positions in elevation plane during receive. It uses seven to eight channels of air-line cylindrical
synthetic aperture radar (SAR) operating at Ku band. The antenna array is designed and developed to meet the stringent electrical and structural requirements of an airborne system. Stacked patch has been used as the basic radiating element in the array to achieve a wide bandwidth. A three-layer architecture consisting of the parasitic patch in Layer I, Roha cell in Layer II and micro-strip patch with feed network in Layer III has been implemented to realise the design goals. Sub-arraying of the lower patch with feed network directional coupler integrated as a modified Blass matrix with inter-connecting true delay lines to form seven beams at the specific beam pointing location. Rigorous evaluation of the feed network has been carried out and peak sidelobe level better than -30 dB and beam pointing accuracy less than 0.1° over a band of 500 MHz has been obtained.

**Micro-strip Antenna**

Micro-strip antenna array as compared to the conventional waveguide slot array antenna, is based on low profile, lightweight, printed antenna technology and thus provides major advantages for applications in man portable surveillance radars. The antenna arrays are easier to manufacture and have superior electrical performance, viz., frequency bandwidth, return loss, and pattern characteristics.

**Micro-strip Antenna Array**

A very wideband micro-strip antenna array has been designed and developed as the radiating array for the synthetic aperture radar antenna array helps in achieving the bandwidth requirement. DRDO has designed and fabricated patch layers, strip-line power dividers using photolithography. A wide
bandwidth system with side-lobe level better than -22 dB in both the planes and gain better than 30 dB have been achieved for the antenna unit.

**Micro-strip Patch Mono Pulse Antenna Array**

This antenna has a very low peak sidelobe with high gain, wider impedance, and pattern bandwidth. To meet the functional and mechanical requirements, a planar array of e-shaped patch radiating elements have been distributed over a circular aperture. The antenna array basically comprises of radiating elements and feeding network printed on two different dielectric substrates. The feed network is integrated with three modified hybrid rings to form mono pulse in both Az and El plane. The design employs coaxial probe feeding and slotted patch techniques.

**HIGH POWER RADAR TRANSMITTERS**

Radar transmitters are used to amplify the RF signals to the required level (generally in the range of few kW) and delivered to antenna through a transmission line like waveguide. DRDO has successfully designed and developed state-of-the-art high power transmitters for different ground-based radar systems. TWT-based transmitters enable coherent amplification thereby achieving MTI improvement factors of the order of 55 dB. The complete high voltage power supply, control and protection scheme, and modulators have been designed in-house using current state-of-the-art technologies in high voltage engineering and switched mode power conversion to ensure reliable operation. The technology for the realisation of ground-based high power transmitters has been well established. It is currently being upgraded to realise compact airborne transmitters.

**High Voltage Power Supply**

High voltage power supply is realised as a series resonant converter (SRC) operating at high frequency (20 kHz). SRC effectively uses the parasitic components of the high voltage high frequency transformer like leakage inductance to its advantage. One of the critical design issues in any switched mode power supply is SRC-enabled soft switching which results in reduced EMI, lower switching losses and reduced stress on power devices.

The output voltage is regulated using phase shift control and a well designed control loop to achieve the required pulse-to-pulse regulation of the order of 0.0005 per cent for the cathode voltage of the TWT.
which forms the fundamental factor, to achieve low phase noise in the transmitted RF signal. High power insulated gate bi-polar transistors (IGBT) have been used as the switching devices.

High Voltage Engineering

TWT requires cathode power supply of -46 kVDC and collector power supply of 33 kVDC. As high voltage, high frequency, high power and higher power densities all are to be handled together, realising a power supply for a high power transmitter is a challenging task. Solid encapsulation using epoxy as dielectric material has been used in the transmitter for HV insulation requirements of different low power high voltage (HV) components, viz., high voltage probes, HV resistors, and HV diodes. Liquid dielectric like silicone oil has been used for assemblies with higher power like EHT transformers and current limiting resistors. Faraday cage is constructed for the floating deck modulator (FDM), which houses all electronic components pertaining to the grid supply and the filament supply of the TWT operating at lower powers.
These components can therefore be mounted on a PCB inside the Faraday cage without fear of excessive field gradients or the necessity for dielectric encapsulation. Special HT connectors have been developed to make EHT interconnections thereby avoiding exposed EHT terminals.

The technology has been used to realise high power transmitters for all indigenous medium range 3D surveillance radar systems.

**C Band Transmitter**

The S band transmitter has been reconfigured with minimum modifications to realise C band transmitter.

**Salient Features**

- RF Power output: 3 kW average
- Phase noise: better than -75 dBC/Hz at 100 Hz offset from carrier
- Spurious: -60 dBC harmonic (with filter) and -70 dBC non harmonic

Mechanically re-configured transmitter has been used in troop level radar (TLR), which is currently under production.

