Technical Report on

400W RF Power Amplifier for Linac

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TECHNICAL REPORT

TITLE **:Technical Report on 400W RF Power Amplifier for Linac (revised)**

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Technical Report on 400W RF Power Amplifier for Linac

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Abstract:

A solid state VHF power amplifier capable of delivering 400 Watts (CW) to superconducting Linac has been developed and mass produced successfully with state of the art RF components. The amplifier is capable of withstanding high standing wave ratio usually experienced in powering superconducting Linac resonators. The modular design of individual amplifier blocks make the maintenance and enhancement easier.

Acknowledgment:

We sincerely acknowledge the support provided by Apprentice Trainees from Workshop and Electronics laboratory at various stages, and constant encouragement by Dr.Amit Roy, Director, IUAC in order to successfully complete this project. We also acknowledge the vendors in supplying machined parts, PCBs, panel preparations.

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Specifications:		**Modular 400 Watts RF Amplifier**
Frequency Range	:	70 - 130MHz (-3dB Bandwidth)
Gain Flatness	:	± 1.5dB
Impedance	:	50 ohm
Power Output	:	+55dBm or 350 watts (CW)
Power gain	:	> 55 dB
Drive level	:	~0 dB m @ 350 watts, Not to exceed +20dBm.
Gain Matching	:	±0.5dB
Phase roll-over	:	20 deg. (50W-350W)
Mode of Operation	:	Class AB Linear
Operation Voltage	:	+34 Volts
Efficiency	:	Better than 50%
VSWR	:	1:∞
Harmonics	:	Better than 32dB down (2nd, 3rd harmonics)
Protection	:	Over temp. 60 Deg. (n.c) on each module,
DC Power	:	+34 Volts/35A, +24V/.2A (Control card)
AC Power	:	180-240V, 50 Hz, Fuse: 5A (SB-5x20mm)
Quiescent Power	:	~100 Watts
Power Monitor	:	Panel meters (0-400 watts), Coupled ports (-27dB) BNC
Connectors	:	BNC (Input), N (Output)
Cooling	:	Water Cooled (room temperature) 2- 4Litres / Min, Forced Air Circulated.
Cabinet	:	19" x 3.5" x 18"(WxHxD)

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Introduction:

The resonator cavities along with control circuit of the *Linac* accelerator at Inter University Accelerator centre require up to 350 Watts of power at 97 MHz to stabilize the RF phase and amplitude in it. Wherein the superconducting resonator accepts only 4 to 6 watts of applied RF power and the rest is reflected back to amplifier. We have designed a 400W amplifier for this purpose and fabricated 30 pieces. It uses a circulator and dummy load to protect the amplifier from the reflected power. In order to limit the power output to 350Watts, over drive limiting circuit is also implemented. The power monitoring is possible though coupled ports, Power meters on front panel as well as remote read out on rear panel.

Operation:

The power amplification is done in cascade as shown in a block diagram. RF input accepted through the rear panel BNC connector and pre amplified to a level of ~1 Watt. This stage also includes the voltage controlled attenuator for OVER DRIVE LIMIT operation. Further amplification is done in a VHF core module up to 15- 20 watts. The final power is obtained by combining power from two identical RF power blocks using quadrature power combiners made from Sage Wireline[1]. The input power to these amplifier blocks are split in quadrature.

The VHF core amplifier is built with MRF 151G, a dual RF Power MOSFET [2]. The device is rated for 300W when operated at 50 Volts and the maximum voltage it can withstand is ~125 Volts (VDS_{MAX}). These devices are operated at 34V to deliver around 175-200 watts of power. These devices are input and output matched with transmission line type transformers. In order to operate the amplifiers for optimum linearity and efficiency, the power transistors are biased for Class AB operation. Idling current of 0.5 A at +34 Volts (Vdd) is set through potentiometer at ambient temperature. It is essential to tune the power amplifier output stages, to maximize the power delivery with good efficiency.

Control Circuits

The control circuit board is provided to generate auxiliary power and generate various power monitoring, status read and over drive control signals. The control card also supports remote control as well as remote read back options.

DC Supply: The card generates +24V, +15 Volt supply lines for powering Control relays and control circuits and the Gate control voltages (V_G) for RF Power MOSFETs.

