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HIGH-POWER MICROWAVE DIAGNOSTIC SYSTEM BASED ON COMPACT, SINGLE-UNIT, RADIATE-AND-RECEIVE DEVICES

Todd A. Treado, Richard S. Smith III, Wesley O. Doggett*, and David J. Jenkins

Varian Beverly Microwave Division, Beverly, Massachusetts 01915
*North Carolina State University, Raleigh, North Carolina 27695

ABSTRACT

Two unique S- and C- band waveguide radiate-and-receive systems were developed as multioctave diagnostics and vacuum loads for high power microwave bursts (> 150 MW) emitted from relativistic magnetrons. The compact devices (< 1 m^3) did not require an anechoic chamber. The complete HPM diagnostic system is described.

INTRODUCTION

The diagnosis of high power microwave (HPM) bursts has been the subject of considerable attention for the last decade [1-4]. The transmission, containment, and measurement of single-shot, short pulse (nanoseconds to hundreds of nanoseconds) microwave radiation at extreme power levels (hundreds to thousands of megawatts) has prompted the development of new microwave techniques. In order to fully characterize an operating high power microwave source, the pulse shape and length, the power and frequency spectra, and the modes of operation and transmission must be measured with electric field levels in the output waveguides up to hundreds of kV/cm but at energy levels of less than a hundred joules.

We report on two new rectangular waveguide radiate-and-receive (RR) systems which were developed as part of an HPM diagnostic system. The 50 ns, 0.1 GW relativistic magnetron experiment is shown in Fig. 1 with power coupled from the magnetron out of the back of two opposite vanes into evacuated S-band waveguides [3]. The RR systems terminated the waveguide sections, serving both as diagnostic elements and microwave loads. A 60 dB, S-band directional coupler was also used for signal sampling from one of the waveguides. Power was measured simultaneously using mixer and diode

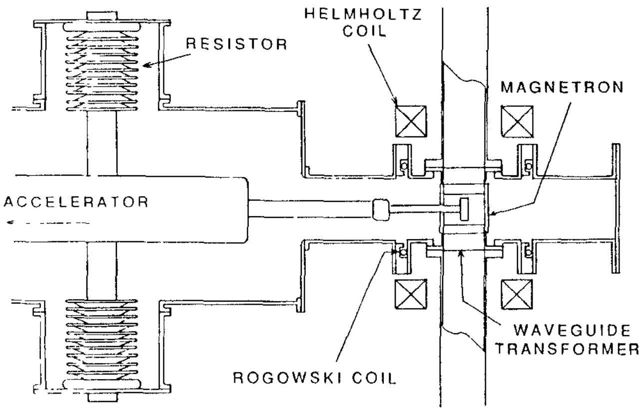

Figure 1. Relativistic magnetron experimental arrangement.

detectors. The frequency was measured using both a dispersive line [4,5] and a mixer heterodyne circuit.

RADIATE-AND-RECEIVE UNITS

The two RR units consisted of evacuated, rectangular waveguide horn transmitters, which were required to reduce the field strength below breakdown levels, plexiglass windows, which provided an air-to-vacuum interface, lossy foam sheets, which provided attenuation and impedance matching, and receivers situated in the radiating horns' near fields, which allowed for compactness. In our experiment, no anechoic chamber was available.

A side view of the first RR unit, the "horn-probe unit" is shown in Fig. 2. It had a 1.75 cm thick, flat plexiglass plate epoxied to an S-band transmitting horn. The horn, with an output to input area ratio of 17, should have allowed transmission of more than 1 GW rms power without air breakdown [4]. The window and vacuum hoses (dashed lines in Fig. 2) were surrounded by layers of Eccosorb foam

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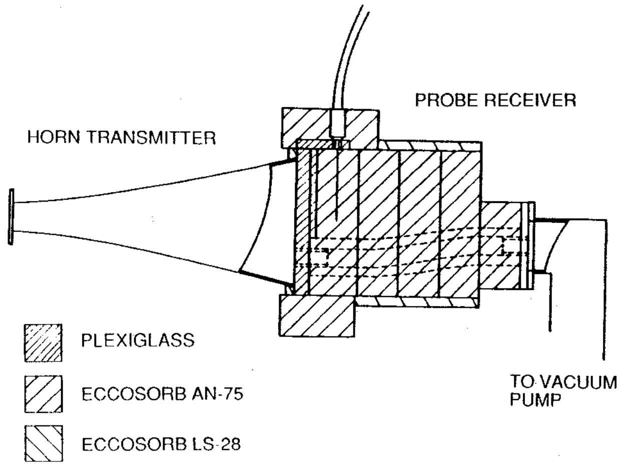

