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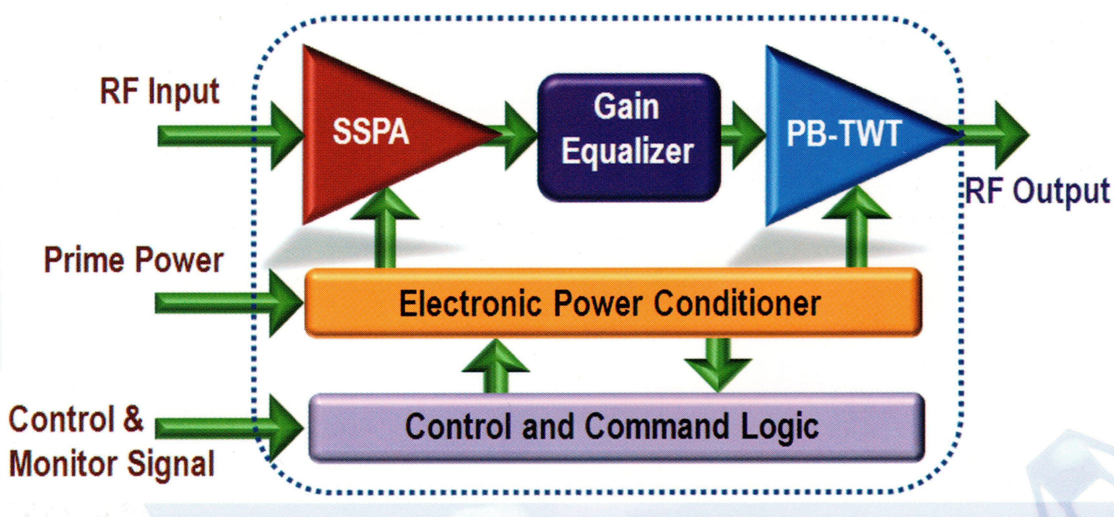
MICROWAVE POWER MODULES AND COMPACT TRANSMITTERS

Modern microwave defence and civilian systems, such as, radars, jammers, terrestrial and satellite communication systems, microwave test and measurement facilities, all require medium power microwave amplifiers. Traditionally, microwave tube amplifiers like travelling wave tubes (TWTs), klystrons and crossed-field amplifiers have been used for such applications. However, newer applications and system concepts necessitate highly compact medium power, broadband and efficient amplifiers. To meet such requirements, compact medium power solid-state amplifiers and transmitter-receiver (TR) modules were developed. These modules were also found attractive to replace microwave tubes in new as well as legacy systems. However, the solid-state amplifiers have their own limitations on maximum achievable power, thermal management and high lifetime costs. Challenged by the competition from solid-state devices, the microwave tube community came up with highly compact, efficient and advanced miniature power-booster TWTs (PB-TWTs) and microwave power modules (MPMs).



Microwave power module (MPM)

Message

The technologies for Microwave Power Modules (MPMs) and MPM-based Transmitters are the demand of the day for the highly compact, medium power, wideband and efficient RF amplifier modules for the advanced strategic needs of radars, jammers, terrestrial and satellite communication systems. I am happy to learn that the present issue of ***Technology Focus*** *will highlight and disseminate the achievements and capabilities developed in DRDO for MPMs and compact transmitters to the system developers and users.*

Dr K. D. Nayak
Distinguished Scientist & Director General
MED & CoS

Message

I am delighted to present this issue of ***Technology Focus*** *dedicated to a highly specialised and crucial technology of Microwave power modules (MPMs) and compact MPM-based transmitters. These are essentially plug-and-play LRUs for improving the performance and capabilities of defence microwave systems. This issue brings out the MPM-based devices developed at DRDO along with a brief appreciation of the state-of-art and the DRDO's strides towards the enabling technologies.*

The module development and productionisation is synergised with Bharat Electronics following concurrent engineering with the design from DRDO. Several sister organisations of DRDO, R&D and academia have also helped in various ways in developing these technologies. We acknowledge their contributions.

I wish to thank the editorial team of ***Technology Focus*** *for their untiring effort to bring out this issue in a nice presentable form.*

Dr Lalit Kumar
Outstanding Scientist & Director
MTRDC, Bangalore

The MPM, a synergistic combination of a solid-state- and a travelling-wave-tube-amplifier, came as a highly efficient, compact and attractive 'avtar' of the bulky microwave tube amplifiers. It is a hybrid super-component that combines the best attributes of both the solid-state- and vacuum-electronic devices to deliver a performance superior to either of these devices individually. The MPM relies on the principle of an equal gain-sharing between a solid-state power amplifier (SSPA) and a PB-TWT, and the use of a modern high-efficiency microprocessor controlled switched-mode power convertor to power both of them.

Globally, the MPMs have been developed with capabilities of delivering a CW power up to 300 W, gain in excess of 50 dB, bandwidth reaching 1.5 octaves and noise figure of the order of 10-13 dB. The MPMs also have tremendous advantages in size, weight, efficiency and reliability as compared to the conventional microwave amplifiers. The MPMs offer about 1/10 reduction in volume, 1/6 reduction in weight and 50% increase in efficiency as compared to those of conventional amplifiers. The reliability is also expected to be about 3 times better owing to fewer components, lower operating voltage, lower operating temperature and superior interconnect technology. They offer versatility and modularity and can be used in pulsed or CW mode, as phase- and gain-matched set for exciting a sector of a phased-array-radar or for spatial power combining. MPMs are particularly suited for ECM systems, radar illuminators, weather radars, synthetic aperture radars, terrestrial and space communication links, remotely piloted vehicles (RPVs), towed decoys, missile seekers and as amplifiers for laboratory applications.

Typically, an MPM consists of a 1-2 W, 20-30 dB gain SSPA; a short gain (20-30 dB), medium power (50-300 W), high efficiency miniature PB-TWT; and a high efficiency microprocessor controlled compact electronic power conditioner (EPC) providing: all the voltages for the SSPA and the PB-TWT, protection and control functions; all integrated in a compact light weight package. The salient features of the components of an MPM are described below.