Thermal Control: In order to safe guard the power devices from thermal damage, the devices and power modules are mounted on a water cooled heat sink. In case of water flow failure, the power amplifier is shut down and indicated suitably on panel. This is accomplished by monitoring temperature on heat sink at various places through Thermal switches, which operate at 60 degrees. In case of switch failure the DC power supply is remotely shut down. The appropriate relay contacts are also made available through remote control port. It is essential to have copper heat spreader to remove the heat from transistor die for effective thermal protection of the devices.

Remote On/Off: The remote control of RF power amplifier is essential for control from Linac Control room. Upon shorting the appropriate pins, the DC power to power amplifier is supplied, else shut down with suitable indication on front panel. The appropriate relay contacts are also made available through remote control port.

Power Metering & Control: It is essential to know the actual RF power flow in forward and return directions. Various options are available to monitor power flow. The actual RF power is monitored through a dual directional coupler which is mounted inside the power amplifier side panel. The coupled ports (-27 dB) are routed through the directional couplers (-10dB) mounted on a control card. The sampled RF on both ports are converted to DC by high frequency full wave rectifier circuits. The developed DC is suitably buffered, amplified for Front panel read out, as well as made available for remote read out through control port. The buffered signal is further processed to activate the OVer Drive

and associated circuits, once the power exceeds the set limit. This is accomplished by various controls like OVD limit, VCA bias current etc. The appropriate relay contacts are also made available through remote control port in order to indicate this status.

Housing: The RF power blocks are mounted on a fine surface finished 5" x 2.5" x .5" copper heat spreader. These power blocks, Circulator and dummy loads are mounted on a finely surface finished water cooled aluminium heat sink. The regulated DC power is supplied by a commercially available SMPS units capable of delivering power up to 900 to 1000 watts and rigidly mounted on heat sink. In order to have free air flow in and out of the cabinet, the openings ae made on side as well as front panels. A high quality IC fan is mounted on rear panel to blow air on the RF power combiner.

Wiring: The interconnections of various power RF blocks are done through conformal coat Beldon coaxial cables. The interconnection of high power blocks are done through PTFE type high temperature coaxial cable with N connectors. The control wiring is done with PTFE type hook up wires for reliable operations. The DC carrying wires are of high current type and suitably bolted and soldered on their ends. The various lengths of wires are listed elsewhere in this report.

PERFORMANCES:

Each unit assembled are tested for their performances and reliability by burn-in test under worst load conditions for more than 72 hours. Some of the performance curves are given in figures, where typical transfer characteristics and harmonic contents at full power output are shown. The phase shift and power compression are also shown within rated power range of 35 to 350 watts. In order to show the reproducibility the transfer characteristics of three different amplifiers are shown in a plot and the characteristics of pre driver amplifier with Voltage controlled attenuator are shown, based on which the Over drive limit circuit is tuned. The addition plots show the output power and corresponding local RF sample port signal (RF) and remote voltage readback (DC).

REFERENCES :

(1)http://www.sagelabs.com/

(2)http://www.onsemi.com/

(3)http://www.polyfet.com/

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PHOTOGRAPHS:

