A HIGH POWER BROADBAND MILLIMETER-WAVE SWITCH AND RECEIVER PROTECTOR

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ABSTRACT

This paper describes the development of a radar receiver protector (RP) that can serve simultaneously as a millimeter-wave RP and a high-current video switch. Presently there is no device that can provide low loss protection at 95 GHz with 50 dB or more of broadband isolation -- a requirement imposed by the spurious moding of millimeter-wave, multi-kilowatt radar transmitters.

Discussion

The purpose of this effort is to develop a radar receiver protector (RP) that will perform simultaneously the dual function of a millimeter-wave receiver protector and a high-current video switch. At present there is no device which can provide low loss protection at 95 GHz with 50 dB or more of broadband (60-100 GHz) isolation. The need for broadband isolation is due to the spurious moding of millimeter-wave, multi-kilowatt radar transmitters.

The device shown in figure 1 consists of 6:1 oversized WR-12 waveguide filled with low-pressure hydrogen gas, slotted sidewalls in the waveguide for orthogonal beam-current passage, a pair of impedance-matching tapers (figure 2) within the vacuum envelope, and specially developed wideband, low-loss, high-temperature pressure windows. The waveguide serves the dual purpose of guiding the EM wave and acting as a trigger grid to actuate the beam. A convergence cone, located between the waveguide sidewall and the cathode, is used to compress the beam in order to obtain high plasma densities without using excessive beam currents or externally applied magnetic fields.[1]

The resultant enhancement ratio of the plasma density at the cone exit relative to the value at the cone entrance has been measured using Langmuir probes under conditions where electron losses to the metallic cone wall are small. The plasma density enhancement method is compatible with small waveguide size because the plasma enhancement ratio, above a certain minimum cone exit area and except for a slight dependence on electron temperature, is proportional to the cone entrance-to-exit area ratio. Thus, the cone exit area is made compatible with the total area of the waveguide sidewall slot openings necessary for beam current passage.

Preliminary results concerning the theory, development, and low RF power evaluation of a 95-GHz plasma waveguide switch (PWS) were presented at the 1970 IEDM;[2] the basic model for the analysis of small-signal attenuation is shown in figure 3 and the computer-run solutions are shown in figure 4.

The present paper concerns high-power experiments using an 8-kW, 95-GHz pulsed magnetron to obtain data on the PWS when used as a pretriggered receiver protector. The results show spike and flat leakage power levels of 20 mW for RF power levels up to 4 kW and under 1 mW for power levels of 1 kW; recovery times under 0.5 microsecond have been obtained. The external RF characteristics of the RP are dependent on the pre-excitation beam current magnitude. The beam current is controlled over a range of 5 to 100 amperes peak to obtain a predetermined fixed degree of RF isolation.

The fixed isolation, measured with a low-amplitude 95-GHz probing wave, represents the minimum attenuation of the pretriggered device with the beam on. The data is given in figure 5. Previous measurements using Langmuir probes have shown the electron density under these conditions to be approximately 10^{15} e/cm^3. With the 4-kW RF pulse incident on the device (figure 6), an intense RF field is superimposed on the pretriggered dc field, resulting in an increase in plasma density with a consequent increase in RF isolation. The high-power data is shown in figures 7, 8, and 9. The beam is pretriggered by a few microseconds to allow the buildup of electrons to equilibrium values prior to the RF pulse arrival. In our experiments, RF pulsewidths between 20 and 200 nanoseconds were used at PRF's from 100 Hz to 1 kHz, and total gas admixture pressures of approximately 100 to 400 millitorr were used.

RF insertion loss has been reduced to 0.8 dB, as shown in figures 10 and 11, by developing an RF choke whose diameter is much less than the diameter of the glass-bonded mica window. This prevented any significant RF current from reaching the glass bonding at the window periphery, thus keeping insertion loss down to 0.2 dB per window. The windows were individually tested at 3 kW after low-power evaluation and hermetic sealing.

The RP design has evolved to include a keepalive electrode that draws a constant but small current of 50 mA. This creates a glow discharge that establishes a virtual cathode a short distance from the actual cathode. Experiments show improved starting characteristics with relatively small pulse-to-pulse jitter; additionally, a longer cathode life is expected relative to the no-keepalive design due to reduced back ion bombardment.

The RP is so designed that low-level insertion loss tests can be run separately on the windows and on the waveguide body prior to committing the windows to the device in the final brazing process. Experimental data to optimize isolation and recovery times will also be discussed.

