Analysis of High Power Ku Band Magnetron Based Radar Transmitter

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Abstract

The Magnetron is an efficient oscillating microwave device that is used to generate high-power electromagnetic energy at microwave band in radar technology. A magnetron is used in various applications due to its compact size, lightweight, low cost, long life and have so many benefits compared to other cross-field oscillators or liner beam amplifiers. Magnetron has few limitations also, like frequency instability and thermal variation effect. Based on the previous literature survey, so many methods are adopted for multi-cavity tuning, thermal stability, and amplitude and phase control of magnetron. In this paper, we put focus on the coaxial cavity magnetron transmitter which is commonly used in modern pulse Doppler and navigational radar technology. The purpose of this analysis is to present a practical field report on the performance of a Ku band coaxial magnetron based transmitter by measuring the key parameters especially concerning its tuning mechanism, HV regulation and output peak power of magnetron with its safety precaution, common faults, and their remedial action and maintenance of magnetron transmitter by knowing the transmitter behavior with a brief on operation and design concept of the magnetron and the radar transmitter.

Keywords
Magnetron, Microwave, Tuning, Radar, Transmitter, Regulation

1. Introduction

As the radar history, the invention of the magnetron transmitter was introduced in the late 1930s that can operate at the higher frequencies called microwaves. In the era of microwave technology, there are various microwave devices for oscillating as well as amplifying the microwave signal like various solid states MW transistors and other cross-field devices. These cross-field devices were followed by linear beam tubes e.g. Klystron, TWT, etc. The klystron amplifier is capable to amplify the high power level used in radar (several KW average powers) with good efficiency and stability. The main disadvantages of the klystron are high power consumption and narrow bandwidth. The traveling-wave tube (TWT) is a new advancement followed by klystron in the field of microwave amplification systems. It has a better combination of wide bandwidth, power output, and gain at a weak signal. But, the peak power levels are increased with decrease bandwidth. TWT has the limitations of its cost, weight & size for high output power, complexity in construction & installation, high power consumption, difficulty to repair & maintenance. Solis state transmitters, such as the transistor are attractive due to their long life, ease of maintenance, and relatively wide bandwidth. But, have some limitations like as accomplished only for relatively low power in short-range radar application and no suited for high power long range at short pulses (micro sec) by an individual solid

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stage. Short pulses are suited for radar operation because signal processing (pulse compression) is required to achieve the desired range resolution.

Each kind of transmitter has its advantages as well as its limitations. In practical, a magnetron transmitter is (efficiency is up to 70%), compact design, low cost, size & weight, long life, easy to maintain, and suitable for short pulse-Doppler radar which is capable to detect the moving target in presence of noise. Hence, such a type of radar-based transmitter is the backbone of radar systems especially in pulse-Doppler radar for military radar applications and navigational equipment.

1.1The Area of analysis

A radar transmitter using a microwave oscillating device like magnetron requires a high-power dc source up to several KV to generate RF output. The HV power source is a major consideration part of a transmitter to obtain satisfactory performance. The pulse radar transmitter produces the short duration high-power RF pulses of energy that radiates into space through the antenna which calls for a suitable energy storage capacitor and inductors operating under high altitude and humidity conditions. Hence, there is a vital need for specific high voltage engineering during the design & construction of it to prevent the unusual loss and partial discharge effect.

The major attractive subunits of a magnetron transmitter under analysis are the HV unit with its regulation used to overcome the pushing effect resulting in increasing the frequency stability of magnetron and servo tuning mechanism performance with a deviation of its every spot of freq. LC filter, HV transformer, rectifier and divider, protection assembly, PFN, fast-switching devices like thyratron and magnetron are the other crucial part of the transmitter. In general, a liquid dielectric is used for compact design HV transformer and PFN for a long time considering its ability to remove heat by convection, good dielectric strength, and its insulation restoration properties to reducing the EMI/EMC factor.

1.2 Industrial significant:

A magnetron is generally used in various MW applications mostly in radar sys to spot the enemy target, submarine periscope, and ship in the dark used by military and naval forces of many counties around the world. A magnetron is also used for home appliances such as microwave ovens, for lighting such as sulfur lamps, in medical with MW radiation such as LINAC, and the industry for lighting and heating purpose. The growing market of communication, medical and smart home appliances are driving the growth of the global magnetron market significantly. Magnetron market can be categories into two broad categories. First, by end-user type, second is by type. End-user types can be categorized as telecom industry, aerospace industry, and defense industry, electronic and mechanical industry. By type, the global magnetron market can be segmented into negative resistance, cyclotron frequency, and cavity magnetrons.