**Compact Airborne Transmitters**

The transmitter technology is being upgraded to realise compact, lightweight airborne transmitters. Due to stringent requirements in terms of size and weight, extensive use of surface-mount power electronic components, novel planar transformers, high efficiency switching, innovative circuit and packaging techniques, have been planned to achieve high power density. With the phase modulation technique in SRC and with the help of Helix series regulator (HSR), a fine regulation of the cathode power supply is possible to
attain required phase noise and stability of the TWT amplifier. Prototype development of the airborne transmitter is currently under progress.

**TRANSMIT/RECEIVE MODULES**

With unprecedented reliability, superior performance, computer-controlled beam direction and shape in microseconds, active electronically scanned array (AESA) technology has transformed the way battlefield space is scanned, target information acquired, and target is engaged.

The basic building block of AESA is the transmit receive module or TR module. It is self-contained miniaturised transmitter and receiver making up one AESA antenna element, and contains low noise receiver, power amplifier, and digitally controlled phase/delay and gain elements. The technology significantly improves power efficiency, antenna low sidelobes and adaptive null placement to counter jamming. The enabling technology for AESA is the Gallium Arsenide (GaAs) microwave monolithic integrated circuit (MMIC) on a single chip and hybrid microwave integrated circuit. The technology has enabled industry to mass produce TR modules with high reliability and repeatability at low cost. DRDO has developed the TR module technology in association with industrial partner.

The noise behaviour of an antenna in AESA is superior as the low noise receiver is within the antenna itself. This improves the receiver sensitivity and thereby detection range in comparison with passive phased arrays and mechanically steered arrays given other parameters being equal.

DRDO has also developed L and S band T/R modules and has established production base indigenously in partnership with Indian industry. Required quantity of both TR modules is being produced to meet requirements of military radar development and production indigenously with the following features:

- Multi-function modules with phase shifter, attenuator and switch on single MMIC package
- High efficiency LDMOS/Bipolar technology for power amplifier
- High power receiver protector
- Efficient thermal management

**MULTI-CHANNEL MULTIFUNCTION ANALOGUE/DIGITAL RECEIVER**

The new generation of active phased array radars require multifunction, multi-channel analogue/digital receivers with additional features like wave form generator, timing and controller and beam steering network in-built into the unit which will reduce the size, weight, volume and the interface complexity. The following units have been developed for different applications and types of active phased array radars.
Central Unit

The central unit is one of the major sub-systems of the active phased array radar. This unit generates RF signal required for the radar transmission and down converts the received signal from the antenna array into digital data for further processing in the signal and data processor unit. The unit also functions to steer the beam in desired direction, apart from monitoring the status of all the sub-modules.

- Dual GBPS Ethernet interfaces to RP unit
- High speed LVDS interface to AAAU
- RS-422 interface to GPS and other units

Digital Receiver

Modern phased array radars rely heavily on high level of flexibility and programmability. Digital receiver technology offers solution to these issues. DRDO has developed FPGA-based digital receiver technology first time in the country right from the conceptual stage to successful product development meeting all the requirements of re-programmable radar system. The digital receiver board is a 6-channel (3 mono pulse channels, 1 each SLB, SLC and Guard channel) analogue second IF signals from the analogue receivers, which are sampled and down converted to the digital base band data in the digital down converter unit.

The digital I/Q samples generated from these IF samples are digital pulse compressed and converted into words. The pulse compressed I/Q data is sent to the SP unit through a high speed SFDPD link. The digital waveform generator block of this unit generates

Special Features

- DDS-based exciter
- 6-channel analogue receiver
- 6-channel digital down converter
- Programmable waveform generator
- I/O and timing module
- BITE/CAL control N/W and channel switch matrix
- Power supply unit
- ATR chassis with ARINC tray and < 28 kg weight

Interfaces

- Dual SFDP interfaces over optical link to SP unit
programmable poly phase coded digital pulse coded expander output with sub-pulse widths of 0.2/0.4 μs.

**Array Group Receiver**

The array group receiver (AGR) unit is the LRU of the radar system. It houses eight identical analogue receivers, eight digital receiver channels, tile level controller, and power supply module. The AGR unit has been realised in two stacked layer modules, viz., analogue receiver module (ARX) and digital receiver module (DRX). ARX module integrates the eight analogue receiver channels along with distribution network for LOs, IF noise and TX drive signals. DRX module integrates eight digital receiver channels, communication FPGA, and power supply module. These two modules are housed in a rugged, forced air cooled, mechanical chassis with appropriate guide pins, mounting screws and connectors for integration with active antenna unit, exciter and the digital beam forming (DBF) Unit.