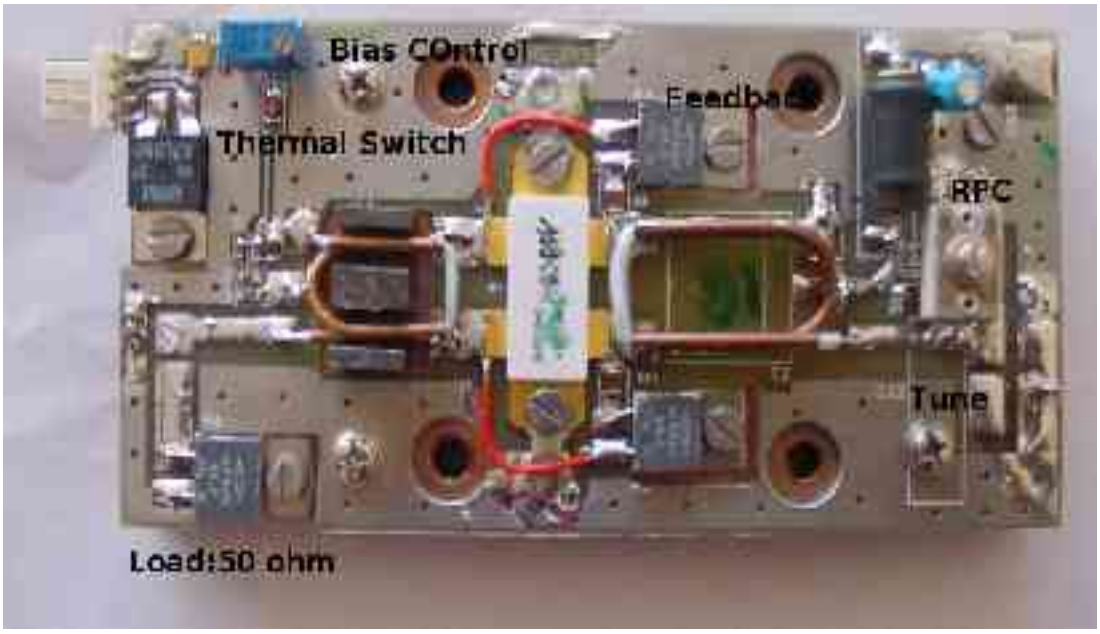

Fig:1 Single RF Amplifier Block

Fig: Transformer Making components, Tools & Soldering Procedure

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Fig: Transistor Heat sink mounting technique

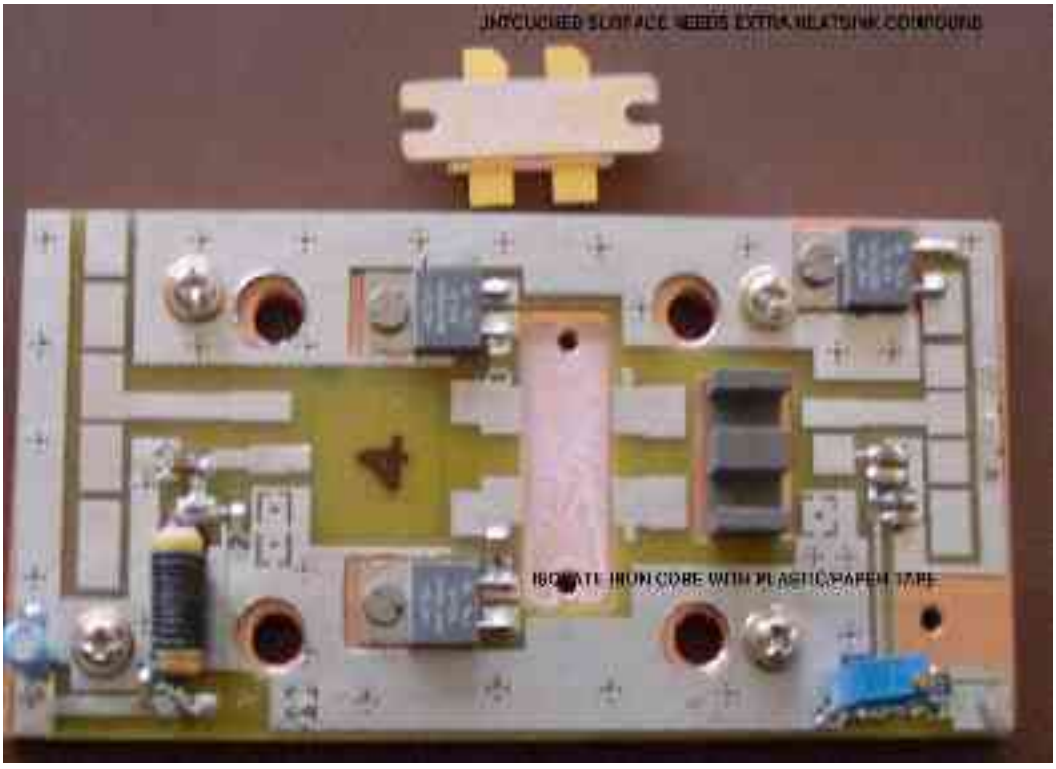


Fig: Mounting technique of Heat spreader on Heat sink

Fig: Front view of Amplifier

Fig: Rear view of Amplifier

Fig: VHF Pre-Driver Amplifier

Fig: Inside view of RF Amplifier

Fig: Setup for Idling Current Setting of MOSFET.