1.3 Contribution

This project work is carried out on a real working radar transmitter to provide the actual field performance report compared with its performance characteristics given by the manufacturer which is helpful to design and construct such a magnetron-based indigenous radar or abroad and other various fields like medical, industry and appliances. The field report on magnetron handling, maintenance, and common faults finding of the transmitter are also helpful to reduce the failure rate and increased the mission reliability of servicing radar. This performance report basis on measurement can be a better input for developing a computer simulation program of the radar sys.

1.4 Organization of this paper

Chapter 1 comprises the introduction of a magnetron transmitter comparison with others, its area of analysis, industrial significance, contribution, and organization of this paper. **Chapter 2** contains a brief description of the magnetron transmitter with their performance characteristics on which project work is carried out. **Chapter 3** presents the measurement and result from the summary carried out. **Chapter 4** deals with its conclusion and the future scope of this study in the relative field.

Chapter 2: Transmitter having magnetron under analysis

This chapter comprises the details of the coaxial magnetron-based radar transmitter on which the analysis is based.

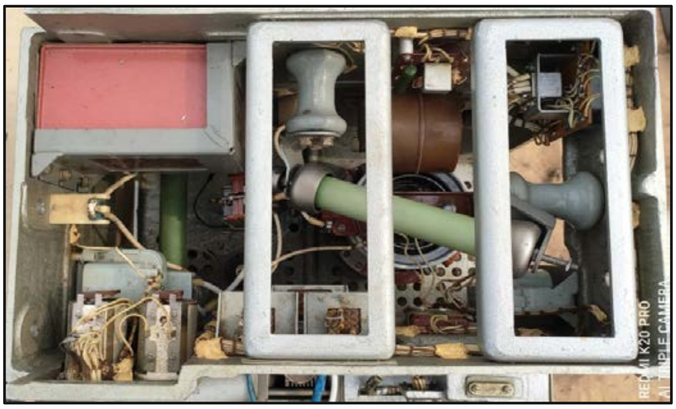

Fig 1: Transmitter Unit

2.1 Transmitter performance characteristics: The high-power magnetron transmitter system key parameter is summarized below.

Operating frequency	6 x spot microwave frequency (Ku Band)
RF peak power	More than 90 KW
Input power	3 Phase, 220V, 400Hz
Filament voltage	6.3V
Cooling system	High RPM blower, 400 Hz supply
RF duty cycle	0.1 %
Pulse width	0.26 micro sec
PRF	3750 Hz
Repetition frequency (Wobbling)	3750 to 2500 Hz
Load SWR	1.35
Warm uptime	3 min
trigger pulse amplitude	15 to 20 v
Trigger pulse duration	0.5 to 1 micro sec

Table 1: Technical description of the transmitter

2.2 Description of transmitter:

This transmitter subsystem is capable to transmit over the 6 x predetermined spot frequency over a Ku band and is capable of being tuned for each frequency by a frequency control servo mechanism. This transmitter unit consists of the following units.

(a) Sub Modulator comprises emitter follower, blocking oscillator.
(b) Modulator containing magnetron, thyratron, tuning mechanism, and PFN.
(c) High Voltage Unit with protection assy.

(d) HV Regulator for regulation of HV DC source for magnetron
(e) Power Supply Unit (-12V, -125V, +250V and, +1.5KV) and cooling system

Sub Modulator is responsible to shapes the trigger pulse of 0.5 to 1 micro sec with 15 to 20 volts and provides the amplitude and duration necessary to the control of the modulator. A modulator is used to switch the RF energy and operate the magnetron in such a way that transmits for a short pulse of duration. The high voltage unit provides the +20 KV to charge up the storage capacitor through the charging resistor of the modulator necessary to the magnetron operation. The stabilization of the power line is due to an automatic increase in high voltage, which is accomplished by the regulator unit. A servo tuning mechanism is used to tune the magnetron over a stable local oscillator. There are many analyzing assemblies shown in the figure below.