Figure 2. Side view of horn-probe radiate-and-receive device.

sheets [6]. The receiver, which consisted of a 0.317 cm diameter semirigid coaxial cable with 1 cm of exposed insulated inner conductor, was used as an electric field probe by orienting it parallel to the TE_{10} waveguide mode electric field direction. The large scale variations in the horn-probe insertion loss (Fig. 3a) were due principally to standing waves set up between the window and the mouth of the horn.

The entire horn-probe unit was bound tightly with tape, covered with aluminum foil and mounted on a movable stand above an untrapped diffusion pump and its mechanical forepump. Pump oil which backstreamed into the microwave horn did not appear to cause rf breakdown at the hundred megawatt power levels.

The second-generation RR device, the "dual-horn" unit, was empirically designed for a minimum VSWR and a maximally flat insertion loss with respect to frequency. A top view of the dual-horn is shown in Fig. 4. A C-band horn transmitter and a C-band horn receiver were mounted mouth-to-mouth in an aluminum frame, separated by 0.37 m. The large area intercepted by the horn receiver minimized the received signal's dependence on the radiating antenna's field pattern. The area between the horns was filled with a combination of Eccosorb and styrofoam [7].

The insertion loss and VSWR were found to be highly dependent on the horn separation. The optimum horn separation of 0.37 m resulted in the smooth insertion loss plotted in Fig. 3a and minimum reflections throughout the 3.5 to 5.5 GHz range (Fig. 5). As the horn separation was decreased below 0.3 m by removing styrofoam, the peak VSWR increased above 2 and the insertion loss increased and

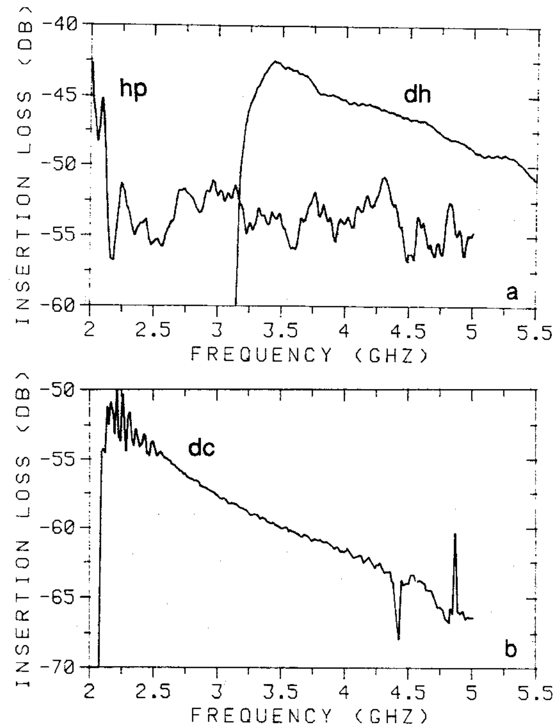

Figure 3. Insertion loss vs. frequency, [a] horn-probe (hp) and dual-horn (dh), [b] directional coupler (dc).

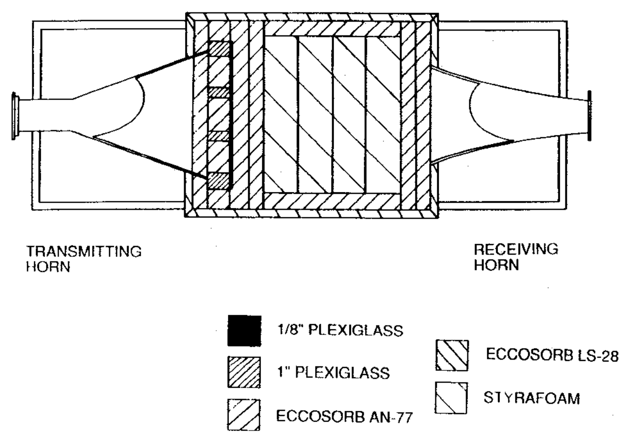

Figure 4. Top view of dual-horn radiate-and-receive device.