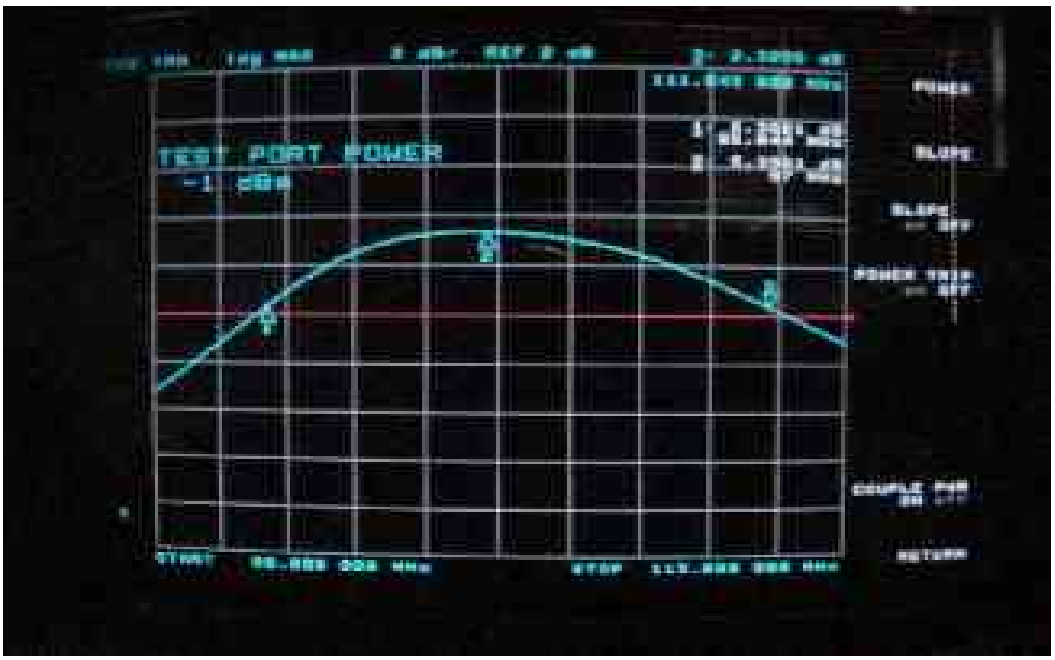


Fig: Magnitude Plot of RF Power Amplifier @ 400 Watts (#30)