Fig 2: HV regulator Unit

Fig 3: Thyratron

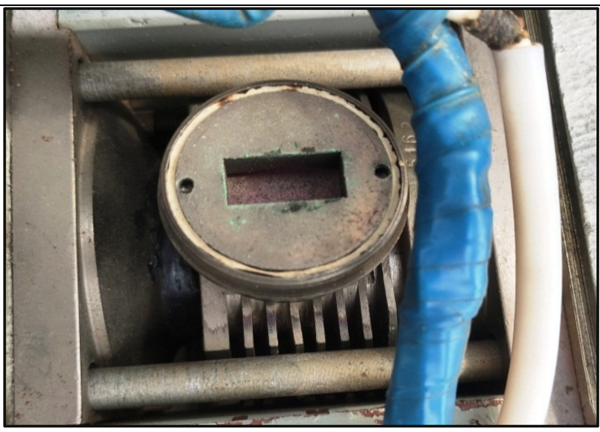

Fig 4 : Magnetron slot

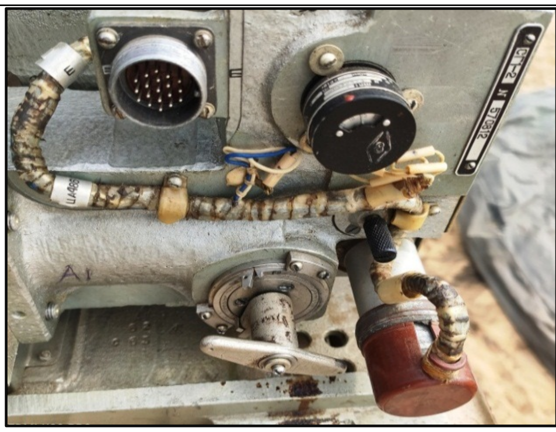

Fig 5: MAFC mechanism

Chapter 3: Measurement and results:

3.1 The Transmitter unit is tested and results are summarized as:

Connection	Reading	Remarks
Cathode to ground	Very high resistance	OC
Anode to ground	Very high resistance	OC
Filament	Very low resistance	SC

Table 2: Cold test of transmitter block

Ser No	Input power supply	Regulator output (160v to 230 v AC)	HV reading	Remarks
(a)	220v, 3 phase, 400 Hz	160 v	17 KV	Pass
(b)	220v, 3 phase, 400 Hz	170 v	17.5 KV	Pass
(c)	220v, 3 phase, 400 Hz	180 v	18 KV	Pass
(d)	220v, 3 phase, 400 Hz	190 v	19.5 KV	Pass
(e)	220v, 3 phase, 400 Hz	>190 v	Switch off the transmitter due to energization of a safety circuit	Transmission troubled due to overloading of HV rectifier.

Table 3: Testing of HV regulation circuit

Ser No	Freq channel	Test signal strength (Rx sensitivity up to 80dB for microwatt signal)	result
(a)	F1	Max	Tuned
(b)	F2	Max	Tuned
(c)	F3	Max	Tuned
(d)	F4	Max	Tuned
(e)	F5	Max	Tuned
(f)	F6	Max	Tuned

Table 4: Testing of a magnetron tuning circuit

Frequency channel	RF output power (dBm)	Results
F1	79.7	Pass
F2	79.7	Pass
F3	79.7	Pass
F4	79.6	Pass
F5	79.6	Pass
F6	79.5	Pass

Table 5: RF power measurements

General faults	Probable reason	Remedial action
Magnetron Arcing	Waveguide arcing & Shunt diode failure	Examine and check for corrosion, pressure, dirt & Replace diode
Twinning	Thyratron failure, trigger pulse missing	Replace the thyratron& check the trigger.
Magnetron Erratic	HV DC failure	Check HV transformer, rectifier, and regulator & insulation resistances
Pulse collapse	Defective storage network	Check capacity
No transmission	Mag temp too high or low	Check cooling sys & adjust the mag current

