Effects of Power Supply Ripple on Microwave Power Module and Tube Transmitters

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Abstract

MPM stands for Microwave Power Module. MPM is a versatile final stage RF amplifier for RADAR, EW and Communication Systems. RF chain in MPM consists of TWT or a Linearized TWT driven by a Solid State Amplifier (SSA). Electronic Power Conditioner (EPC) provides DC Voltages required for operating TWT, SSA and Linearizer. The required DC voltages are mainly derived from 28VDC or a 270VDC supplies. The MPM is very compact compared to similar output power TWTA amplifier system. MPM is having various Resonant DC-DC convertors for supplying voltages of Heater, Helix and Collector Electrodes. The process of DC-DC conversion involves lots of switching MOSFETS correspondingly switching frequencies. The Practical rectification and filtering circuits will not entirely remove the ripples present because of these switching frequencies. These ripple voltages residually modulates the voltages present on the electrodes of TWT. Residual modulationaffects the MPM's AM-AM, AM-PM, Spurious and phase noise. This paper analyses ripple requirement for meeting the various specifications of MPM and for various transmitters.

Keywords:*MPM,EPC,TWT,Ripple,AM-AM,AM-PM, Spurious, Phase Noise, Linearizer.*

I INTRODUCTION

MPM is the preferable choice for most of the Transmitter applications in RADAR, Electronic Warfare (EW) and Satellite Communication as a final stage amplifier. MPM is having RF sub-module for amplifying the microwave signal and Electronic Power conditioner for powering the RF section. Driver solid-state amplifier (SSA)delivers up to 1watt power to drive the mini TWT.SSA, Gain Equalizer and Travelling Wave Tube (TWT) form the RF line in EW and RADAR applications. Satellite communications where complex modulation schemes and multi carrier signals involves TWT required aLinearizer for compensating itsown Non-linear effects. The present MPM developed at MTRDC is an LMPM. Linearizer will be designed for a particular test data of TWT and for specific voltage parameters.So linearizer alone will not eliminate the unwanted RF performance from TWT. The performance of any MPM depends on purity of Power Supply. A good Power Supply with tight regulation and minimum ripple can provide the good RF results. RF performance of MPM is frequency dependent. This paper tried to explain about the ripple requirement of the of Power supply for meeting the required RF performance in terms of spurious and IM.

II ELECTRONIC POWER CONDITIONER

Electronic Power Conditioner (EPC) provides Required DC Voltages for active RF components and protects them against voltage variations. The EPC is constituted with multiple DC-DC converters for powering various electrodes like Cathode, Heater, Beam Focusing electrode (BFE) and depressed collectorsof TWT. The micro controller in the EPC manages the sequencing, coordination, fault monitoring and protection within the MPM. EPC is having five major blocks. EMI/EMC filter is for blocking the conductive emissions from either side and housekeeping power unit is for initial startup. Cathode – Collector voltage converter for their voltages and modulator voltage for pulsing the Beam Focusing Electrode and microprocessor based fault action with in EPC.A ripple regulation of the order of 0.01% achievedis over 4.3KV.Table 1 gives the brief EPC specifications.

Table 1: EPC Specifications

S.No	Parameter	Remark/value
1	Input DC Voltage	28VDC
2	EMI/EMC	MIL-STD-461E
3	Volume	205X 260X 60Cu mm
4	Operating Temp Range	-40°C to +55°C
5	Storage Temp Range	-40°C to +70°C
6	EPC Efficiency	> 90%

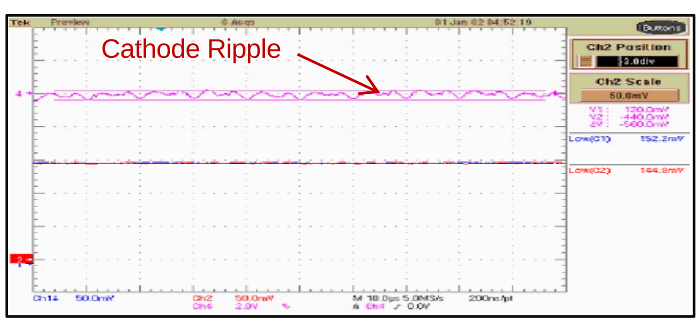

Fig 1: Ripple in the Cathode line (<0.5V Pk-Pk)

III RFMEASUREMENTS

1. *MPM specifications*

The MPM performance is specified and measured in terms of RF parameters. Table 2 gives the RF specifications of the MPM.