The **Solid-State Power Amplifier** acts as a pre-amplifier to the PB-TWT and amplifies the input signal of typically 0-5 dBm to the output level of 25-33 dBm at the input of the PB-TWT which further amplifies the signal by about 25-30 dB to provide the required output of 50-60 dBm at the output of the MPM. It may also incorporate additional functions, such as, gain-equalizer, amplitude modulator, voltage-variable attenuator, phase-shifter, temperature compensator, and drop-in isolator depending upon the system requirements. The temperature compensation circuit ensures gain flatness irrespective of internal/ external temperature variations. The low noise figure of the SSPA ensures a lower noise figure for the MPM as compared to that of a TWTA. The efficiency of the SSPA, though lower (<15%) than the TWT, does not drastically affect the overall efficiency of an MPM.

A **Gain Equalizer** maintains the gain-frequency response of each TWT that is variable and unique. However, certain applications require a flat gain response over the full bandwidth to achieve a constant output at saturation or back-off point. A gain-equalizer connected at the input of the TWT ensures a gain flatness of the MPM across the frequency band within the acceptable levels (typically 1-2 dB). The attenuation response of the equalizer is the complementary to the TWT gain. A typical equalizer may have a 'half sine', 'half inverted-sine', or 'parabolic' attenuation profile depending upon the gain characteristics of the TWT in use. The equalizer can be realized in either the coaxial-, or microstrip-form. In coaxial form it has multiple attenuation stubs to cover sub-bands of the full frequency band and is little bigger in size.

Miniature Power-Booster TWTs are compact, light-weight, low noise, low-to-moderate-gain, high-efficiency, helix type TWTs. These tubes are configured with bare minimum packaging to have small length (150-250 mm) and small transverse dimensions to enable a slim MPM profile. The PB-TWTs with low-to-medium average/ peak power for broadband and narrowband operations (peak output power of the order of 80-300W and gain ranging from 25-30 dB) are usually used in the MPMs. Electronic efficiency of around 20-25% and collector efficiency of around 75-80% are common in this class of TWTs with overall efficiency of around 30-35%. Ultra-low harmonic contents is a special attribute for this class of TWTs.

The **Electronic Power Conditioner** (EPC) is required to be highly compact, highly efficient (90-95%), rugged, reliable and microprocessor controlled. The EPC provides power supplies for all the units of MPM: SSPA, PB-TWT, RF switches, linearizer and housekeeping.

The electronics is controlled through an onboard microcontroller to take care of the fault protection, sequencing of operation and managing a command and communication interface with the external platform. It is essentially a miniature high-efficiency power supply comprised of a low-voltage and control module, a high-voltage (HV) power converter, beam modulator and an EMI filter housed in a single package. It uses multi-layer PCBs, surface-mount devices and planar transformer technology to achieve high efficiency, reliability and compact size. In contrast to conventional HV converters, the HV converter in an EPC employs high frequency switching techniques and planar magnetics for appreciable reduction in size and weight.

A brief account of the MPMs and MPM-based transmitters developed at DRDO and the enabled technologies are presented in the following sections.

MPM Development

The design and development of MPM, as a plug-and-play module, was started in DRDO in the early 2000 and different variants of MPMs have been developed, manufactured at Bharat Electronics and inducted into systems.

The development of an MPM involves several criticalities in design and fabrication. It is necessary to choose the compatible SSPA, PB-TWT, and EPC modules to achieve a high performance MPM. These modules are integrated into a compact light weight, rugged and thermally efficient chassis. The thermal management and efficiency enhancement are key issues in the design of MPMs. The high efficiency of the MPM is obtained by using a high-efficiency PB-TWT (30-35%) with multi-stage-depressed collector and high voltage-conversion efficiency (90-95%) for the EPC. A significant amount of heat has to be still dissipated even with a high efficiency MPM. Moreover, as the 'hot' PB-TWT and temperature sensitive MMIC and EPC are to be packaged into a single module the thermal management becomes more critical. The MPMs are usually designed for base plate cooling requiring mounting on a cold plate.

Some typical MPMs developed for the electronic warfare (EW) and radar systems are described here.

MPMs for Electronic Warfare (EW-MPM)

An ECM system or a radar jammer requires a broadband medium power MPM capable of pulsed or CW mode operation. The technology development at DRDO has enabled the potential capability of covering the entire EW band from L-band to Ka-band. However, considering the large market for C-Ku band jammers, this band has been particularly focussed. Some typical MPM products developed in this range are mentioned here.

C-Ku Band 80 W EW-MPM (MCS-3549)

It is the first MPM developed in India for jammer applications and met all electrical and environmental specifications for ground based deployment. It delivers 49 dBm output power with overall gain of 50 dB. The EPC is powered with 270 V DC and has the prime power requirement of 430 W. The EPC modulator provided a throughput delay less than 150 ns and operates up to PRF of 1MHz in burst mode and 125 kHz normally. Remote command and control of this MPM is based on discrete interface. It weighs around 4 kg with dimensions 310×280×40 mm^3. This MPM has been tested for the gain- and phase-matching in a batch of 4 MPMs.

C-Ku band 80 W MPM (MCS-3549)

C-Ku Band 100 W EW-MPM (MCS-3550M)

This MPM was designed for the gain- and phase-matching in a batch of 16-20 MPMs. It is very compact with a size of 296×280×40 mm^3 and weighs around 4 kg. A significant volume reduction of 60% and weight reduction of 75% was achieved compared to its conventional counterpart resulting in enhancement of power conversion density conventionally from ~10W/cu-inch to >40W/cu-inch. The EPC modulator provided a throughput delay less than 85 ns and operates up to 3.5 MHz in burst mode, making it highly desirable for ECM and other applications. This MPM provides higher PRF of 20 kHz and comparable throughput delay over contemporary leading products. The MPM has been productionised and inducted in a laboratory multi-beam transmitter unit.

C-Ku band 100 W MPM (MCS-3550M)

MPMs for Radar

This MPM has been designed for a compact passive phased-array radar. This radar-MPM was developed to replace a conventional TWTA in a phased-array radar. As the MPM could be mounted directly at the back of the antenna, it saved huge transmission loss, and avoided cabling through a rotary joint and cooling system required for the existing high power (~1kW) TWTA.