**Salient Functions**

- Conversion of eight S band receive signals to analog IF level through double super heterodyne conversion which is further converted to base band using eight digital receiver channels
- Base band data multiplexing and transmission to DBF over high speed optical link
- Receives the dwell data, array control and timing signals from DBF over high speed optical link
- Generates timing signals as well as the control signals required for the eight analogue receivers, digital receiver channels, and AU
- Receives TX drive, LO1, LO2 and 50 MHz clock signals from the RF distribution network
- Distributes TX drive, LO1, LO2, IF noise signals to analogue receiver and 50 MHz clock signals to digital receiver channels
- Applies self-BIT and reports failures/status of dual TR modules and AGR to the CU.
- Communicates with DTRMs over asynchronous serial link for AU configuration and control.

**DIGITAL BEAM FORMING TECHNOLOGY**

Digital beam forming (DBF) technology is the state-of-the-art technology to digitally synthesise multiple simultaneous receive beams, used in active phase array radars. DBF-based radar has wider dynamic range ability to automatically steer nulls for rejection of interfering noise, facilitates enhanced dwell time, higher Doppler resolution, scalability, upgradability, flexibility, etc.

The DBF system synthesises multiple receive beams in digital domain from the complex video digital signals received from 480 digital channels of array group
receivers (AGR) and transmits the multiple beams to the signal processing (SP) system. DRDO has developed DBF system to ensure scalability and adaptability. The system is designed with high-end FPGAs and uses high-speed optical links for communication with other sub-systems and also for internal data communication. Floating point representations have been used for the implementation which ensures better dynamic range. DBF hardware has been optimised with minimum number of FPGAs, by operating at higher frequency and reusing resource for multiple beams.

The design has been implemented with reconfiguration and reuse feature. DBF capabilities have been enhanced by implementation of built-in radar environment simulation module. Multiple virtual threats can be generated with user fed information on scenarios of threat, Doppler effect parameters, relative attenuations among synthesised beams, etc. DBF also receives health messages from the antenna front end, TR modules, AGRs and communicates consolidated information to the radar maintenance processor. It is capable of configuring all AGRS and perform all calibration related processes. In order to independently test and validate all the algorithms, interfaces, etc, automatic test equipment (ATE), to simulate all the messages and digital video from array.

The DBF system has been integrated with other sub-systems of a medium-power active phased array radar and successfully calibrated.

**DIGITAL SIGNAL PROCESSOR TECHNOLOGY**

**Digital Signal Processor Hardware Technology for 3D Surveillance Radar**

Radar signal processor (RSP) caters for simultaneous processing of multiple beams, to extract elevation (height) information, in the 3D surveillance radar systems, used by the services. Indigenous SHARC digital signal processor (DSP) board, with eight parallel processing channels has been realised to meet the radar signal processing requirements.

SHARC DSP board is in the form of high standard 6UVME 64x board, and consists two ADSP2106x processors on the motherboard and two SHARC PAC modules as daughter boards, each consisting of eight ADSP2106x processors. The motherboard has been fabricated as 12-layer board and the daughter board as 8-layers board.

The DSP board performs the following real-time core processing tasks:

- Data slicing and distribution
- Filtering modes like moving target detector (MTD), moving target indicator (MTI), etc.
- Map building/non-MTI detection
- Video generation
Collection of processed data and transfer of the detection reports to Data extractor

ECCM processing

The first processor on the motherboard collects the data from sensors. The second processor collects the processed data from computational nodes and interfaces it with subsequent radar sub-system. The processors on the daughter boards are used as processing/computing nodes. The processors are connected via processor link ports, which enable point-to-point bulk data transfer.

Salient Features

- SHARC 0 can boot from 512 K x 8 bits or 1M x 8 bit FLASH memory from a VME host or from another SHARC board via link port. All other SHARC and SHARC PACs boot over links attached to SHARC 0
- Each on-board SHARC is provided with 512 K x 32 bit zero wait state SRAM
- VME bus interface with access to SHARC 0 and its local memory
- RS 232 interface for serial communication. This interface is accessible from SHARC 1
- SHARC and SHARC PAC reset available through front panel reset switch, VME system reset and VME P2 connector. Writing into a register through VME can also reset SHARC 0
- LED indicators of SHARCs and SHARC PACs flags on front panel
- Processors and SHARC PACs are interconnected with link ports. Network topology is highly flexible and network can be expanded to multiple boards

Compact and Low Power Field Programmable Gate Array-based Single Board Digital Signal Processor

DRDO has successfully designed and realised highly miniaturised low power robust and programmable DSP for portable battery powered radar applications. The entire signal-processor sub-system is realised on a single multi-layer PCB using field programmable gate array (FPGA) technology. This System-on-Chip (SOC) technology has been adopted for the DSP.