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1. A. Singh and J. Rowe, "Enhancement of Plasma Density in an Arc Discharge," *J. Appl. Phys.*, (November 1967).

2. H. Goldie, "A 60 to 96 GHz Fast Acting Plasma Waveguide Switch," *IEEE-70-C45-ED*, (October 1970), page 40.

Experiments were performed at X-band to demonstrate the feasibility of using the PWS as a pretriggered RP and a dc switch. Figure 12 shows the actual front end to be used in a millimeter-wave radar; overall noise figure is about 9 dB, and gain is about 20 dB when measured from the input port of the RP to the output port of the 1-1.5 GHz IF preamplifier.

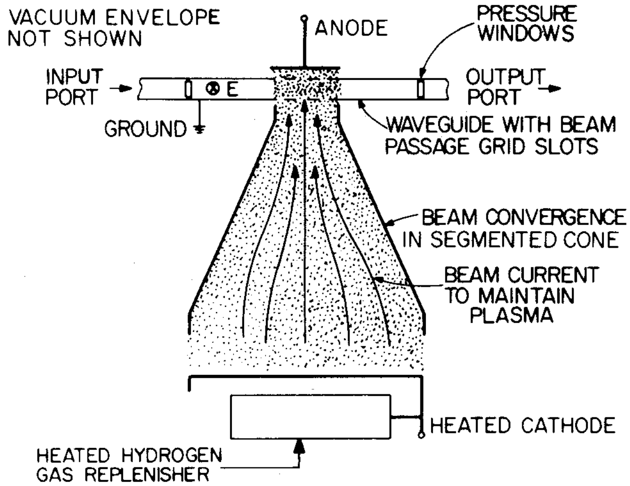


Figure 1. Functional Sketch of Millimeter-Wave Plasma Waveguide Switch

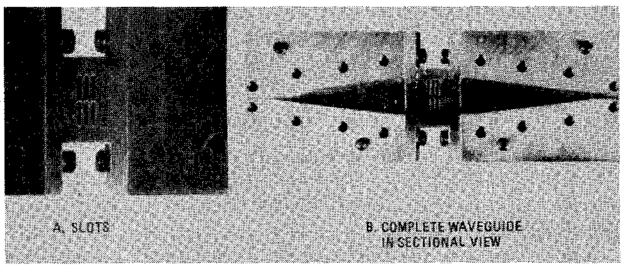


Figure 2. Photo of Body Showing Waveguide Sidewall Geometry for Beam Passage and Two Impedance Transformers

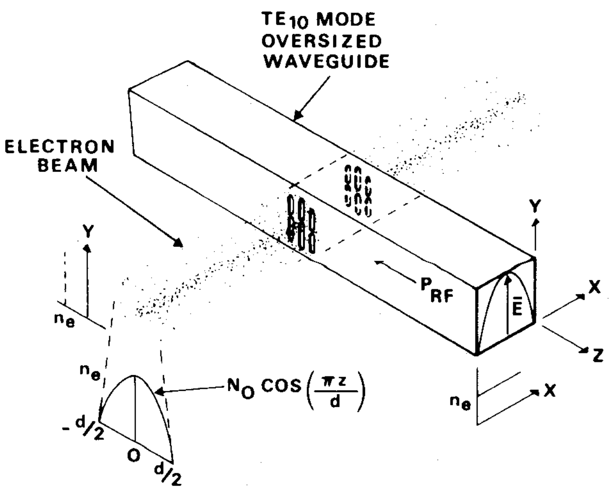


Figure 3. Model Used for Computation of Small-Signal Attenuation as a Function of Electron Density and Frequency from Computer Solutions of Wave-Plasma Transmission Equations

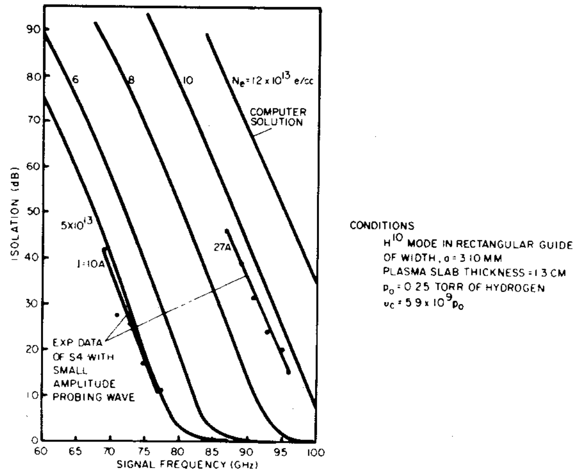


Figure 4. Comparison of Computer-Run Results of Small-Signal Wave-Plasma Interaction Theory with Small-Signal Measured Attenuation Data