Additional advantages in terms of compactness, efficiency and overall system noise were available, which improved the overall performance and range of the system. Two versions of X-band, narrow band 120W RF peak power pulsed MPMs (MPS-4051) have been developed. These convection air-cooled MPMs weigh ~3 kg. The MPM works in burst mode up to 1 MHz PRF. It has undergone all the functional-, environmental-, and EMI/EMC-tests as per MIL-STD-461E. A modified and highly ruggedized version of this MPM (MPS-4051M) with highly stringent EMI specifications has also been developed for a more severe ambient RF environment.

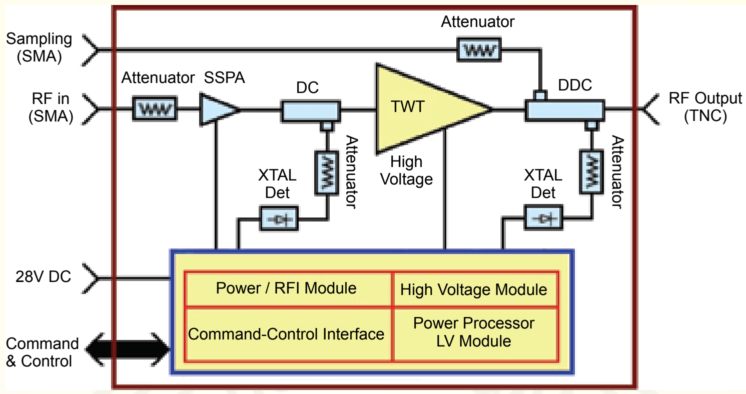
X-band pulsed 120 W MPM (MPS-4051)

X-band pulsed 120 W MPM (MPS-4051M)

Features of DRDO MPMs

Characteristics	Model No.			
	MCS-3549	**MCS-3550M**	**MPS-4051**	**MPS-4051M**
Application	EW	EW	Radar	Radar
Frequency band	C-Ku	C-Ku	X	X
CW/ Pulsed	CW/ Pulsed	CW/ Pulsed	Pulsed	Pulsed
Output Power (W)	80	100	120	120
Input voltage (V DC)	270	270	270	270
Prime power (W)	430	430	170	170
RF input connector	SMA(F)	SMA(F)	SMA(F)	SMA(F)
RF output connector	TNC(F)	TNC(F)	TNC(F)	TNC(F)
Cooling	Cold plate (external)	Cold plate (external)	Natural air (integrated heatsink)	Natural air (integrated heatsink)
Dimension (mm^3)	310×280×40	296×280×40	345×325×70	345×325×70
Weight (kg)	4	4	12	12

MPM-based Transmitter Development



Typical schematic of an MPM-based transmitter

The MPM concept was extended further to develop full-fledged transmitters to deploy as a line replaceable unit (LRU) in a system environment. A family of broadband 50-1000 W pulsed and CW transmitters have been developed.

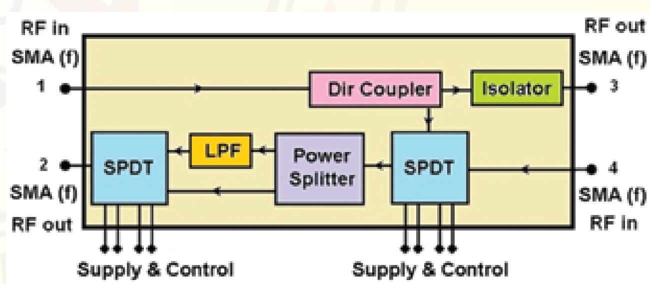
MPM-Transmitter (MPM-Tx) for Electronic Warfare

C-Ku Band 50 W MPM based Transmitter (MCS-3547)

This compact transmitter is capable of operating both in pulsed and CW modes. The input/ output power to/ from the TWT can be monitored externally with a monitoring port provided on the transmitter. Over VSWR protection is also incorporated in the MPM. The EPC comprises a highly efficient, highly compact, micro-controlled DC-DC converter with high speed modulator. The embedded intelligence into the transmitter is responsible for the power management of multiple DC-DC converters. For improving the interface reliability, a redundant bus has been incorporated for the remote command and control. The communication is based on a serial RS422 protocol. The firmware uses state machine based multitasking that offers both advantages of pre-emptive and cooperative multitasking heuristics to meet the real design metrics of the control system. The transmitter incorporates thermo-electric cooler as well as scooped RAM air for thermal management.

C-Ku Band 150 W MPM based Dual Transmitter (MCS-3552)

This MPM based dual transmitter consists of two miniature-TWTs and two EPCs housed in a common enclosure and delivers output power in excess of 150 W from each individual segment of the dual transmitter over the C-Ku frequency band. The cooling is facilitated by ECS air flow of mass flow rate of 126 kg/hour at 15°C with an allowable pressure drop of 623 Pa. The low power RF monitoring chain in the transmitter has been configured as a compact hybrid module ('RF Monitoring Unit – RFMU'), and considerable space is made available to accommodate all the modules inside the transmitter having stringent volume and weight constraints.

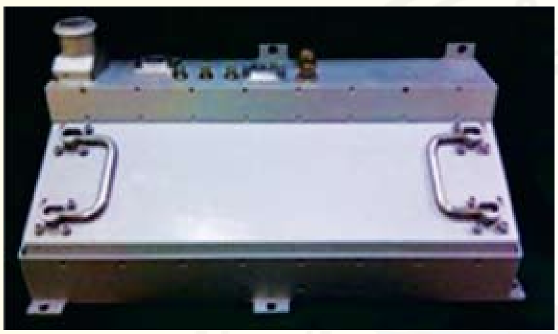


RF Monitoring Unit (RFMU)

C-Ku Band 1000W MPM based Transmitter (MPS-3562)

This is an MPM based pulsed transmitter offers 1000 W pulsed power at 4% duty cycle. It is very compact transmitter with dimensions 465×165×130 mm^3 and weight <15 kg. The EPC with integrated grid modulator is designed to drive the pulsed helix TWT in both pulsed and burst modes of operation. The EPC with modulator also includes, control, command, housekeeping supplies and fault management electronics.