Electronic design automation (EDA) software tools developed by DRDO provide flexibility to design changes before implementation and to incorporate in-system iterations without the requirement of modifying the hardware.

The speed and processing gain of FPGA’s can handle complex signal processor algorithms including digital pulse compression, complex filtering, long length FFTs and computationally intensive algorithms in real-time, while maintaining good detection with constant false alarm rate (CFAR). The design has been adopted and implemented in portable ground-based surveillance radar like BFSR-SR (4 W), low-level lightweight radar (LLLR; 7 W), 3D LLLR (10 W) and millimeter wave collision avoidance radar (MMW-CAR; 8 W).
RADAR DATA PROCESSOR

Radar data processor (RDP) is a vital sub-system of modern radar systems, comprising of real-time computer software with a set of algorithms, to automatically recognise, estimate kinematics and track the targets, based on the successive radar detections. DRDO has developed RDP for all indigenous radar systems, the features of which are summarised in the table below.

<table>
<thead>
<tr>
<th>Radar system</th>
<th>Features of Radar Data Processor</th>
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</table>
| Battlefield Surveillance Radar-Short Range | ◇ Tracks slow moving targets like crawling man, single walking man, group of walking men and vehicles.  
 ◇ Linear Kalman filter  
 ◇ Global nearest neighbour (GNN) methods for estimation and data association |
| Low-level lightweight radar (LLLR) and 3D LLLR | ◇ Interacting multiple model (IMM) with two Kalman filters  
 ◇ GNN methods for estimation and data association  
 ◇ IFF data association  
 ◇ Extraction of target height information |
| Maritime patrol airborne radar | ◇ Kalman filtering with novel heuristics methods for tracking in the air-to-sea mode  
 ◇ Periscope tracking in the small target mode |
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<tr>
<th>3D Surveillance radar for air force</th>
<th>Minimisation of false track generation by clutter mitigation techniques</th>
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<tbody>
<tr>
<td>3D Surveillance radar for navy</td>
<td>IMM with two Kalman filters for achieving required track accuracy</td>
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<td></td>
<td>Tracks during target manoeuvres</td>
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<td></td>
<td>GNN and Hungarian assignment algorithm for correlation and data association</td>
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<tr>
<td>Multifunction radar</td>
<td>IMM with two Kalman filters for aerial track estimation</td>
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<td>Stringent heuristic track initiation criteria to suppress false track initiation in sea-surface target tracking</td>
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<tr>
<td>Weapon locating radar</td>
<td>IMM for aerial targets track estimation and missile guidance</td>
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<tr>
<td></td>
<td>Adaptive update rate and handling maneuvering targets</td>
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<tr>
<td></td>
<td>Extended 7 state Kalman Filter</td>
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<td></td>
<td>Estimation of target kinematic parameters</td>
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**PRINTED CIRCUIT BOARD TECHNOLOGIES**

Integration of Electronic components into well-defined functional modules or sub-systems relies on the development of high density interconnect (HDI) techniques on printed circuit board (PCB) technology. The present day PCBs are designed to accommodate high input/output (IO) fine-pitch devices, chip-size packages (CSP), flip-chip attach (FCA) and direct-chip attach (DCA). The HDI PCBs are realised using sequential build-up (SBU), also referred to as built-up multi-layer (BUM) technology. LRDE has developed HDI-PCBs with micro-via through vias from surface-to-surface. Blind micro-vias and plated through holes have been used for interconnection.

**Sequential Build-up of 10 Layer HDI Printed Circuit Board with Micro-via Technology**

A 10 layer printed circuit board (PCB) of 70 x 14 mm dimension with SBU technique with a micro-via of 0.15 mm has been realised using high speed mechanical drilling machine. The operating frequency of the board is 8 GHz to 12 GHz. The RF and digital portions are housed on a single PCB consisting of fine pitch FPGA device with 0.5 mm pitch, power amplifier, and core chip of pitch 0.2 mm. During the PCB design, the inner row signals of the QFN package are routed using via-in-pad (VIP) technique. The blind vias and through holes on the PCB have been achieved using dual sequential lamination for formation of dielectric layers. The process has been established and four boards have been realised.
Embedded Passives for Printed Circuit Boards and Microwave Integrated Circuits

Embedded passives is currently the most interesting technology among the MIC and PCB industry. The technology enables classical passive surface mount components such as resistors, capacitors and inductors to be integrated inside the primary interconnect circuit. Ohmega-Ply RCM with sheet resistance of 25 Ohms/square, a nickel phosphorous (NiP) metal alloy coated on copper foil and the laminates are formed by laminating nickel-phosphorus layer underneath a sheet of copper foil on which circuitry is etched. Polytetra fluoroethylene (PTFE) material RT 5870 and RT 5880 has been used for fabrication of the microwave components/circuits required for the radar applications.