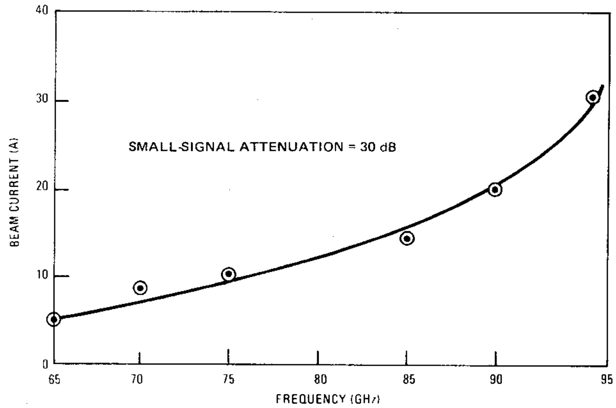
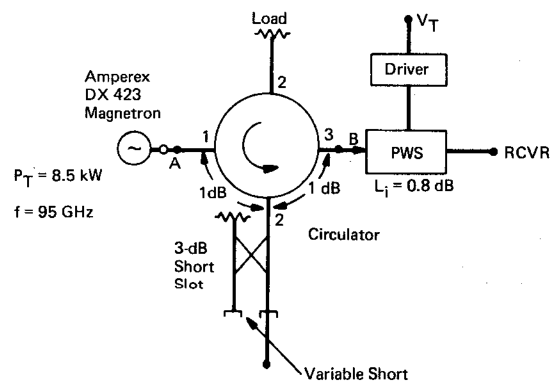


Figure 5. Required Beam Current to Maintain a Small-Signal Attenuation of 30 dB. Data Taken Using a 1-mW Probing Signal. Gas Fill of 40 mT of Krypton plus 1 mT of H_2; 3 μsec Beam Pulse Duration

Circulator-Inline RP Duplexer Radar Configuration



Minimum loss between points A and B was measured at 95 GHz to be 3.7 dB. The variable impedance at port 2 gave a 33-dB variation in power range.

Total System T-R Losses:
Transmit Losses = 1 dB
Receive Losses = 1.8 dB
2.8 dB

Figure 6. Simulated Radar Experiment Using PWS as a Pretriggered Receiver Protector