50 W CW (MCS-3547)



150 W CW (MCS-3552)

1000 W Pulsed (MPS-3560)

C-Ku band MPM-based transmitter

MPM-Transmitter (MPM-Tx) for Digital Satellite Communication

Two versions of Ku-band CW MPM-based transmitters with 100 / 120 W CW power have been developed for satellite up-link communication: (i) MCS-5050 incorporates a linerized PB-TWT and integrated heatsinks for forced air cooling, and (ii) MCS-5051 incorporates a linerized PB-TWT with heatsinks integrated along with cooling fans. In these MPM-transmitters, the PB-TWTs are driven in the linear region at 3-7 dB back-off from saturation, depending on the type of application. As the linerizer is a pre-distortion amplifier, a separate SSPA is not required in these MPM-transmitters. The linearity achieved through linearizer reduces the AM/PM rates, intermodulation products, and noise figure to control the bit error rate during communication commands. The outputs of the EPC, driven by 28 V DC, energize both the linearizer and PB-TWT. The demand for high spectral purity (-50 dBc), better noise figure (20 dB), better AM/PM (3 deg/dB) over the operating bandwidth makes the design of EPC very critical as the droop and voltage ripple contributes significantly towards the spectral degradation, phase noise, AM/PM, etc. Operation in QPSK (quadrature phase-shift keying) mode makes these transmitters suitable for satellite up-link with high data rate video signal from an OB-van or other platforms.

Ku-band Transmitter (MCS-5050)

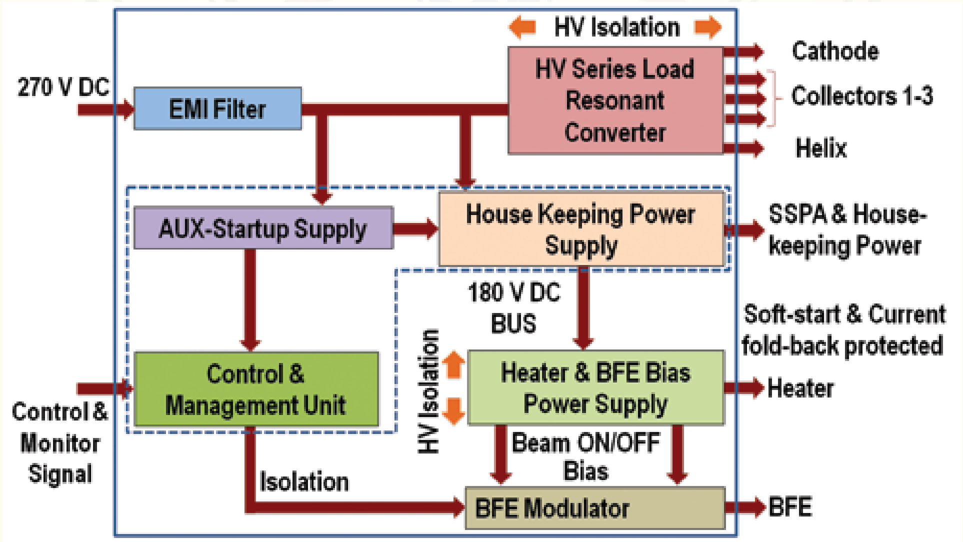
Ku-band Transmitter (MCS-5051)

Features of DRDO MPM-based Transmitters

Characteristics	Model No.				
	MCS-3547	MCS-3552	MPS-3560	MCS-5050	MCS-5051
Application	EW	EW	EW	Communication	Communication
Frequency band	C-Ku	C-Ku	C-Ku	Ku	Ku
CW/ Pulsed	CW/ Pulsed	CW/ Pulsed	Pulsed	CW/ Pulsed	CW/ Pulsed
Output Power (W)	50	150	1000	100	120
Input Voltage	270 V DC	115 V, 400 Hz, 3-Phase AC	115 V, 400 Hz, 3-Phase AC	28 V DC	28 V DC
Prime Power (W)	560	2800	850	430	570
RF input conn.	TNC(F)	TNC(F)	SMA(F)	SMA(F)	SMA(F)
RF output conn.	TNC(F)	WRD-650	WRD-650	N(F)	N(F)
Cooling	Forced air (external)	Forced air (external)	Forced air (external)	Forced air (external)	Forced air (integrated fan and heatsink)
Dimension (mm^3)	390×210×150	570×270×195	465×165×130	320×160×150	280×300×160
Weight (kg)	19	30	< 15	<9	10

Enabling Technologies

Electronic Power Conditioner



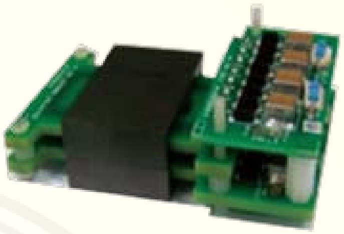
Schematic of general architecture of a typical EPC

The EPC is comprised of multiple high efficiency DC-DC converters, coordinated by an onboard microcontroller for sequentially powering and monitoring various internal functions of the MPM: SSPA, PB-TWT, RF switches, linearizer, a high voltage converter for TWT cathode power, a control & management unit and a beam focusing modulator. The controller onboard also takes care of the fault protection and the communication interface with the external platform. The HV power converter uses multi-layer PCBs, surface-mount devices and planar transformer technology to achieve high efficiency, reliability and compact size.

An **EMI filter** with multiple cascaded sections of common-mode and differential-mode filters receive the prime power for ensuring compliance to the latest EMI/EMC standards. A **high voltage series load resonant converter** with planar magnetics switches at 100-250 kHz employing innovative topology and soft-switching techniques (ZVS) offering light load efficiency above 92% for the HV power conversion.

A brick model EPC with modular subassemblies

Size of the **HV-tank** is appreciably reduced by using high energy density HV multilayer ceramic chip capacitors with voltage-multiplier network configured with advanced ripple-balancing techniques. The multi-layer PCBs are stacked in multitier to occupy minimum footprint area while maintaining all necessary interconnects. Switch silencing features are also utilised for shutting down the converter on demand for achieving extremely low ripple, spurious and near-carrier phase-noise. The dense packaging is managed through innovative thermal management techniques: infrared imaging and corresponding mitigation of hot-spots, use of conformable materials like indium and gap-pads for mounting of power dissipating components and PCBs, AlN wafers for simultaneous HV isolation and thermal management of power MOSFETs.