became less smooth as reflections from the receiving horn became more dominant. For separations larger than 0.4 m, the VSWR remained constant and the insertion loss increased but became less smooth. In contrast, for the horn-probe unit the VSWR was independent of the transmitter-receiver separation and the insertion loss increased with increasing separation, i.e. the probe was nonperturbing. For both RR systems, the VSWR depended strongly upon the window thickness and the first

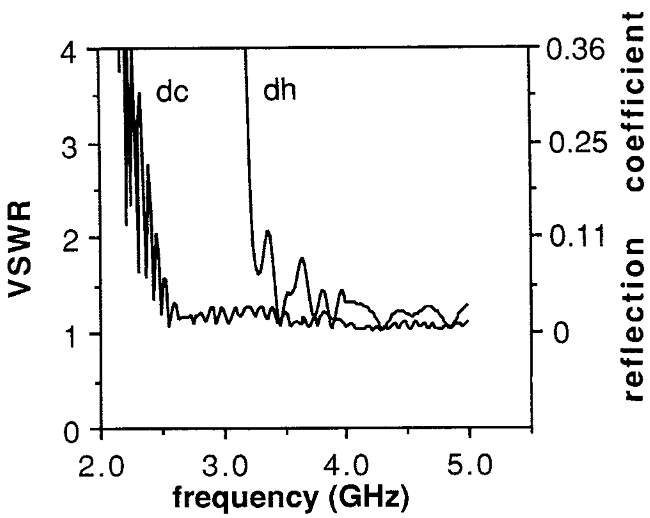

Figure 5. VSWR and power reflection coefficient vs. frequency for directional coupler (dc) and dual-horn (dh).

Eccosorb sheet. The Eccosorb sheets acted like a series of attenuators, with the first one dominating the reflection behavior.

The dual-horn window consisted of a thin, 0.317 cm, plexiglass sheet with an additional support structure which was required to withstand the pressure at the air-vacuum interface. Two stress relieving 2.54 cm thick plexiglass ribs were oriented in the direction of the TE_{10} electric field in order to least perturb the fields. For a TE_{10} electric field distribution at the window, 69% of the power incident on the window was incident on the thin plexiglass. To further reduce the standing waves set up in front of the window, two layers of Eccosorb were epoxied against the window inside the transmitting horn.

To insure that the RR systems behaved linearly with power, an S-band sidewall directional coupler which had previously been used in a 1 GW relativistic magnetron experiment [8], was used for comparison. The directional coupler was placed between an output waveguide section and the horn-probe. The insertion loss through the directional coupler's secondary arm is plotted in Fig. 3. The spikes near 4.4 GHz were identified as resonances in the S-band waveguide-to-coax adapter which was mounted to the secondary arm. It should be noted that the directional coupler's insertion loss was no smoother than the dual-horn's insertion loss. The VSWR is plotted in Fig. 5 for the directional coupler terminated by a high power S-band dummy load.

MIXER AND DIODE DETECTORS

Part of the short-pulse microwave detection circuit is shown in Fig. 6. The signal from one of the waveguide diagnostic elements (1) was sent through a 10 m coax cable, represented in Fig. 6 by its attenuation (2), and through a dc block (3) into a power splitter (4). The split signals were each reduced with fixed (5) and variable (6) attenuators before being sent into a diode detector (7) and a subnanosecond-risetime, double-balanced mixer (9) in a heterodyne circuit (9-14). The rest of the heterodyne circuit consisted of a directional coupler (10), fixed attenuators (11), a TWT amplifier (12), a local oscillator (13), and a power sensor (14). The detector output signals were fed into 400 MHz or 1 GHz bandwidth oscilloscopes (8) for display of the pulse shape, power, and frequency.

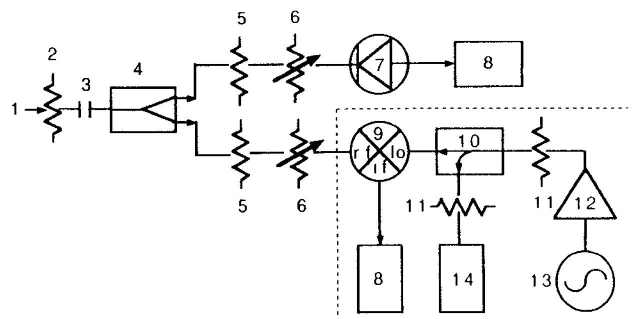

Figure 6. Schematic of single-pulse microwave detection circuit.

