Design & Development of 80W X band Transmitter for Active Radar Seeker

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Abstract

The microwave transmitters are used for variety of applications in the fields of communications, radar and Electronic Attack. The airborne transmitter design should address the needs like size, weight, efficiency, reliability etc. Travelling Wave Tubes (TWT) are extensively used in microwave transmitters as RF power amplifiers. TWT requires a highly sophisticated power supply and a fast switching modulator. In this paper, an 80W X Band transmitter developed currently for an active missile seeker is discussed. The design goal was to achieve stable operation of the transmitter having spectrum purity with near carrier noise of - 80dBc/Hz at 1000 Hz away from the carrier while delivering 80W (minimum) of peak power.

Key words: TWT, seeker, EPC, Fast switching modulator

I INTRODUCTION

The seeker is a system on the missile that performs the on-board target sensing for flight guidance, with the ultimate purpose of bringing the intercepting missile's warhead within a lethal radius of the target. Radar guided missiles exist in four basic categories namely command guided, active homing, semi active homing, and passive homing. Active radar seekers are the most popular in all the current missile programs owing to their flexibility of design and implementation to suit almost every mission requirement apart from all-weather capability. The most extensively employed configuration of active radar seekers so far realized is the coherent mono-pulse tracker with a gimbaled antenna structure. The active radar seeker, defined as an application-specific compact missile-borne mono-pulse tracking radar whose antenna is mounted on a gyro-stabilized platform such that the antenna is isolated / decoupled from the body movement of the missile. Pulsed TWT based transmitters are extensively used for this type of radar.

TWT is a multi-electrode vacuum device, which is a blend of particle, wave and plasma physics and poses lot of challenges to its power supply for delivering the RF performance for the intended operational life. This is a technology for which very limited information is available in open domain. The challenges in realizing a TWT power supply are elaborated below.

- The design and configuration has to be state of the art with most suitable topology. It should also be realizable with high efficiency and compact packaging. The converter topology selection must also consider the feasibility of Zero Voltage Switching / Zero Current Switching and energy limiting requirements of the high voltage outputs.
- Cater the voltage requirements from few volts to few kilo volts together with large load variations caused by the DC and RF conditions of TWT.
- Maintain filament warm up timing during turn ON and cold filament inrush current limiting. Typical filament warm up time is 3 minutes. Cold inrush current is limited with peak current mode control in Filament converter.
- A fast switching modulator with low propagation delay to pulse the output RF, the modulator switches the BFE from BFE cut off voltage to the beam on voltage with respect to the TTL logic input signal.

II SYSTEM DESCRIPTION

Transmitters for seeker systems are designed for maximum efficiency, minimum mass and size for being state of the art. The transmitters need special attention regarding the design and configuration, closed loop stability of multi converter system, energy limiting of HV outputs, component selection, material selection, HV Potting, fabrication & process control etc. For this purpose study of various technologies related to the transmitter is very important.

Figure 1 X Band transmitter

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

Sl. No	Parameter	Specification

1	Peak Power	80W
2	Phase Noise @ 1kHz away from the carrier	-80 dBc/Hz
3	Prime Supply Voltage	+(28±4) V, 8A
4	Weight	<5kg

Table 1 Transmitter Specifications

The EPC consists of low voltage and high voltage electronics ranging from few volts to several kilovolts. It consists of DC-DC Converters, EMI filters and Protection circuits to protect itself and the TWT. It uses Switch Mode Power Supply (SMPS) technology, which is highly efficient, compact in size and light in weight. These qualities are essential for the requirements of airborne power systems. Special potting techniques are used for obtaining very high electrical isolation.