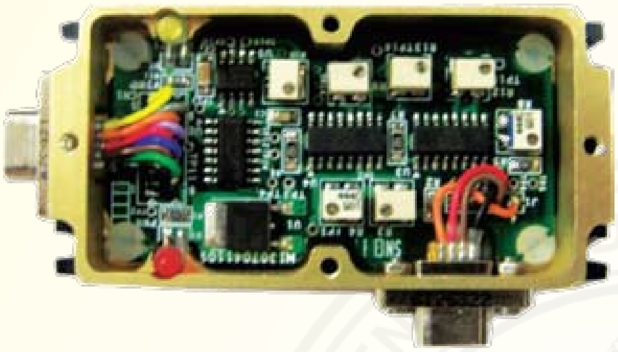
A typical HV planar transformer developed for delivering 400W of power at 4.5 kV

The electron beam modulation is facilitated using a built-in **ultra-fast beam modulator** that pulses from 70 ns to CW mode with PRF up to 3.5 MHz. The modulator introduces very low throughput delay less than 60 ns making it ideal for modern EW applications. Modulators employ innovative signal coupling techniques combined with direct online monitoring of pulse commands for offering state-of-the-art protection features on the minimum and maximum duty applied to the TWT. These unique features offer the MPMs configurable for self-protection modes from excess PRF and /or duty limits.

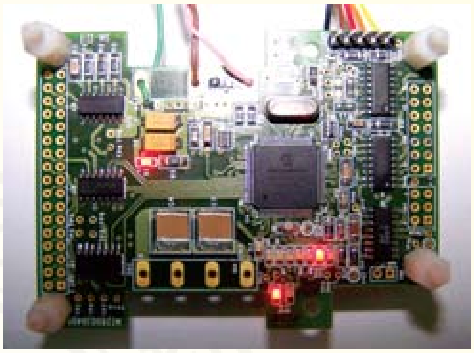
Multiple cascaded power converters switching in several multiples of MHz serves the **housekeeping** functions. The converters are controlled by advanced spread spectrum techniques for reducing the peak current intake and superior EMI control. The power management of EPC is based on embedded microcontroller incorporating the latest digital control and management techniques for fault-monitoring, control-sequencing, error recovery and remote management. Advanced redundant bus architecture is followed for configuring the MPMs on a system communication bus. MPMs support advanced network capabilities with multiple MPMs on the control bus which can be handled in individual or on broadcast mode for facilitating array operation.

An innovative **VSWR protection module** is an added feature of the MPM based transmitter developed by DRDO. Conventional VSWR protection mechanisms fail when the expected forward power is below the designed power level for triggering VSWR error due to inherent design limitations. DRDO has designed and developed a VSWR protection module circumventing this limitation allowing exact VSWR protection down to 25dB back-off operation.

An add-on **communication and control module** allows configurable front end for the communication interface for flexibility in operation of the MPM on an addressable common bus with RS232, RS422, CAN, Ethernet, USB or a parallel interface protocols.



VSWR protection module



Communication module for customizing interface requirements

Features of DRDO EPCs

EPC Model (MPM/ MPM-Tx Model)	Prime Power (W)	Input Voltage (V DC)	Output Voltage (kV)	Eff. (%)	Salient Features
PUCMMAM-001A (MPS-4051)	150	270	4.3±0.2	85	• Fast rise and fall time modulator optimized for burst operation • Burst operation - 1MHz • Natural convection cooled
PCEWMNV-001A (MCS-3549)	430	270	4.3±0.2	89	• Throughput delay < 150 ns • PRF < 125kHz • Discrete interface • Conduction cooled base plate
CWCMMAF-001A (MCS-5050)	430	28	4.3±0.2	91	• Low ripple converter < 2 Vpp • Serial interface • Forced air cooled
PCEWTAF-001A (MCS-3547)	440	270	4.3±0.2	91	• Airborne highly stable converters • Analog readouts on serial interface
PCEWTAF-002A (MCS-3552)	1500	115	6.0±0.2	91	• Airborne highly stable dual cathode converters • Analog readouts- serial interface
PCEWMNV-002A (MCS-3550)	450	270	4.3±0.2	92	• Throughput delay < 70ns • PRF < 250KHz • Network interface for remote management

Solid-State Power Amplifier

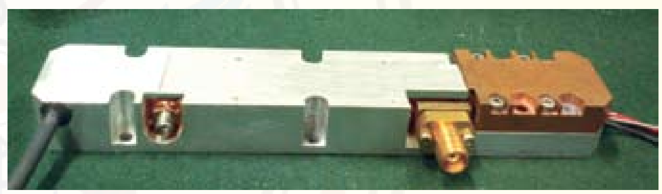
In general, a broadband PB-TWT shows a maximum gain in the band-centre and comparatively lower gain at the band-edges of the operating frequency band, which can be compensated to achieve flat gain response by employing an SSPA with inverted gain performance to that of a PB-TWT. For this purpose the concept of digitally variable gain control has been used that provides spot frequency tailored gain profile of an SSPA, which is required to produce a flat gain profile for the MPM. The gain of the SSPA has been reduced by removing one of the driver stages to avoid early saturation. Two variants of SSPA were developed one incorporating the equalizer using the concept of voltage variable attenuators (VVA) and in-built biasing circuit and the other as a simple SSPA with built-in isolator. The VVA uses 64 bit combination to adjust the attenuation level at the output of SSPA for different frequencies that is required for driving the TWT to saturation. The SSPA was developed using two-tier technology, one for power supply internal sequencing and the other for driving amplifier stages. The recent SSPAs have been developed using phase shifters incorporated inside for achieving the phase and gain tracking. In the present MPMs, SSPAs with a gain of around 27 dB at 1 dB compression point have been used for getting the desired performance of the MPM. The input drive to the SSPA is typically 0 dBm.

