Design of Compact C Band High Power Transmitter

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Abstract
This paper presents the design issues and challenges in the realization of compact high performance Travelling wave tube (TWT) based C Band Transmitter. The design goal was to achieve stable operation of the transmitter having spectrum purity of near carrier noise of -75dBc/Hz at 100 Hz away from the carrier while delivering 70 kW (minimum) of peak power and 3 kW of average power across the bandwidth of 400MHz at C-Band. The transmitter is realised in a volume of 1.2m^3 and weight of 575kgs. The TWT requirements translates into High Voltage Power Supply (HVPS) design, i.e., Cathode voltage of -39 kVDC and Collector voltage of 27kVDC with stringent cathode pulse to pulse regulation of the order of 0.0004% under adverse environmental conditions which includes operation at altitudes of 16000feet. Transmitter system design and approach followed for the realization of major subsystems like High voltage power supply, floating deck 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.

Keywords: Tapped transformer, Interleaved Boost converter, High voltage engineering, series resonant converter

I. INTRODUCTION

High Power Radar Transmitters using microwave tubes like TWT require high quality power at HVDC to obtain satisfactory performance in terms of RF output spectrum. Further Radar power supplies are subjected to pulsed load, which calls for a suitable energy storage capacitor at the output. Operating HV power supplies under environmental conditions such as humidity and high altitudes calls for specific high voltage engineering to prevent corona and partial discharge effects.

HV transformer is a crucial element in HV power converters due to large number of secondary turns and insulation requirements resulting in non-idealities like leakage inductance and winding capacitances. Series Resonant converter (SRC) absorbs some non-idealities with its own advantages and disadvantages. Liquid dielectric has been in use for HV transformer for a long time considering its ability to remove heat by convection, good dielectric strengths and its insulation restoration properties. A tapped High voltage High frequency transformer is used in this transmitter to generate both the cathode and collector supplies for the TWT. Cathode voltage is regulated by phase modulation of the SRC and collector voltage is maintained by proper cross regulation of transformer.

The paper also presents the approach used to reduce the size of the floating deck modulator (FDM) 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 and possibility of high current discharges in the HV section.

II. SYSTEM DESCRIPTION

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

Parameter	Specs
RF Peak Power output	70kW
Duty cycle	5%
RF Frequency	C Band
Phase noise	-75dBc/Hz @ 100Hz offset
RF input	0dBm
Input Power	3 Phase 415V, 50Hz
Size	600mm(D)X950mm(H)X2100mm(L)
Weight	600kg max

Table 1

The voltage variations from pulse to pulse of the TWT electrodes and the phase sensitivities of the TWT electrode voltages contribute to the phase changes from pulse to pulse and 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. Typical cathode phase sensitivities for a High power TWT is in the range of 35 to 45 degree/ 1% change in the voltage. To achieve the required phase noise performance a cathode voltage regulation of the order of 0.0004% is required in this transmitter. 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 tapped high voltage high frequency transformer with cathode voltage regulated and the collector voltage maintained by the cross regulation of the transformer.

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

1. *High voltage power supply*

A four stage interleaved boost converter with power factor control (PFC) is used as the preregulator for the inverter. The boost converter is operated at 20 kHz. The high frequency pre regulator enables to reduce the size of the DC bus filter components which occupies the bulk of the volume in any AC/DC converter. Also PFC control enables the use of a smaller EMI filter at the input. A 50 kHz phase modulated SRC and Tapped high voltage high frequency transformer is used to generate the required cathode and collector voltages for the TWT. Zero voltage switching (ZVS) is used to reduce switching losses in the switching devices (IGBT's). The transformer has been designed with Low leakage inductance and good cross regulation to maintain collector voltage of TWT within acceptable limits from no load to full load. Sandwich bas bars are used for providing DC input to the full bridge IGBT inverter.

2. *Modulator*

Beam switching of pulsed linear beam tubes can be performed using low power or high power modulator to switch the beam on and off [4]. Low power modulators exploit a control electrode such as grid, a focus electrode or an anode. In cathode modulation, high instantaneous powers are involved since both the full beam voltage and current have to be switched simultaneously. TWT's generally require a grid voltage swing of ±800V approx for switching ON and OFF the beam.

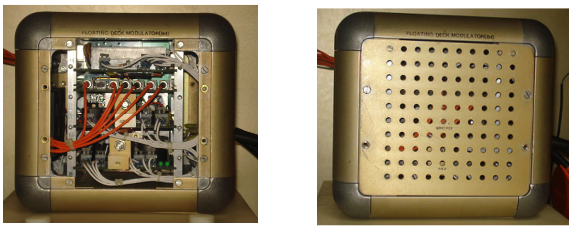

Fig 1. FDM unit

Floating deck modulator (FDM) is so called because the control electrode drive and bias supplies, as well as the switching devices are floated on the cathode voltage, which could typically be several kilovolts with respect to ground. The transmitter system being described here uses a Floating deck modulator for pulsing the TWT. FDM is constructed on the principle of Faraday cage.

In order to realize a compact transmitter, realization of compact FDM is essential as FDM has to be mounted in the transmitter providing required clearance from the ground surfaces to ensure that there is no corona initiation under worst operating conditions. FDM generates the filament and grid supplies and uses a solid state High voltage push pull switch (Mosfet based) for pulsing the TWT Grid as per pulse width and PRF requirements. A half bridge inverter operating at 30 kHz is used to provide AC input to the FDM through a high frequency isolation transformer to reduce the size.