The high level mixer in the heterodyne circuit used for frequency determination was also used as a power diagnostic. The mixer required calibration at each RF and LO frequency combination encountered during the experiments. The mixer input power was kept in the linear regime below the 1 dB compression point. Typical microwave pulse shapes emitted from a relativistic rising-sun magnetron are shown in Fig. 7 [3,4]. The mixer and diode detector outputs are shown at the bottom of Fig. 7. The mixer LO is 3.8 GHz. Shown at the top of Fig. 7 are the power envelopes derived from these signals using the attenuation after the magnetron and the rms power calibrations of the detectors.

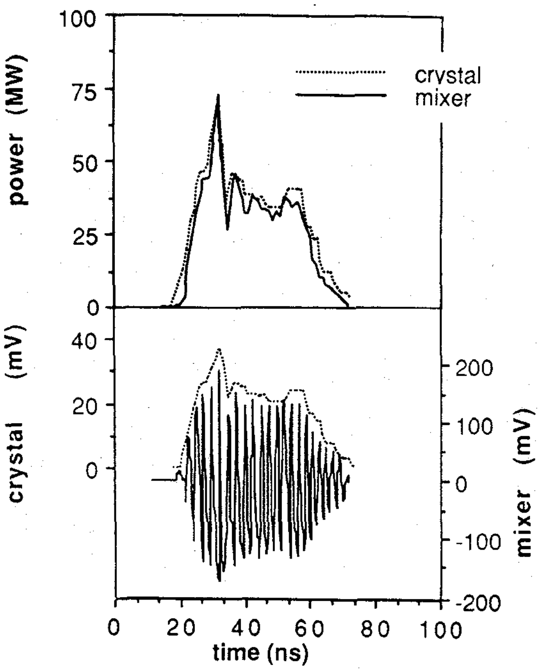

Figure 7. Mixer and crystal diode detector outputs for a typical HPM burst. LO = 3.8 GHz.

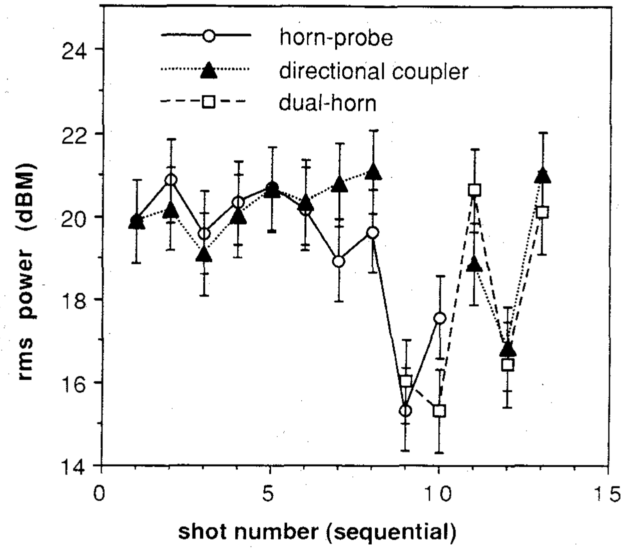

Figure 8. Microwave power emitted from a relativistic magnetron in dB relative to 1 Megawatt (dBM) and measured with waveguide diagnostic elements.

RESULTS AND CONCLUSIONS

A comparison of the power diagnostic results at 4.1 and 4.3 GHz can be seen in Fig. 8. Figure 8 is a plot of the rms power per output waveguide emitted by an A6-type relativistic magnetron with a 1.58 cm radius washer-type cathode at 485 to 495 kV for 13 sequential shots with power simultaneously measured from all combinations of two of the three waveguide diagnostics. Only the diode detector powers are shown. For the data plotted in Fig. 8, the directional coupler (▲) and the horn-probe unit (○) terminated a common output waveguide section, while the dual-horn (□) terminated the opposite output waveguide section. Agreement within the total ± 1 dB uncertainty is evident in all but one shot.

In summary, the characteristics of the complete, short-pulse microwave diagnostic system were: vacuum pressure of 10^{-5} Torr, frequency range of 2.2 to 5.5 GHz, peak VSWR less than 2, total insertion loss of 100 to 110 dB, accuracy of ± 1 dB in power, ± 0.1 % in frequency, and measured power handling capability greater than 150 MW rms. The diagnostic system could be utilized in many HPM experiments and could be scaled to other microwave frequencies as well as to circular waveguide.

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