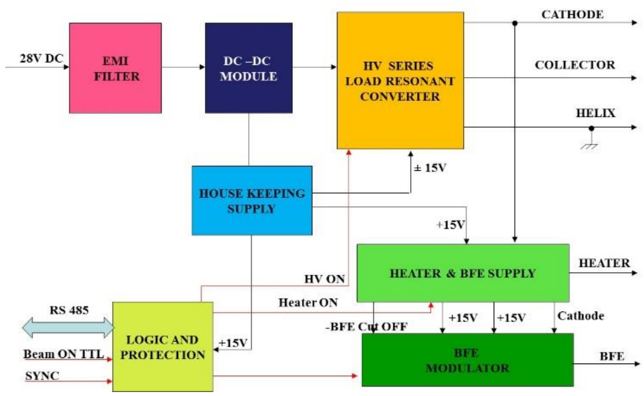

Figure 2 Block diagram of EPC

The main blocks of EPC, are shown in figure-2. The EPC accepts 28V DC input. The input DC-DC module converts this in to a higher voltage DC bus and all other sub modules use this DC voltage as input. The high voltage converter generates the voltage required for the cathode and collector of the TWT. The heater and Beam Focus Electrodes (BFE) converter generates the voltages required for the BFE and the heater of the TWT. A house keeping supply is used for generating V_{CC} required for all other sub modules. The logic and protection circuit monitors all the critical system parameters and protects the EPC and the TWT.

III HIGH VOLTAGE CONVERTER

The power supplies used in TWT transmitters are generally high voltage supplies, which are required to operate with capacitive filters and deliver large peak currents due to the pulsed load [1]. They need tight voltage regulation on pulse-to-pulse basis with very low cathode pulse droop. For airborne transmitter the space is a constraint, which will call for stringent requirement of high power density. Of the various methods of generating the high voltage, Phase Modulated Series Resonant Converter (PM-SRC) seems to be the most preferred converter topology for high-voltage, high-power, and pulsed load applications. The advantages are many such as high efficiency, soft switching, low EMI, ease of control, suitability for wide load range applications, inherent short circuit protection capability and a well-understood topology. Use of constant frequency, phase-modulation control provides controllability of series resonant converter even under no load/light load conditions, which is not possible with variable frequency control [2].

Another important aspect of PM-SRC design is selection of switching frequency. The HV transformer with higher switching frequency seems to be advantageous but the Lr and Cr values becomes too small as compared with the parasitic elements of HV transformer. Manufacturing of these components with accurate reproducibility is a serious concern. Even small variations may result in drastic changes in converter behavior.

Implementation

The specifications of the HV power supply are derived from the TWT requirements. The input DC voltage is converted into high voltage using resonant bridge inverter operating at hundreds of kilo hertz followed by step-up transformer with multiple secondary, HV rectifiers and filter capacitors. The purpose of the inverter in a high voltage power supply (HVPS) is to convert the DC bus into an AC voltage which drives the step-up transformer whose outputs are then rectified to provide the high voltages required for the TWT. The rectified outputs are stacked in series to generate the required high voltage. The duty ratio is varied through phase modulation. The resonant inverter is operated at a switching frequency greater than the resonant frequency; thereby the resonant inverter offers net inductive impedance. This enables Zero voltage switching (ZVS) reducing switching losses in the MOSFET devices and enabling the use of loss less snubber.

High voltage and high pulse current capacitors are connected to the output of the rectifier stage. These are used for reducing the cathode and collector droop and improving the output ripple. The stored energy in the output capacitors is limited to prevent damages of TWT during internal HV arcs in TWT. High voltage section potted with high dielectric material to achieve the HV isolation. The load and line regulation achieved is ±0.1% for the cathode and efficiency of more than 90% at full load. The HV converter provides 100W of conditioned power for the TWT.

IV BFE MODULATOR

Beam switching of TWT can be performed by controlling the BFE electrode. The design of the modulator is very critical because it is floating at cathode potential, special care is required for the high voltage isolation and thermal management of modulator components. The modulator is floating at cathode potential. The TTL pulses are applied to the modulator using pulse transformers. The pulse transformers are selected because of its very low propagation delay compared to fiber optic links.

The main requirements of the grid modulator design are,

a. The circuit must be floating at cathode potential.
b. BFE pulse rise and fall time should be minimum to reduce body current.
c. Should have very low propagation delay from TTL pulse to BFE pulse.

Pulse transformers are used for applying the modulator trigger pulse to floating deck modulator circuit. High voltage wires are used for winding the pulse transformer secondary to get very high voltage isolation.

Two high voltage MOSFETs are connected in totem pole arrangement to switch the BFE voltage from 0V to the BFE cut off voltage.