Table 2: MPM RF specifications

S.No	Parameter	Specification	Measured
1	Output Power	100Watt	110 Watt
2	P1dB Power	80Watt	80 Watt
3	Spurious	-50dBc	-52dBc
4	Harmonics	-10dBc	-28dBc
5	AM/PM	6°/dB	3°/dB
6	OIP_3(2 equal carriers,5MHz apart, 3dB OBO)	-17dBc	-24dBc
7	OIP_3(2 equal carriers,5MHz apart, 7dB OBO)	-21dBc	-27dBc

Specifications of MPM or Tube Transmitter can be met by considering the Pushing factors of TWT apart from EPC parameters.

Fig 2: Testing of MPM

2. *TWT's Amplitude and Phase Pushing Factors*

TWT is linear beam vacuum device. Variation in electrode voltages causes change in output phase and output amplitude. Based on the phase and amplitude pushing factors of TWT (Table 3) power supply ripple requirement can be estimated. Pushing factors can be understood as change in voltage to change in output phase and output power. Phase pushing factors can be effective mainly on AM/PM and amplitude pushing factors will affect mainly Spurious and IM. Compact power supplies like EPC employs many DC-DC converters and filters to cater required DC voltages to TWT electrodes. Due to practical filtering problems DC voltages contains ripples at different switching frequencies.Frequency of ripple voltage will appear in RF spectrum as Residual AM Sidebands.

Table 3: TWT pushing Factors

S.No	Sensitivity parameter		Value	Remarks
1	Phase Variation with Heater Voltage	$\frac{(\Delta\varphi)}{(\Delta Vf)}$	10°/V	Max
2	Phase Variation with Helix Voltage	$\frac{(\Delta\varphi)}{(\Delta Vh)}$	2°/V	Max
3	Phase Variation with Collectors Voltage	$\frac{(\Delta\varphi)}{(\Delta Vc)}$	0.05°/V	Max
4	Phase Variation with Temperature	$\frac{(\Delta\varphi)}{(\Delta Te)}$	0.1°/°C	Max
5	Output Power Sensitivity to the helix Voltage(∞m)	$\frac{(\Delta Po)}{(\Delta Vh)}$	0.04dB/V	Max
6	Output power Sensitivity to the heater Voltage(∞m)	$\frac{(\Delta Po)}{(\Delta Vf)}$	1dB/V	Max
7	Output power sensitivity to the collectors voltage(∞m)	$\frac{(\Delta Po)}{(\Delta Vc)}$	0.05dB/V	Max

3. *Ripple requirement for spurious*

The residual AM is analogs to simple AM modulation and we can look ripple voltage variation as message signal and RF input signal as carrier. A simple AM equation gives fairly good assumption for calculating the spurious levels. AMModulation index ∞AMcan be defined from [1].

$$\text{Residual AM} = \infty AM/2 \text{ -------- } (1)$$

$$\infty AM = (V1-V2)/(V1+V2) = \Delta V/V \text{ ------ } (2)$$

Where V1 and V2 are ripple modulated signal maximum and minimum and V is the RF peak voltage.Amplitude Sensitivity of the TWT (∞m) will be specifies in change of output Power P (dB/V) and

$$20\log((V+\Delta V)/V) = \infty m \times V_{Peak} \text{ -------- } (3)$$

V_{Peak} = Ripple voltage

$$\Delta V/V = (10^{(\infty m \times V_{peak})/20})-1 \text{ ------ } (4)$$

From equation (2) Residual AM

$$= 20\,\text{Log}\,(10^{(\infty m \times V_{rms})/14.14} - 1) - 6\text{dBc} \text{ -------- } (5)$$

$$V_{rms} = (14.14 \log(\{1+\text{antilog}\,[(\text{Residual } AM_{dBc}+6)/20]\})/\infty m \text{ ----- } (6)$$

From equation (6), for spurious of -50dBc required ripple RMS voltage for cathode is767mV. This is less than the ripple appeared in practical circuit shown in Fig 1. From [1] we can calculate the same way for residual PM and residual FM.

