Design of TWT Based Ka Band Radar Transmitter for Tracking Radar

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Abstract

This paper presents the design issues and challenges in the realization of high performance Travelling Wave Tube (TWT) based Ka Band Transmitter for Tracking Radar. The design goal was to achieve stable operation of the transmitter having spectral purity of -60dBc/Hz at 100 Hz away from the carrier while delivering 700W (minimum) of peak power and 70 W of average power across the bandwidth of 1GHz at Ka-Band. The transmitter is realized in a volume of 0.065 m^3 and weight of 50kgs. The TWT and the required transmitter spectral purity translates into High Voltage Power Supply (HVPS) design, i.e., Cathode voltage of -20.5kVDC and Collector voltage of 7.5 kVDC with stringent cathode pulse to pulse regulation of the order of 0.0004% under adverse environmental conditions. Since the transmitter is mounted on a rotating antenna pedestal, the transmitter needs to be designed for outdoor operating condition with low volume and weight. Transmitter design is catered for reliable operation at altitudes up to 10,000 feet MSL. Transmitter system design and approach followed for the realization of major subsystems like High voltage power supply, modulator and control and protection circuits in a compact volume and weight is discussed in detail. A FPGA card is used for status transfer and remote operation. The transmitter has been designed to meet environmental requirements as per JSS 55555-2012, EMI/EMC as per MIL-STD-461E.

Key words: Phase noise, TWT, High voltage engineering, FPGA

I. INTRODUCTION

RADAR Transmitters using microwave tubes amplify the RF signals from few milliwatts to few hundreds of watts and several kilowatts. The requirement of high stability, large band width and large gain can generally be met by Master oscillator power amplifier (MOPA) type transmitter using coherent amplifier like TWT as final power amplifier. Transmitters using TWT as the basic RF amplifier needs high quality power supply in terms of voltage regulation to achieve the spectral purity required for Tracking Radar application. Further Radar transmitters are to be realized in compact weight and volume, working reliably in stringent environmental conditions. So the High Voltage Power Supply (HVPS) needs to be highly efficient.

Power supplies for Radar transmitters have to supply pulsed loads and thus require high energy storage capacitors at the output. These power supplies are designed using high frequency converter topologies to achieve precise output voltage regulation, improved performance and to realize in compact size.

HVPS is a phase modulated series resonant converter (PMSRC) with a single inverter and a single tapped High voltage High frequency (HVHF) transformer supplying cathode and collector of the TWT. The cathode voltage is regulated very precisely by phase modulation of the inverter and the collector voltages are maintained by the cross regulation of the HVHF transformer.

Solid encapsulation technique is used to provide the necessary insulation. Potting materials are used considering the dielectric strength, thermal conductivity and the density of the encapsulating material in various modules.

The paper also presents the approach used to reduce the size of the Grid modulator and control and protection strategy employed for the transmitter. A FPGA board is used for status transfer and remote operation. Schemes employed to ensure reliable operation of the FPGA board in the transmitter has been described considering the high EMI/EMC environment.

II. SYSTEM DESCRIPTION

Some of the important specifications of the transmitter are given in Table 1.

Parameter	Specs
RF Peak Power output(min)	700 W
Duty cycle	10%
RF Frequency	Ka-Band
Phase noise	-60dBc/Hz @ 100Hz offset
RF input	0±2 dBm
Input voltage	320 VDC & 28 VDC
Size	570mm(D)X350mm(H)X330mm(L)
Weight	50 kg max

Table 1

The specifications for the HVPS and the Grid modulator of the transmitter are derived from the power supply requirements of the TWT electrodes, which decide the TWT performance in terms of the spectral purity of RF output. The voltage variations from pulse to pulse of the TWT electrodes and the phase sensitivities of the TWT electrode voltages contribute to the phase noise in the RF output. Phase noise performance to a large extent is decided by the regulation of the cathode supply of TWT. To achieve the required phase noise performance of -60dBc/Hz, a cathode voltage regulation of the order of 0.0004% is required on pulse to pulse basis. Since TWT's can tolerate much higher variation in collector voltage without degrading the phase noise performance, the High voltage power supply topology selected is a single phase modulated SRC powering a single tapped high voltage high frequency transformer with cathode voltage regulated and a collector voltage maintained by the cross regulation of the transformer.