Packaged Solid-state Power Amplifier

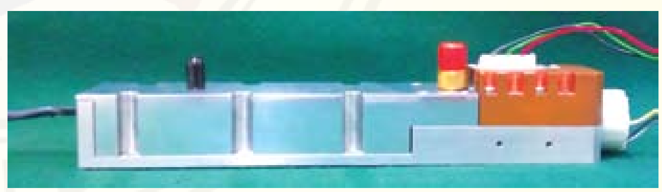
Power Booster Travelling-Wave Tube

A helix- travelling-wave tube (helix-TWT) is a broadband microwave amplifier based on conversion of the kinetic energy of high energy electron beam to RF energy by its continuous interaction with the electromagnetic wave travelling through a helical slow-wave structure (SWS). The PB-TWT is a short-gain medium-power helix-TWT. A PB-TWT comprises an electron gun to produce the electron beam, a magnetic focusing system to confine the electron beam, a non-dispersive short-length SWS to facilitate synchronous beam-wave interaction, and a collector to recover and dissipate the energy from the spent electrons after extraction of RF output.

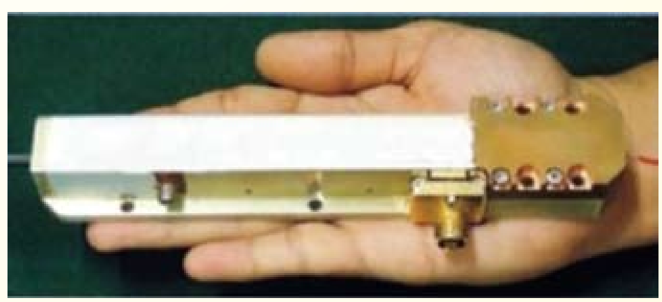
100W C-Ku-band PB-TWT



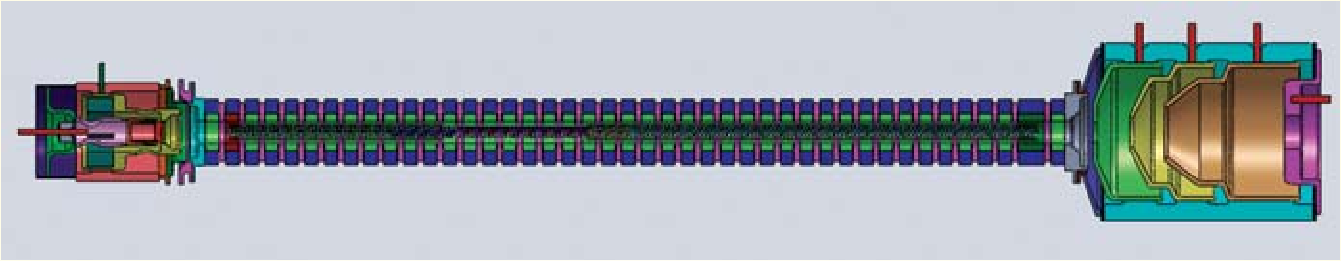
180W X-band PB-TWT



200W C-Ku-band PB-TWT

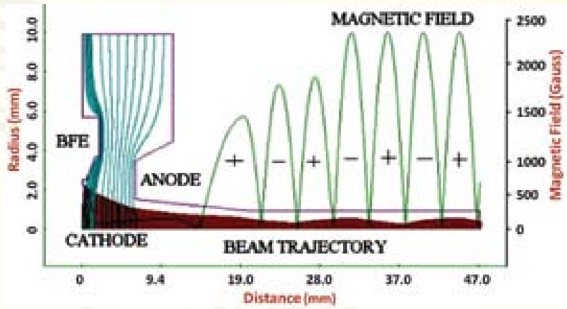


375W Ku-band PB-TWT



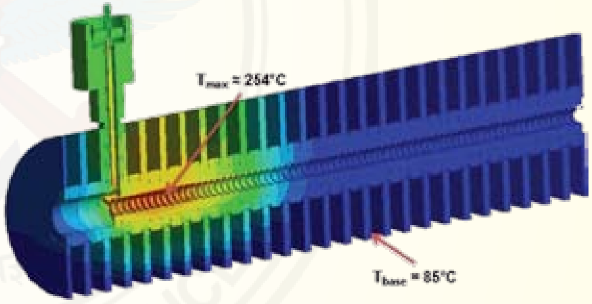
Cut-view of a typical PB-TWT

The PB-TWT is designed to operate at a low cathode voltage and high perveance resulting in considerable shortening in the lengths of the electron gun, RF interaction structure (higher gain per interaction length) and the collector as compared to conventional TWTs operating at high cathode voltages. A family of PB-TWTs for low-to-medium average/ peak power, broadband or narrowband operations has been developed and have been used in MPMs for EW and radar applications at frequencies ranging from C- to Ku-bands.

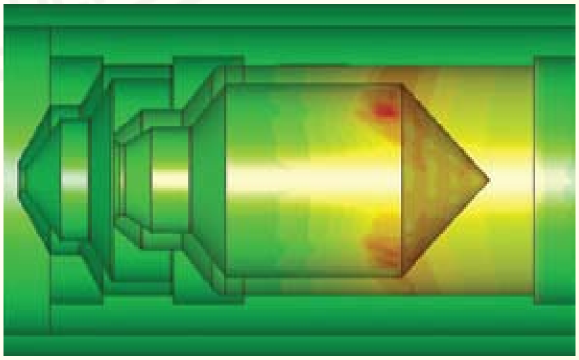


Trajectory analysis of electron gun

Computer-aided-design and fabrication techniques have been perfected to achieve 'First-Pass Design Success'. Highest performances of PB-TWTs have been achieved through developing special techniques: (i) multi-octave bandwidths (ii) stability against stop-band and backward-wave instabilities and (iii) efficiency enhancement by reducing RF losses and by optimising secondary electron effects in the collector. A novel multi-dispersion concept of broad-banding is implemented to achieve bandwidth up to 1.6 octaves with second harmonic ~8 dBc against conventional techniques in vogue that provides around 1.2 octaves bandwidth with second harmonic ~ 4 dBc. Special efficiency enhancement techniques could enable achieving state-of-the-art performances in a broadband TWT like ~24% RF interaction efficiency; and ~75% efficiency in a 3-stage depressed collector. Thorough thermal analysis and implementation of novel thermal management techniques also enabled in reduction of the volume and weight of the TWT and its housing. These TWTs are capable of delivering 100 -375 W output power in CW/ pulsed mode.