4. *RF Measurements*

TWT is RF Amplifier in MPM. Before integrating with EPC, TWT was tested separately with bigger linear power supply HAZEMEYER. This power supply has more control over ripple voltages with lot of flexibility in varying voltages and protection of TWT. RF spurious and Inter Modulation (IM) products of TWT measured with this power supply are shown in Fig 4 and Fig 6 respectively.

Fig 3. Testing of TWT with Hazemeyer power supply

Fig 4 shows TWT spurious measured as -76dBc and away from carrier by 500 KHz. since its ripple voltage is less in HAZEMEYER power supply, the appeared spurious frequency is from filter leakage.

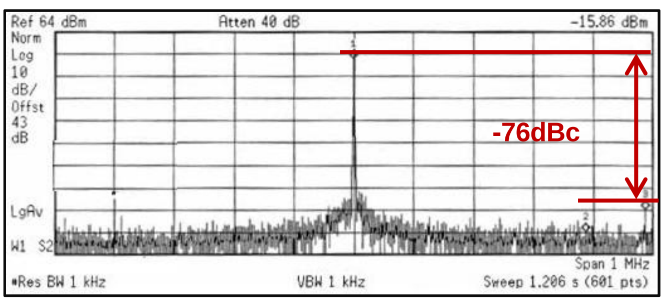

Fig 4: Spurious of TWT with Hazemeyer power Supply

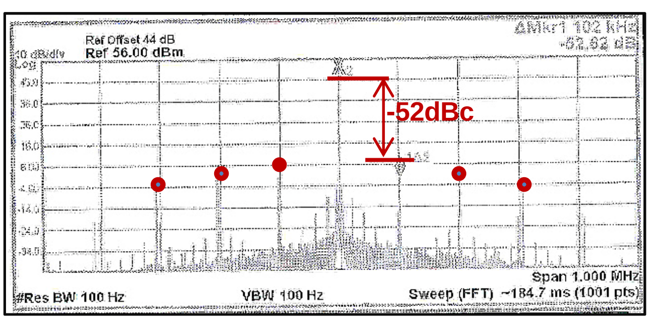

Fig 5: Spurious of MPM (TWT+EPC)

From Fig 5 MPM spurious is -52dBc max at 102 KHz away from carrier which is a MOSFET Switching frequency for high voltage cathode converter. We can see other spurious lines at harmonics of switching frequency 204 KHz, 306 KHz away from carrier. A lot other spurs are there between fundamental and harmonics of switch frequency because of imperfect shape of output switching voltage after high voltage bridge.

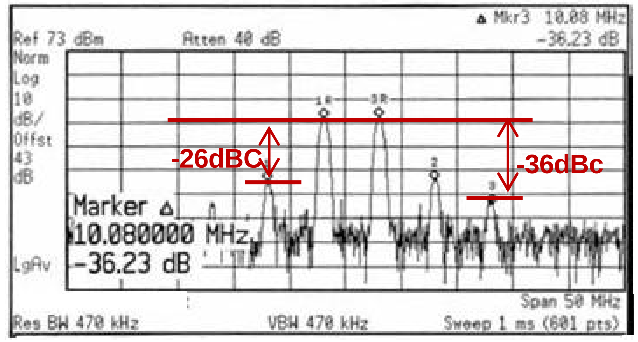

Fig 6: TWT- IM @3dB OBO with Hazemeyer Supply

Fig 6 shows TWT intermodulation (IM) products of 3rd and 5th order were -26dBc and -36dBc respectively. Fig 7 shows MPM's 3rd and 5th order IM of -24dBc and -34.2dBc respectively. MPM is having 2 dB poor performance of IM, compared to TWT alone because of the ripple present in electrode voltages of TWT.