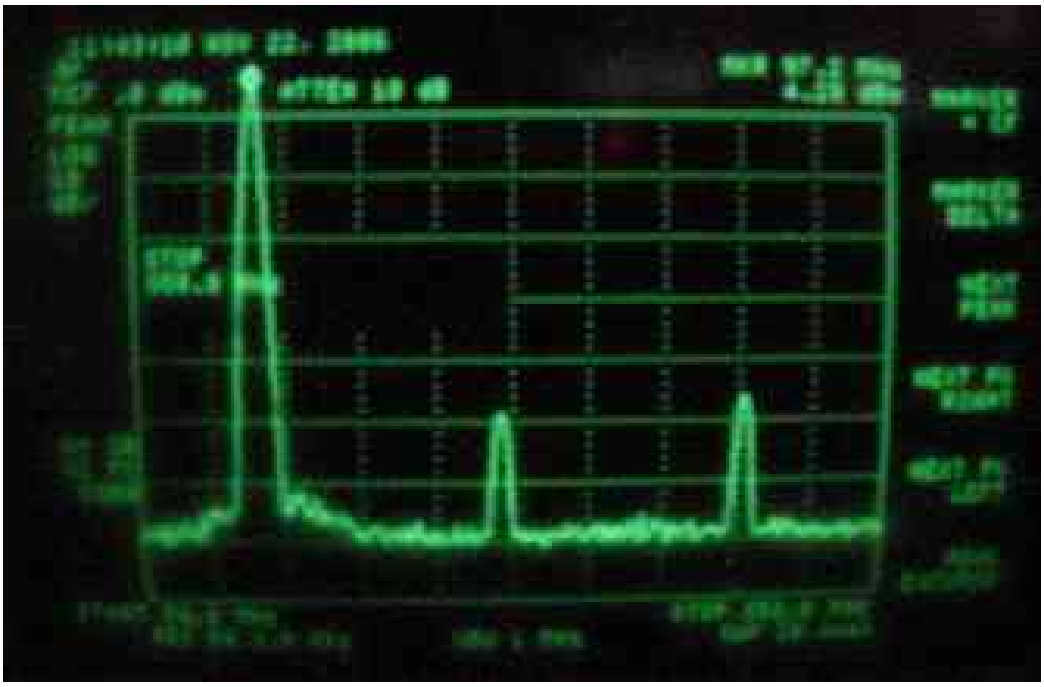
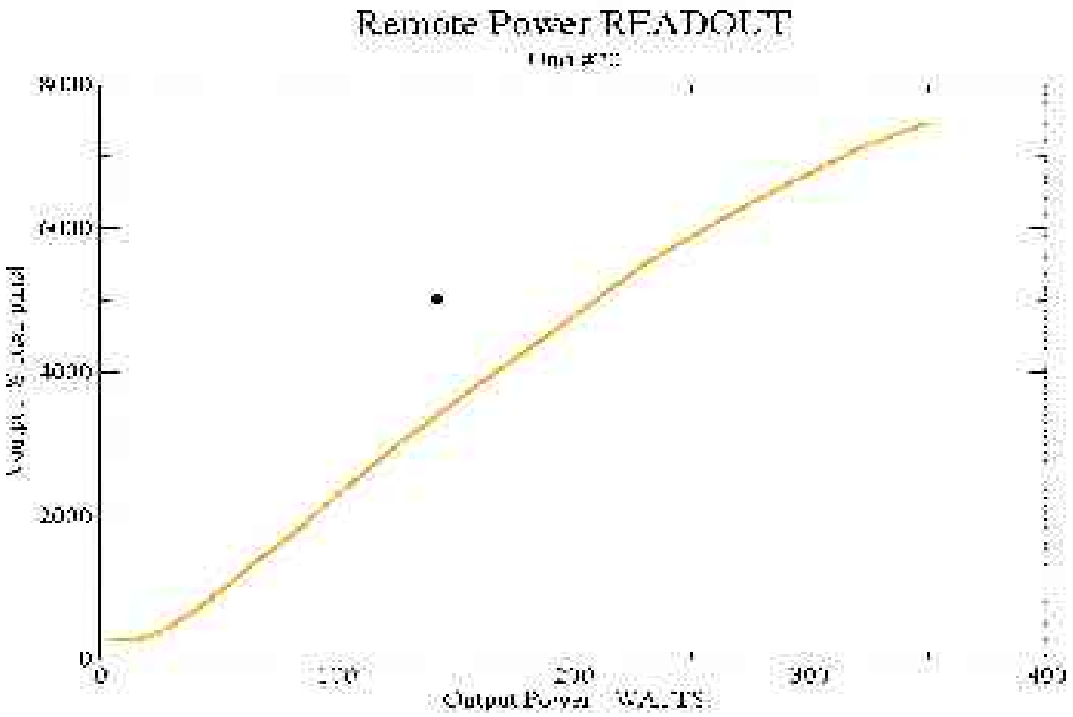
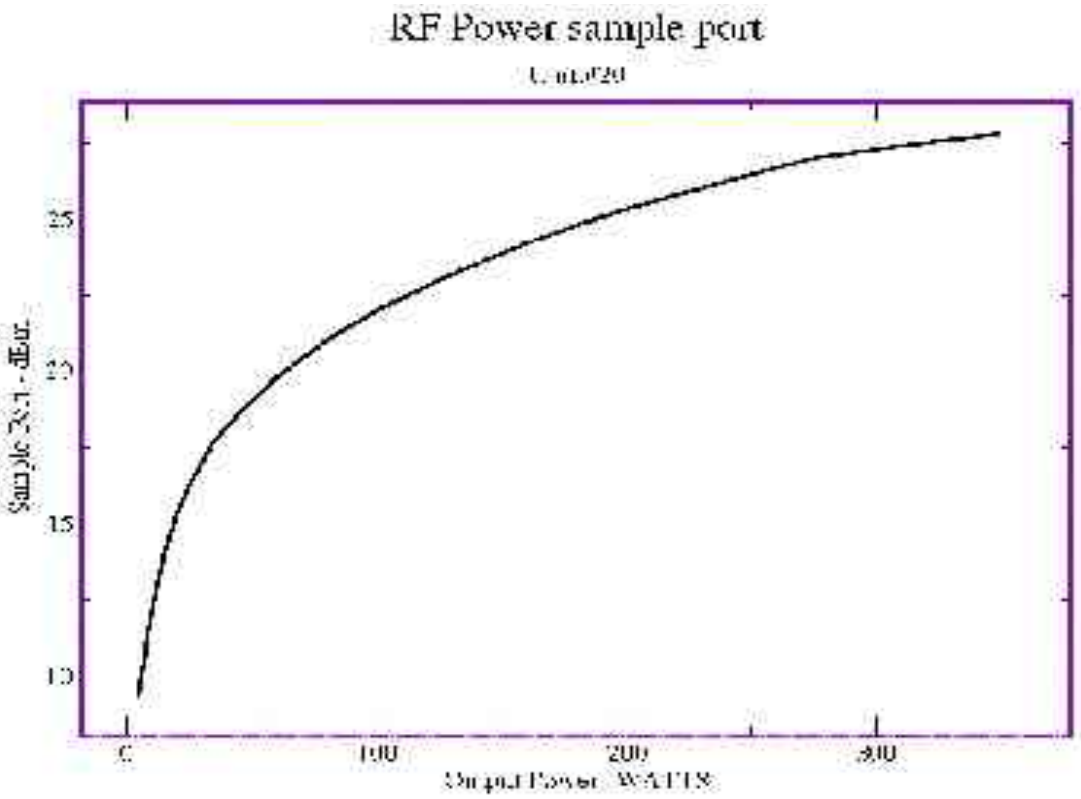