Thermo-structural analysis of SWS



Thermal co-simulation of a multi-stage collector

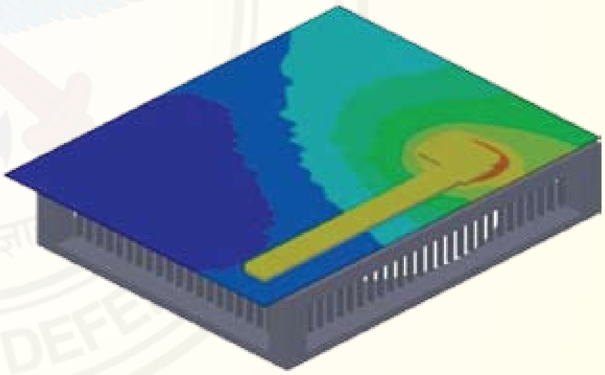
DRDO PB-TWT Characteristics

Characteristics	Model No.			
	MCH-3550	MCH-3553	MPH-4052	MPH-5055
Frequency band	C-Ku	C-Ku	X	Ku
Bandwidth (GHz)	12	12	1	2
Duty	CW/ Pulsed	CW/ Pulsed	Pulsed	Pulsed
Peak Output Power (W)	100	200	180	375
Focussing	PPM	PPM	PPM	PPM
Cooling	Cold plate	Cold plate	Cold plate	Cold plate
Weight (gm)	540	800	500	500

Thermal Analysis of MPMs and Transmitters

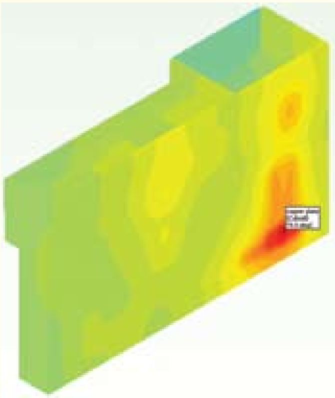
The compact sizes of the MPMs and transmitters along with its densely packed heat dissipating modules demand efficient dissipation of severe heat fluxes. Therefore, the thermal and structural analysis is very important during the development of MPM to ensure a reliable and repeatable performance of MPM in service. The thermal management technologies implemented in the DRDO MPMs are conventional heat sinks (Free and Forced air cooling), heat pipe as heat spreaders, liquid cooling through cold plates, mini-channel cooling, phase change cooling for transient needs and thermoelectric coolers. Predominantly natural convection and forced convection techniques are employed wherever possible for the ease of realization and field maintenance. Special cooling techniques are also adapted in most demanding situations:

- **Natural convection cooling** technique is used in the MPMs for radar applications (MPS-4051) for dissipating the heat to the ambient through square type pin fins attached to the MPM housing.



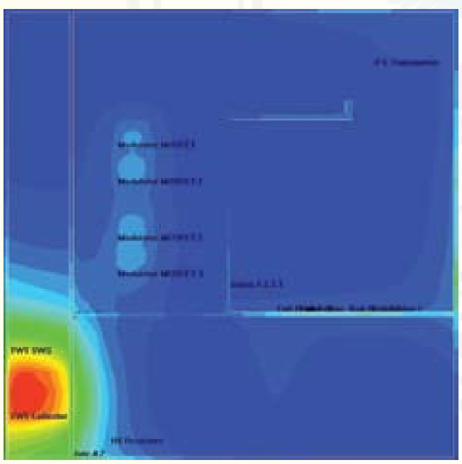
Thermal footprint of natural air cooled MPM (MPS-4051)

- **Forced convection cooling** technique is followed in the MPM-based transmitters (MCS-3547, MCS-3552, MPS-3560, MCS-5050 and MCS-5051) that are integrated with suitable heatsinks to facilitate the forced-air cooling. The heatsink fins are designed to reduce the pressure drop within limit while maximizing the heat transfer coefficient. The transmitters MCS-5050 and MCS-5051are developed with built-in EMI qualified fans.



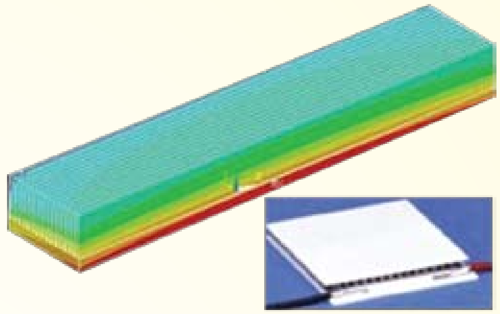
Thermal footprint of forced air cooled MPM-based transmitter (MCS-5051)

- **Cold-plate assisted cooling** through base-plate is used in the MPMs (MCS-3549 and MCS-3550), where the MPM housing is specially designed to thermally isolate the electronics and the PB-TWT, and the mounting is designed such that the heat is finally conducted to the base-plate from the power MOSFETs and the PB-TWT.



Thermal footprint of cold plate assisted MPM (MCS-3550M)

- **Thermoelectric cooling** (TEC) technique is the unique feature of the transmitter MCS-3547. This mechanism has be adopted for the thermal management to keep the electronics at a temperature below 70°C with the available cooling air temperature above 96°C.



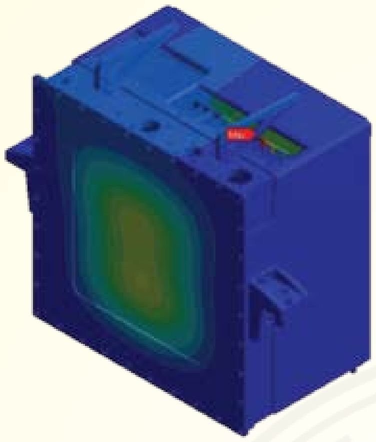
Thermal contour while using TEC

- **Heatpipe embedded heatsink based cooling** in employed in the transmitter MCS-5051, in which the heatsink of the PB-TWT is embedded with heatpipes to spread the heat-flux to the cooler zones for facilitating effective cooling with lower capacity cooling fan.