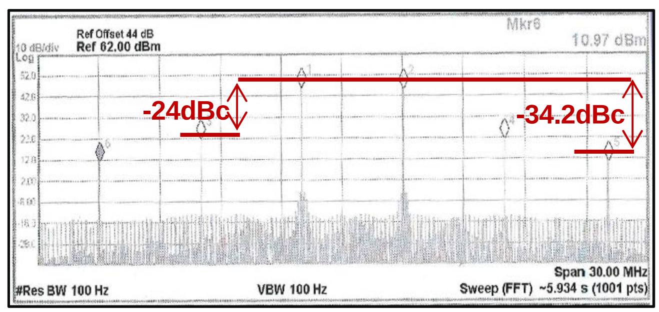

Fig 7: IM of MPM @3dB OBO (TWT+EPC)

IV CONCLUSION

MPM is tested for parameter like AM/PM, Spurious, Harmonics, Intermodulation products and Noise figure. For achieving low ripple voltage, a passive filter was placed on cathode return line. This particular MPM is meeting all the electrical parameters and it is under qualification.

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REFERECNES

[1] Power supply ripple affects power amplifiers, Joe Hajduck, Jack Steck
[2] Basic Equipment Design Tutorial, J.P Silver
[3] Microwave Tube Transmitters, by L.Sivan

[4] The microwave power module: a versatile RF building block for high-power transmitters, Proceedings of the IEEE (Volume: 87, Issue: 5) Carl R. Smith, Carter M. Armstrong, Member, IEEE, and Joseph Duthie

[5]The Linearized Microwave Power Module, Allen Katz and Robert GrayLinearizer Technology Inc., Hamilton, NJ, USA

[6] Analysis of RF Radiated feedback on MPM Performance, IVEC-2015, Nani. M, Mala.R, Sidharthan.P, Khilawan.C, Mirjith.K, Kamath.S and Lalit Kumar.

[7] Mike Golio, RF and Microwave Circuits, measurements, and Modeling, CRC Press, 2008ISBN10: 0849372186

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Nani Medicherla Received B.Tech Degree in Electronics and communication with Distinction from JNTU, Hyderabad in 2005. Started career as a lecturer in 2005 and in 2006 he joinedas scientist in DRDO. He is Involved in design and development of MPM for various EW and Communication applications. He largely contributed to Test and Measurements of MPM, TWT and Solid-State Amplifiers. He is recipient of Technology group Award 2008, DRDO Agni award 2013 for Excellence in Self-Reliance. He is the life member of VEDA society, life member in Society of EMC engineers (India).His Research Interest is MPM and Terahertz systems.

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Dr.Sudhir Kamath is Director, MTRDC. He joined MTRDC as Scientist in 1985.He has handled various responsibilities as Project Manager, Group Head, Divisional Head & Project Director and he has contributed to a number of projects and technologies for development of Microwave Tubes such as Gridded Electron Guns, Collectors, and Electronic Power Conditioners etc. He has been involved in the Design and Development of various types of Helix- and Coupled-Cavity TWTs for Defence Systems. As a Project Director he has successfully developed Microwave Power Modules (MPM) and MPM based Transmitters for Radar, EW and Communications. He is a Senior Member - IEEE, Fellow - Institution of Electronics and Telecommunication Engineer (IETE), Fellow & Vice President - Vacuum Electron Devices and Applications Society (VEDAS), Member - Magnetic Society of India (MSI) and Society of EMC Engineers India.He is the recipient of the DRDO Agni award for excellence in Self-reliance in the year 2003 and 2013. He has also received Scientist of the Year award in 2009 for his significant contribution in the field of Microwave Tubes. He has also received a number of awards at the laboratory level including the Laboratory Scientist of the year award in 2003.

Note: Additional info in the form of Photographs, Graphs etc are available on request.