Fig: Power Spectral Density of Amplifier @ 400 watts, 97MHz (1st) (#30)





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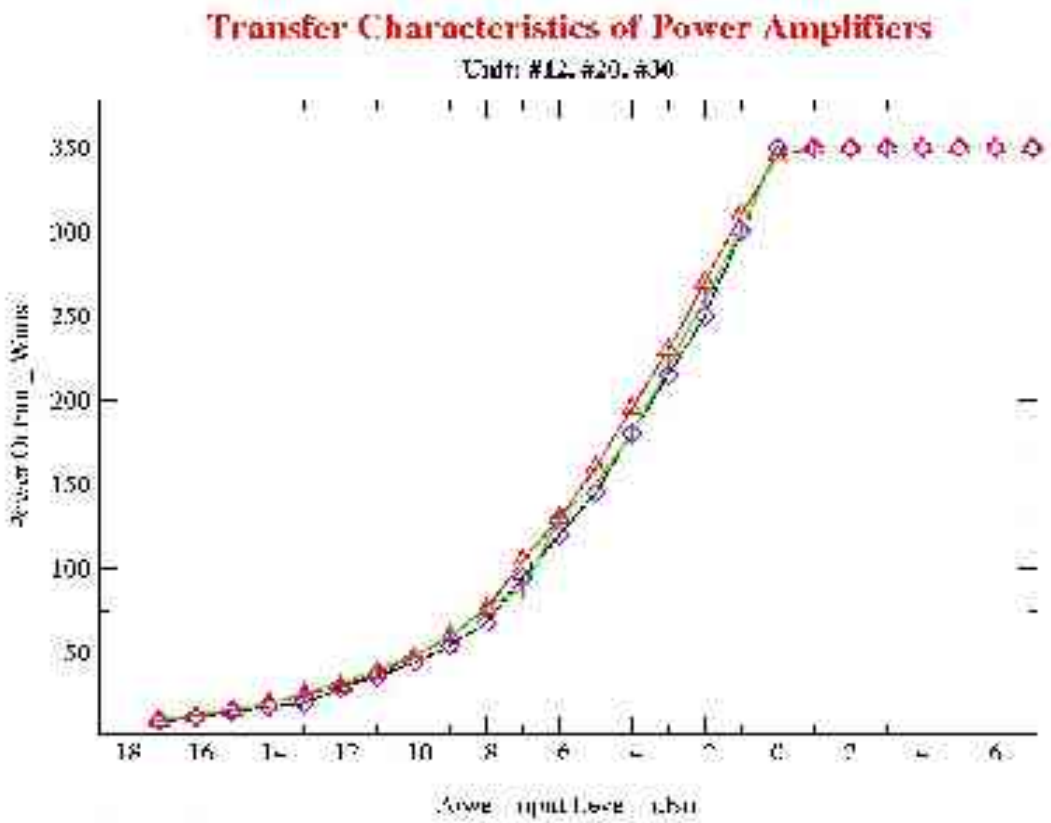