The voltage droop on the electrodes of the TWT with-in the pulse and the amplitude sensitivities of the TWT electrodes will collectively decides the RF amplitude flatness of the output. To meet the RF amplitude flatness requirement of the system large energy storage capacitors are required on the TWT electrodes which not only increase the size and weight, but also the large energy stored can cause permanent damage to the TWT in the event of arcing. Hence in this transmitter the capacitor values are selected so that the energy stored is well below the TWT energy limits and the droop on the cathode supply is also controlled.

High voltage power supply, modulator and control circuits form the major subunits of any TWT based transmitter. The approach for realization of these units in a compact volume is discussed below.

1. *High voltage power supply*

The specifications of the High voltage power supply are derived from the TWT requirements. The PMSRC is a full bridge resonant inverter operating at high switching frequency using MOSFETs as switching devices followed by step-up transformer, HV diode bridges and Energy storage capacitor. The converter is provided with common mode and differential mode EMI filter to meet MIL 461E requirements.

Series Resonant topology is selected because Zero voltage switching (ZVS) is achievable. Hence, switching losses can be reduced which results in higher efficiency and power density. The inverter is short circuit protected.

The input 320VDC voltage is converted into high voltages of -20.5kVDC, 7.5kVDC as required by the TWT electrodes. Fig.1 shows the block diagram of the TWT Power supply. The transformer has been designed with Low leakage inductance and good cross regulation to maintain collector voltages of TWT within acceptable limits from no load to full load.

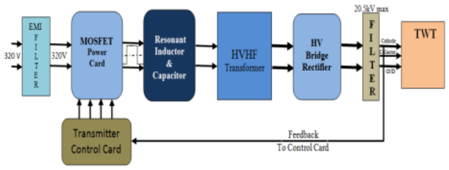

Figure 1. Block Diagram of the TWT Power Supply

Multiple section secondary winding is used to reduce the inter-winding capacitance of the transformer. Each section voltage is rectified and stacked. The HV transformer, HV rectifier and the storage capacitors are encapsulated in a solid dielectric with sufficient thermal conductivity to extract the heat generated in the modules.

2. *Modulator*

The Grid is a low voltage control electrode to control the electron beam of the TWT thereby controlling the RF output. Modulator generates the control electrode voltages and the filament voltage as required by the TWT and also pulses the TWT grid as per the pulse width and PRF requirements of the transmitter. Above all, the voltages generated by the modulator are floating at a very high potential of the cathode i.e.,-20.5 kVDC.

Grid Modulator is solid encapsulated to provide the necessary isolation and thermally conductive potting material is selected for the heat removal. The grid pulse and modulator fault signals are transferred using optical links. All the power supplies are realized using multi output flyback converter operating at high switching frequency and the required voltage regulation is achieved by the post regulator at each output.

The flyback converter is provided with current control to protect against short circuit and limit the surge current through TWT heater during cold start. RF MOSFET based push-pull switch is used for Grid pulsing between positive and negative supplies. The switch is provided with a passive bypass to ensure availability of Grid bias to TWT in the event of failure of the switch.

3. *Control Circuits*

The Control unit enables the sequential switching ON of the transmitter, continuous monitoring and real time interlocking of control parameters. It also classifies the faults and puts the transmitter in appropriate state. The control board uses fast acting voltage latch comparators, for detection and storage of faults. FPGA is used to transfer the status of the transmitter to Radar controller through RS422 serial interface. Transmitters being an EMI environment, FPGA and control circuits are designed to work reliably to prevent false alarms. Given below are few of the points considered for fail safe operation of the control circuits.

- All samples are taken through RC filters and terminated with transient absorbers at PCB input.
- Multi layer PCB board is used
- High currents are provided with shortest path lengths in the transmitter to reduce the inductance effects.
- Isolated power supplies for the FPGA .
- All signal transfer to FPGA through opto couplers

4. *High Voltage Engineering*

Solid encapsulation techniques have been used in the transmitter for HV insulation requirements. The breakdown strengths of the dielectric have been sufficiently de-rated to ensure reliable operation at high altitude. Series current limiting resistors have been used

at the output of the High voltage power supply to protect the power supply components and TWT in the event of High voltage arc.
The potting materials are selected based on the below factors:

- Dielectric strength of the material to provide required insulation under worst environmental conditions
- Low co-efficient of thermal expansion,
- Thermal conductivity to enable heat removal

High voltage probes are used to obtain samples for protection and cathode voltage regulation. EHT connectors are used to make EHT interconnections thereby avoiding exposed EHT terminals. Copper heat spreaders have been used to remove the concentrated heat below the TWT collector.