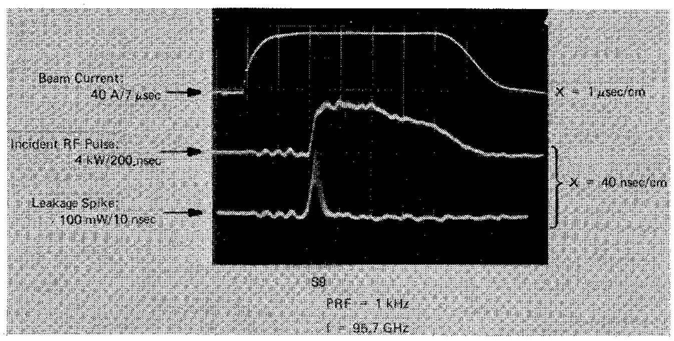


Figure 7. Input and Output RF Waveforms at 40-Amp Beam Current

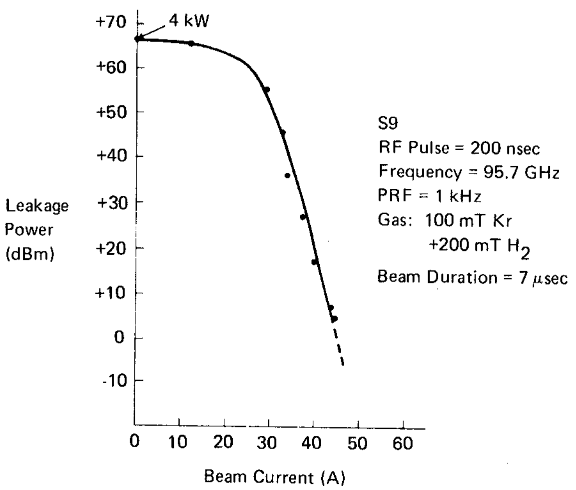


Figure 8. Leakage Power as a Function of Beam Current

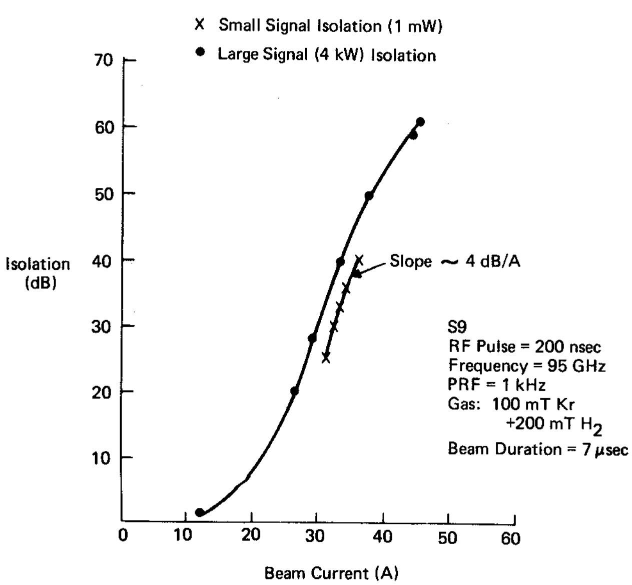


Figure 9. RF Attenuation as a Function of Beam Current

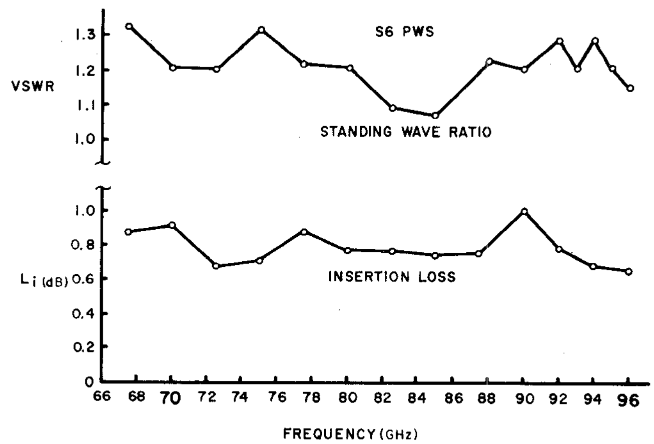


Figure 10. Measured Point-by-Point VSWR and Cold Loss Data of S6

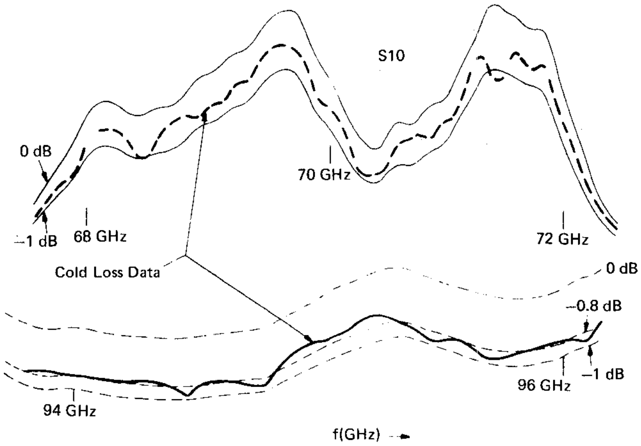


Figure 11. Swept Insertion Loss Data as a Function of Frequency in Cold State

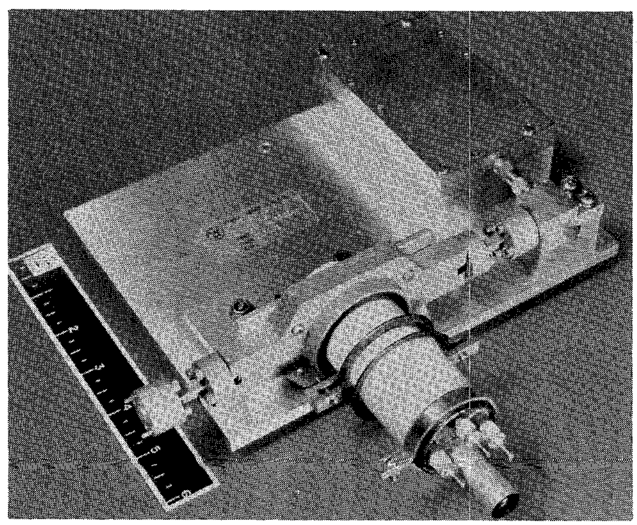


Figure 12. Millimeter-Wave Front End Showing PWS Used as a Receiver Protector, Single-Ended Mixer (LO Not Shown), and 1-1.5 GHz IF Preamplifier