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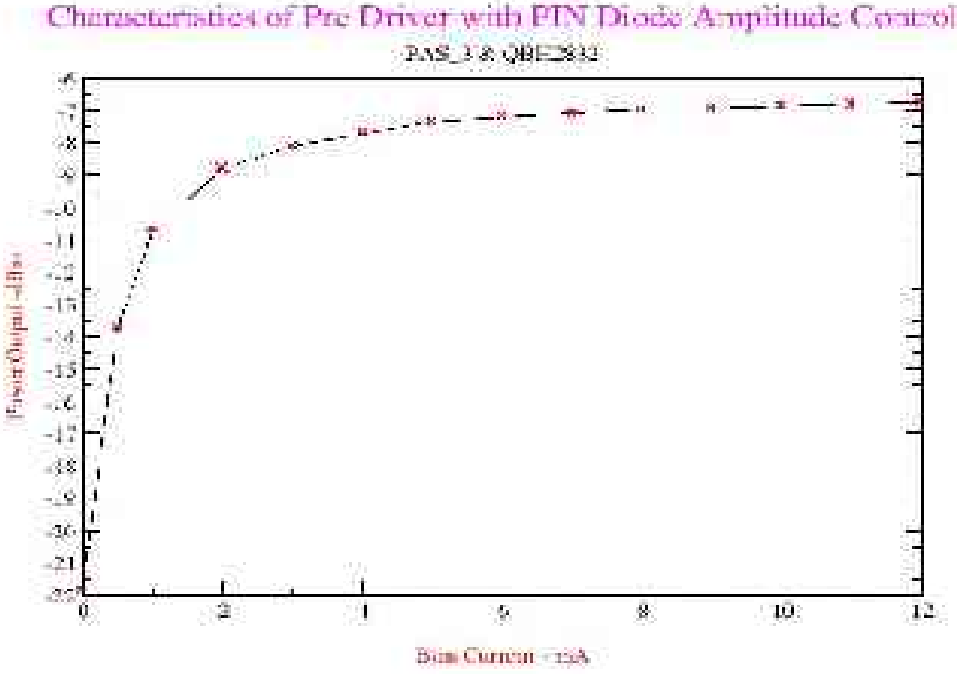

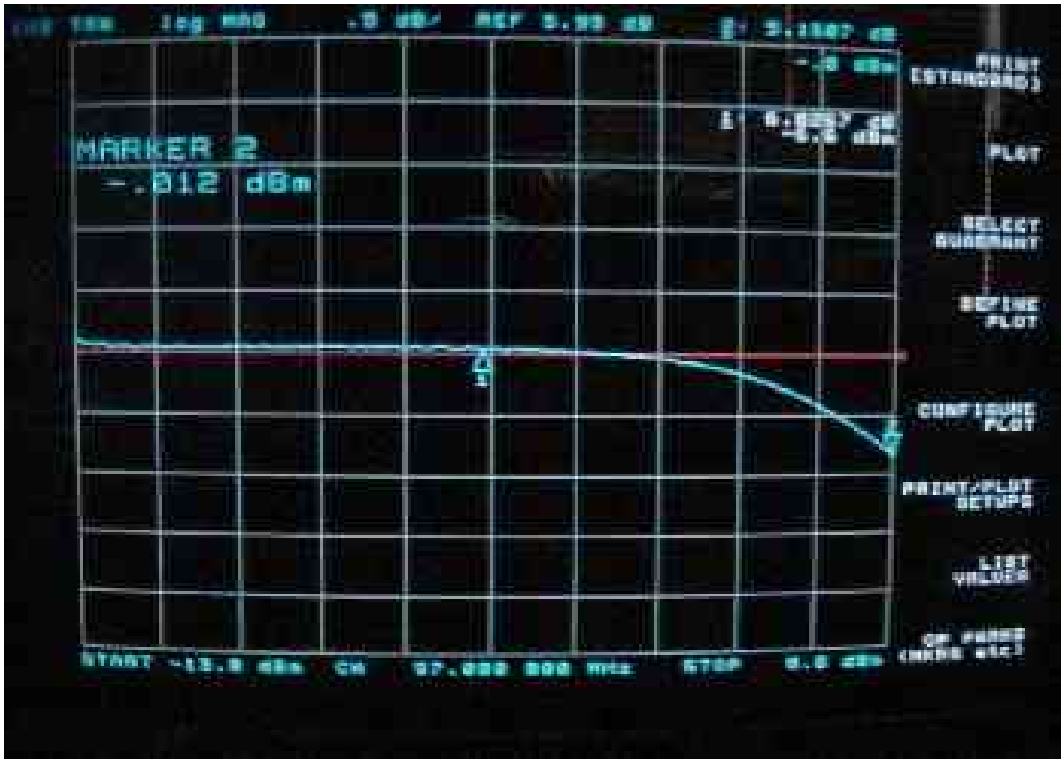

Fig: Power Sweep between 35 to 350 watts (#30)