5. *Microwave Engineering*

The Ka band TWT with gain ~~of +~~of +39dB is used for RF amplification. RF input of 0±2dBm is fed to the transmitter from Radar Exciter. The Solid state Amplifier(SSPA) at the front end of the transmitter amplifies the RF input to match the drive requirements of TWT. The SSPA with a gain of 26dBm and a 10dB adjustable attenuator can be tuned to the TWT nameplate value of RF drive. The three port Circulator at the output of TWT protects TWT from excess VSWR at Antenna port & Dual Directional Coupler(DDC) is used for the measurement of TWT output Power and reverse power for VSWR protection interlock. RF arc sensor is fitted right at the TWT output to protect the TWT in case of RF arcing.

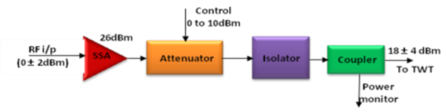

Figure 2: Block diagram of low power microwave chain

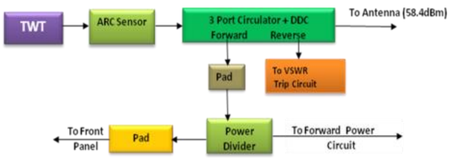

Figure 3: Block diagram of high power microwave chain

III. RESULTS

The Ka Band transmitter is realized and tested for its full duty and performance. TWT ~~cathode current~~Grid pulse input, Inverter bridge voltage and Inverter current waveforms at 10% duty cycle operation is shown in Fig.4.

Figure 4a. TWT pulsing at 10% duty cycle. CH2 Output/~~P~~ voltage of the inverter, CH3 Grid pulse input TWT, CH4 inverter current

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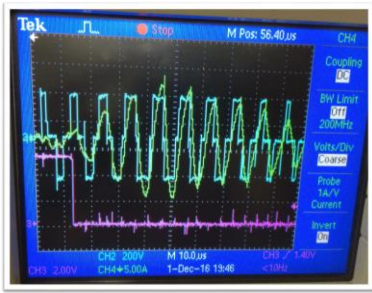

Figure 4b.CH2 Output/~~P~~ voltage of the inverter, CH3 Grid pulse input TWT, CH4 inverter current)

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Transmitter has been realized in the volume of 570mm(D)-X -350mm(H)-X -330mm(L) and a weight of 50 kgs (-Fig 5-). ~~Agilent E8257D~~ A RF source is used to drive the transmitter with -2 dBm to 2 dBm input with a near carrier noise of -74dBc/Hz @ 100Hz offset. The output spectrum was measured as -72dBc/Hz @ 100Hz offset (Fig 6).

CONCLUSION

A high performance TWT based Ka Band Transmitter using state of art technology for Tracking Radar has been realized. The transmitter has been tested up to 10% duty cycle. The transmitter is tested for 12 hours of endurance, driving rain test and vibration test. ~~The transmitter will be qualified for~~Qualification for EMI/EMC requirements as per MIL-STD 461E and environmental requirements as per JSS 55555-2012 is under progress~~.~~

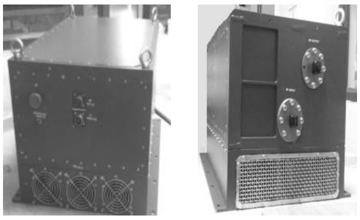

Figure 5. Front and Rear view of Ka-band transmitter

Figure 6. RF output Spectrum

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Raghu Ramudu Chinnem received BE degree in Electronics & Communication Engineering from Osmania University, Hyderabad, in 1996. Since 1997 he has been with Bharat Electronics Limited [BEL], Bangalore involved in design and development of high power Radar transmitters. He contributed towards indigenous development and realization of high power radar transmitters using TWT for Battery Level Radar (BLR III), Flight Level Radar (FLR), Weapon Locating Radar (WLR) and Troop Level Radar (TLR). He has made significant contribution towards indigenous development of WLR (Swathi), which bagged the prestigious Raksha Mantri Award for Excellence 2010-11 for import substitution. He is recipient of BEL R&D Excellence Award for year 2011-12 under category "Key Contributor" for developing transmitters for the Radars.

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