3. *Control and Protection*

The control and protection unit (CPC) performs three major functions:

- Control functions like sequencing the switching on of the transmitter, generation of timing signals for subsystems and checking the status of subunits.
- Protection functions include detection of faults, classifying them according the level of seriousness and auto switching off the faulty subunit to prevent destructive damage. It also displays the nature of fault.
- Monitoring and display of essential parameters.

Quick acting latching comparators are used for interlocking high voltage and pulse parameters. Fault clearing time is less than 5us. FDM parameters are obtained using Voltage to frequency (V to F) and F to V conversions with data transmitted as light pulses on optical links. All PCB's are realized as multilayer boards with power and ground planes.

A Vacuum florescent display (VFD) is used to display the transmitter status and parameters. A rugged metallic keypad is used as user interface for operating the transmitter. Representation of critical transmitter parameters, monitoring the transmitter status and health of the various subunits on the local VFD display and communication with the radar controller through Ethernet is achieved using a FPGA board.

Transmitters being an EMI environment following precautions have been taken to prevent nuisance operation of protection circuits and FPGA board.

- All samples are taken through RC filters and terminated with transient absorbs at PCB input.
- All PCB's are mounted inside grounded metallic enclosures.
- Single point grounding scheme has been adopted for the transmitter with ground impedance of less than few milliohms.
- Small loop area for high current paths in the transmitter to reduce the inductance effects.
- Isolated power supplies for the FPGA board
- All interface between the transmitter control circuits and FPGA board through optical isolation
- High voltage discharge currents are limited to <500A using suitable current limiting resistors during arcing and crowbar operation.
- Dedicated ground paths are provided for carrying crowbar currents

4. *High Voltage Engineering*

Solid encapsulation techniques have been used in the transmitter for HV insulation requirements of different HV components. The breakdown strengths of the dielectric have been sufficiently derated to ensure reliable operation. Compact molded High voltage probes are used to obtain samples for protection and cathode voltage regulation. Compact HT connectors have been developed to make EHT interconnections thereby avoiding exposed EHT terminals.

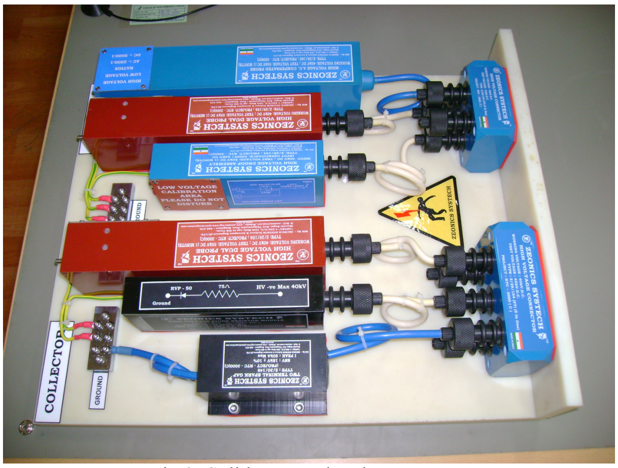

Fig 2. Solid encapsulated HV components

Solid encapsulated HV components used in the transmitter are shown in Fig.2. Polyolefin cross linked polymer is used as the dielectric material with a dielectric strength of 30kV/mm.

III. RESULTS

Compact transmitter has been realized in the targeted volume of $1.2m^3$ and a weight of 570kgs, shown in Fig.3. Currently the transmitter has been tested up to 2% duty cycle. Agilent E8257D RF source was used to drive the transmitter with 0dBm input with a near carrier noise of -62dBc/Hz @ 100Hz offset. The output spectrum was measured as -60dBc/Hz @ 100Hz offset (Fig 4). Final RF spectrum measurements at 5% duty cycle will be carried out with RF input from exciter with near carrier noise of -82dBc/Hz @ 100Hz offset.

Fig 3. Realized compact C-Band transmitter

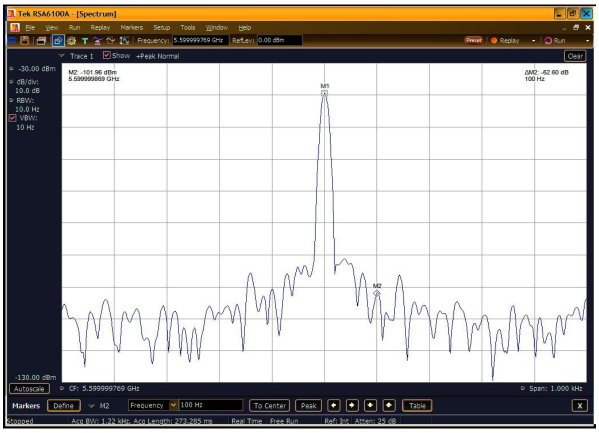

Fig 4. RF output spectrum

IV. CONCLUSION

A high performance Compact TWT based Transmitter using state of art technology for Weapon locating Radar has been realized. The transmitter has been tested up to 2% duty cycle and testing is under progress to complete the 5% duty cycle operation. The transmitter will be qualified for EMI/EMC requirements as per MIL-STD 461E and environmental requirements as per JSS 55555.

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