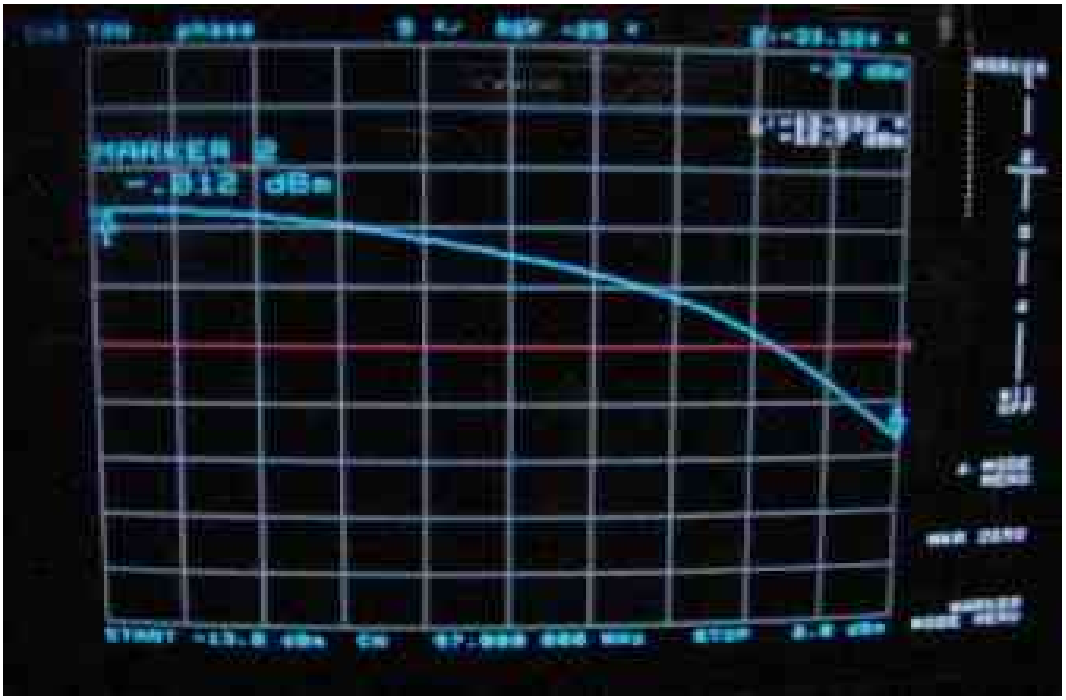

Fig: Phase response of RF Power Amplifier between 35 to 350 watts (#30)

Troubleshoot guidelines:

Upon receiving the feedback from user, please ensure that the unit is not opened or altered by anyone.

1. Check for any visible or problems with inter connecting cables.
2. Disconnect- the main power supply and CHECK FUSE – REPLACE with 5A/230Vac SB Type fuse if found faulty.
3. Check for internal visible symptoms:

   Dark/Black spots due to arching, shorting etc.

   Loose wires, Solder splinters etc.

   Burned parts / components, Tracks on PCB

   Poor connector termination, Loose interconnection, Wiring etc.

   Make use of Ohm meter in Multimeter for this purpose.
4. If found alright,

   Power the unit, and check for

   Auxiliary supply lines form Control card: +24V, +15V, +5V

   Pre set point voltages for OVD operation, Bias current for VC Attenuator

   Gate bias VG reaching each input matching transformer. (2.5 to 3 volts)

   Supply Voltage +34.0 Volts reaching output transformer.
5. If VG line Open or short: Rectify the fault.

   If GATE to SOURCE is shorted (otherwise: 10Kilo ohms), replace MOSFET

   If Drain to Source-Gate os Shorted or Open replace it with good MOSFET.
6. If all seem to be alright: Ensure that without any Input power, Idling current from DC supply is ~1.5Amperes DC.

   If NOT: Excess current is due to Spurious Oscillations.

   Less currnet is due to faliure of one or more MOSFETs.
7. Oscillation is due to poor impedance matching between amplifier stages. This is solved by isolating the problem causing unit by removing interconnections between amplifier units.
8. Oscillation is mainly due to faliure of interconnection within that circuit block, or due to external / stray feedback. That needs careful study to fix the problem.

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9. If amplifier is fixed, Tune the amplifier for maximize the power.
10. Calibration of Power amplifier with Signal geneator and power meter is essential.
11. During calibration, also check the DC power intake for efficiency calculation, with DC clamp meter.
12. Check for status readback, OVD operation, OVD Limitfor 350Watts @~dBm etc
13. If all found alright, Close the unit, check for its thermal shut down operation, under open load condition for one or two cycle.
14. Mandatory: Record the history of troubleshooting, repair in the register **neatly**. That shall include:

    Unit Number appear on its rear side.

    Symptoms... Idling current, meter reading etc.

    Action taken in brief

    Calibration done or not

    Thermal shut down cycle done or not.

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