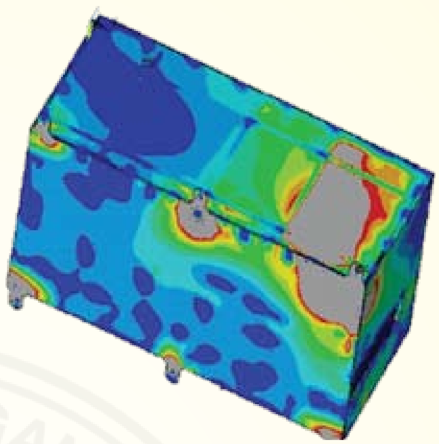
Heatsink with heatpipe

Structural Analysis for MPM and Transmitter

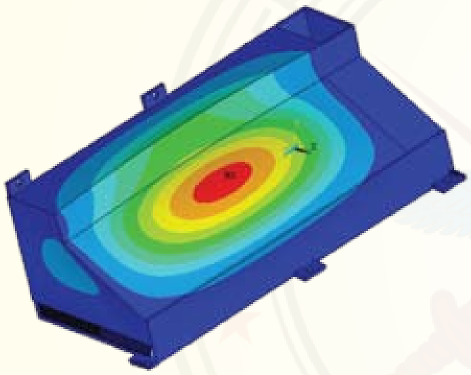
Structural integrity of the modules under severe environmental conditions poses tough challenges for the design of the modules and housing of the MPMs and transmitters. The structural design begins with the design of mounting bolts for static and dynamic loads. Natural frequency of the transmitters is found out by resonance search analysis. The structural modifications such as inclusion of stiffeners, change of cross section, addition of ribs to resist bucking are carried out. Harmonic analysis is carried out to keep the deflection and stress levels in safe limit within the working range. The transmitter chassis are fabricated and tested to validate the structural design. The FEM based software is being used extensively for the structural analysis. The picture below shows the modal analysis and harmonic analysis contours of various MPM transmitters.



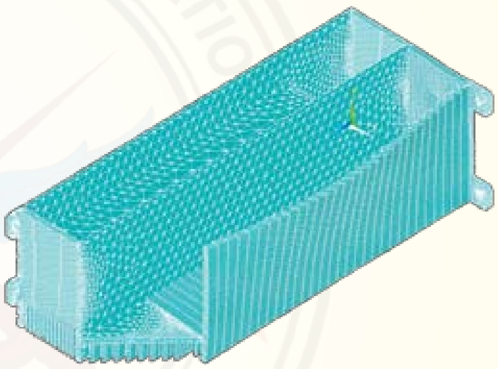
Normalised displacement contours under vibration
(MCS-5051)



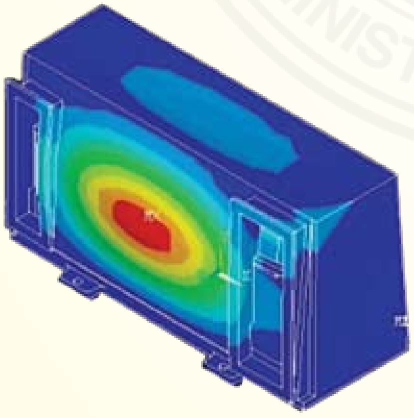
Stress contour under vibration
(MCS-5050)



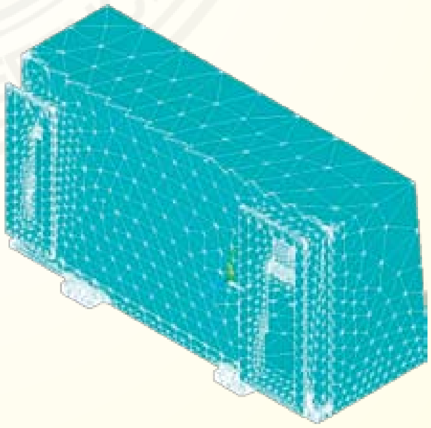
Normalised displacement contours under vibration
(MCS-3552)



Displacement contours under vibration
(MPS-3560)



Normalised displacement contours under vibration
(MCS-3547)



Displacement contours under vibration
(MCS-3547)

Conclusion

The MPM offers considerable performance improvements over conventional tube amplifiers. DRDO has fully established the technology for MPM, MPM-transmitter, and their modules: PB-TWT, SSPA, EPC and complete structurally/ thermally rugged chassis. A family of MPMs, MPM-transmitters, PB-TWTs, SSPAs and EPCs have been developed in-house for radar, EW and communication applications in C-X-Ku bands with 80-1000 W power. These units and modules have undergone stringent qualification tests and integrated in radar systems. The capability is expendable to higher frequencies. The impact of MPM induction at system level has facilitated: i) Saving of prime power due to high efficiency, ii) Ultra broadband operation (1-1.6 octave), iii) Phase and gain tracking of MPMs for achieving higher ERP, iv) Higher reliability due to reduced port-connects/ inter-connects, v) Compact size and weight, vi) Better thermal management due to reduced heat loads, vii) Ease in serviceability and fault diagnostics and in-suit log of operation, viii) Flexibility of pulsed/ CW operation, ix) Configurable protocols due to programmable controller and power save mode, x) Flexibility in system architecture due to availability of various modules, and xi) Reduced cost due to mass-production and standardization of modules for various applications. The reduction in cost can be effected by exploiting the concepts of modularity of subsystems, commonality of modules for various different applications and economics of scale of manufacturing. Further, the flexibility of design, automation and utilisation of known process techniques will also reduce the cost. Continuous efforts are on to improvise the performance of the MPMs and MPM-Tx's towards reduction of weight and volume using higher frequency switching for HV conversion. MPMs are also being conceptualised for mm-wave applications and for compact multi-beam type of devices.

Technology Focus focuses on the technological developments in the Organisation, covering the products, processes, and technologies.

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