Table 6: Common faults finding

3.2 Waveform characteristics of the transmitter

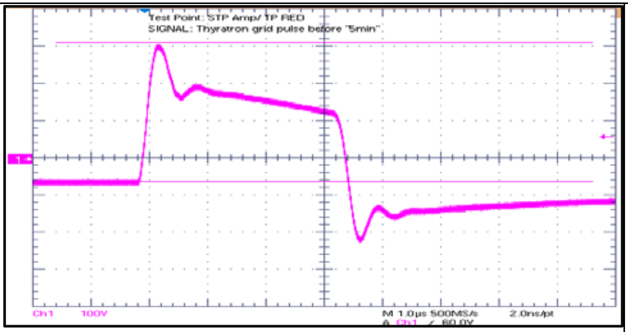

Fig 6: Thyratron grid pulse

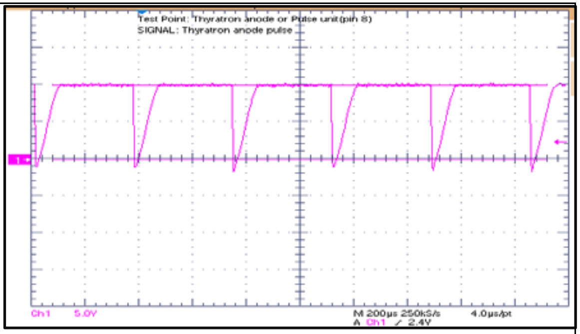

Fig 7: Thyratron anode pulse

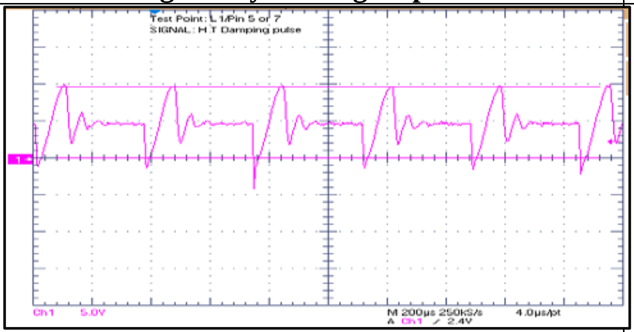

FIG 8: HT damping pulse

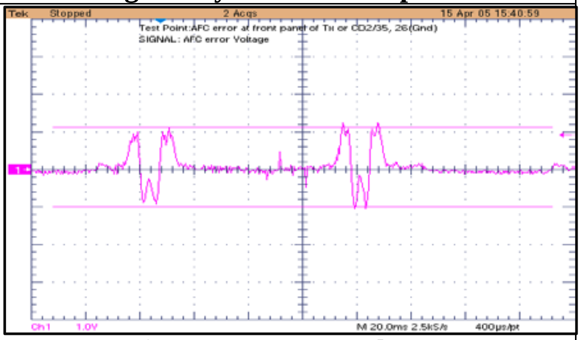

Fig 9: AFC error voltage

3.3 Precaution and safety measures: General safety and radiation hazards of the high power microwave measurement/repair are as under:

(a) Ensure, the p/s must be switched off before dissembling the parts/ components.
(b) HV unit capacitor charged up to 20 KV due to residual volt after SW off the p/s.
(c) During operation conditions, the transmitter door cover should be closed and the door switch activates the transmitter as a safety circuit.
(d) Don't touch the transmitter block with a naked hand and neither put an electrical or magnetic device nearby magnetron.
(e) Personal should never stand nearby and in front of radar ant during Transmission.
(f) It should be advised to avoid the end of an open waveguide when turned ON.
(g) EM energy radiated beam heats the skin causes may pain without lasting damage and sign, while muscle, nerves, and blood vessels may be significantly damaged.

3.4 Maintenance: Handling of magnetron:

(a) Avoid any mechanical and vibrating shock directly it can damage the device.
(b) Avoid the direct contact of any magnetized and conductive materials.
(c) Maintain the space gap bet's lead wires and chassis to avoid the HV breakdown.
(d) Operate the magnetron under specified operating conditions.
(e) Provide adequate cooling and limit the system which induced high VSWR.
(f) When installing the new magnetron, the filament should be warm up to 8 hrs. appx.
(g) Never operate the magnetron at operation direct unless the warm-up ready status (a specified time) lamp glow of the system.
(h) Season the magnetron after a long period of storage.
(i) Dispose of the magnetron after it reached to end of life specified.

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5. References

IoT is a network of physical objects or "things" that contain embedded technology to enable these objects to collect data, creating opportunities for more direct integration between the physical world and computer systems. In other words, the result of the IoT is automation in all fields (Santhi, 2016). The idea of IoT was developed in parallel to Wireless Sensor Networks (WSNs), therefore, Applications of the WSNs include monitoring a wide variety of ambient conditions like temperature, humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, in the military for target field imaging, earth monitoring, disaster management, fire alarm sensors, sensors planted underground for precision agriculture, intrusion detection and criminal hunting (Bakaraniya, 2012), (Kaur, 2016), (Akyildiz, 2010). Applications of IoT frequently perform data analysis and real-time predictive analytics. Hence, the integration of IoT technology with radar and other MW devices can be new advancement in modern technology.

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