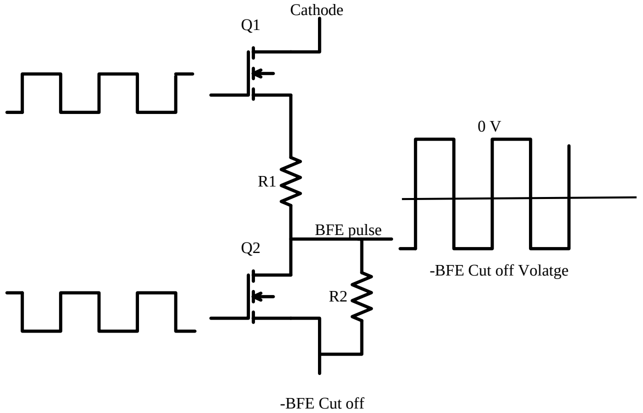

Figure 3 Totem pole arrangement

The arrangement of totem pole switches is shown in figure-3. In 'beam on' condition MOSFET Q1 is ON and Q2 is OFF, in the 'beam off' condition the switch settings are reversed. The switching speed of the modulator depends on the capability of the switching device to charge and discharge grid capacitance of the TWT and output capacitance of the MOSFET. Peak charging and discharging current of the MOSFET will be very high to get very low rise and fall times. Resistor R_1 will prevent cross conduction of Q1 and Q_2 MOSFETs. Resistor R_2 is a pull down resistor which ensures that a cut off voltage is available during the fault condition when Q_2 goes open circuit.

Power handling

The power dissipation of the modulator transistors includes dissipation due to the current drain of the BFE electrode, as well as the energy losses associated with charging and discharging the BFE electrode and the switching MOSFETs themselves [14]. The resistive losses in the MOSFET are less because the current required for the BFE is very less, but the capacitive switching losses will be higher depends on the Pulse Repetition Frequency (PRF). The Q_1, Q_2 MOSFETs each will dissipate a power P, where

$$P = \frac{1}{2}(c.v^2.\mathrm{f})$$

c = sum of MOSFETs output capacitance and grid capacitance
v = total grid voltage swing
f = maximum PRF

V LOGIC AND PROTECTION

The main functions of the logic and protection circuitry are,

- Maintains proper switching ON/OFF sequence for safe operation.
- Real time interlocking of control parameters and initiating necessary corrective action.
- Checking the status of sub-units in various modes.
- Detection of the various faults that may occur in a transmitter and reporting the status to a remote terminal.
- Interfacing the transmitter with other sub-units.

The logic and protection unit always monitor all the critical parameters like, temperature, helix peak and average current, inverter current and cathode voltage etc. The unit processes all the commands from the seeker controller and sends all the required status information to the seeker controller.

VI RESULTS

The X transmitter has been realized in a compact size and weight of 4.6kg. Transmitter has been tested for the full specification and delivering 80W peak power. The figure 4 shows the RF output spectrum.

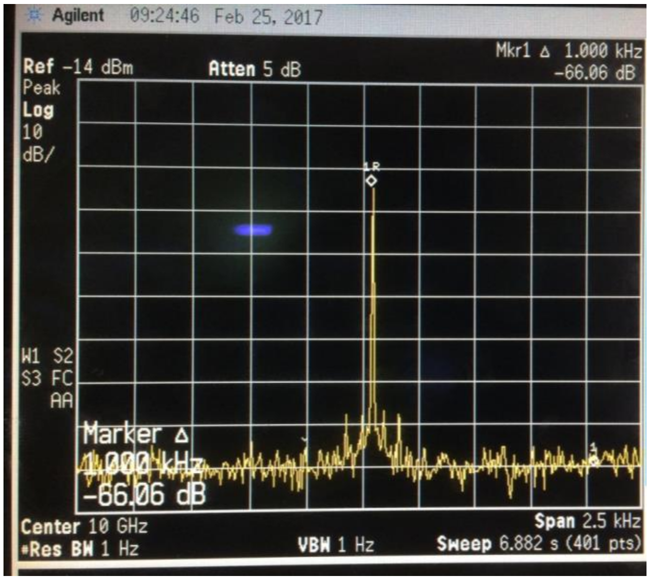

Figure 4 RF output spectrum

VII. CONCLUSION

A compact TWT based X band Transmitter using state of the art technology for Active Radar seeker has been realized. The transmitter is qualified for EMI/EMC requirements as per MIL-STD 461E and ESS is in progress.

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