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A Plasma Video Detector

Abstract—A low-noise microwave detector has been developed for use with high CW carrier power and low modulation frequency. Under some conditions, the sensitivity and noise temperature of this device are better than those exhibited by the best crystal video detectors.

A plasma video detector has been developed for use in a high-power electron paramagnetic resonance (EPR) spectrometer where the signal appears as low-level modulation on power reflected from an almost critically coupled resonant cavity. This spectrometer needs a low-noise detector which operates at an RF level of about 10 watts. Because these cavities cannot be reliably coupled to the point where they reflect milliwatts when the incident power is hundreds of watts, attenuators must be placed between the cavity and any detector crystal. These attenuators reduce the signal as well as the carrier power, so crystals are unsuitable.

Lampert and White [1] studied the effect of microwave fields on limited regions of a dc discharge. The discharge was maintained continuously by a battery, and the current was limited by a series resistor. When a 5-GHz microwave field acted on a small region of the discharge tube, they observed a change in the direct current proportional to the power applied. Maximum sensitivity was found to be in the region of reversed electric field near the cathode. The authors suggest that the region of reversed electric field is a barrier that slow electrons cannot cross on their way to the anode. Trapped electrons may be helped over the barrier if they are accelerated by a microwave field.

Burroughs and Brownell [2] used a plasma to detect 9-GHz microwave pulses in a waveguide with large cross-sectional area. Crystals are not suitable because they detect the RF electric field at a single point, whereas plasmas, which detect the RF power over a larger region, can detect all the modes which are excited in a large waveguide. Several detection tube designs were tried. Using constant dc driving current, the authors observed that the discharge dc voltage drop is typically 50 to 55 volts. An RF voltage applied across the electrodes causes the dc voltage to decrease by an amount proportional to the incident microwave power, and that sensitivity is greatest when the plasma contains the greatest density of electrons. Their best sensitivity was about equal to that of a 1N23A crystal detector. The signal-to-noise ratio was 75 dB, but they do not report the power or bandwidth used when this value was measured.

Farhat [3] describes a free-field high-power microwave detector using an argon-filled bulb. He suggests that detection involves an increase in electron temperature proportional to power density. The device exhibits good pulse response (0.5 µs rise time) and sensitivity. No noise temperature or CW measurements were made.

Our preliminary studies of plasma detectors used inexpensive NE-2 and NE-51H gas discharge bulbs which were mounted in a coaxial transformer designed to match the RF impedance of the plasma and then fine tuned with a ferrite slug. Microwave power was supplied by a Hewlett-Packard 8616A S-band signal generator. Power calibration was checked with a bolometer power meter.

When a neon bulb discharge is driven by a constant dc current ranging from 10 to 100 µA, the discharge voltage drop is typically 50 to 55 volts. An RF voltage applied across the electrodes causes the dc voltage to decrease by an amount proportional to the RF rms voltage across the discharge. For instance, one NE-51H neon bulb changed its dc operating voltage from 52 volts without RF to 48.6 volts when excited by 1 mW at 3 GHz. Sensitivity is quite high and no preamplification is needed.

Low-level audio modulation was applied.
to the microwave carrier and used to measure noise temperatures. For any given carrier power setting, the amplitude modulation percentage was varied to find the point at which the audio signal-to-noise ratio was 10 to 1. Detector noise, measured by this known sideband power, is compared to the theoretical noise power from a blackbody source. Noise temperature is defined as the equivalent noise power to the theoretical noise power ratio, and can be expressed in decibels. The minimum detectable signal was measured with 100 percent square-wave modulation; it is defined here as the carrier power at which the signal-to-noise ratio is one to one. RF oscillator, audio modulator and amplifier circuits were not a significant source of noise in these experiments.

At modulation frequencies above 10 kHz the detection efficiency of neon bulbs drops, but noise shows no frequency dependence from 20 Hz to 10 kHz. Noise output is somewhat dependent on dc current, but independent of RF power except that each bulb ceases detecting abruptly as power is increased past some characteristic value. Many bulbs stop operating at -5 dBm, the best quit at +15 dBm. About 30 NE-2 and NE-51H gas bulbs were tested. A few bad bulbs showed noise temperatures 40 dB worse than the best one. The average bulb was perhaps 5 dB worse than the best. Minimum detectable signal is -65 dBm using a 30-Hz detection bandwidth at 1000 Hz modulation frequency.

Close examination showed a correlation between the visible discharge and noise temperatures. The best bulbs had parallel electrodes. Their dc discharge was steady and the visible portion covered the whole of one electrode. The worst bulb had parallel electrodes but its discharge flickered back and forth. Intermediate bulbs had nonparallel electrodes or imperfections so that the discharge was smaller and localized. While magnetic fields of up to 10 000 gauss could improve the performance of poor bulbs by stabilizing their flicker, the best bulbs were not improved by a field. Results reported are only for the best bulbs tested.

Some crystal noise temperatures were measured using the same equipment and techniques so that systematic errors would cancel in direct comparisons with plasma detectors. Crystals were operated in a commercial waveguide mount and with a low-noise audio preamplifier. Of ten specimens, the best was a Sylvania 1N21E, for which the minimum detectable signal is the same as the plasma detector's, -65 dBm with a 30-Hz bandwidth at 1000 Hz. Noise temperatures measured in this work are found in Table I where they are compared to those obtained by Feher [5]. These data show that the plasma detector is better than a crystal for 1000-Hz modulation at powers above 1 mW. For 100-Hz modulation it is always better than the best crystal.

An NE-51H bulb was tried as a detector in a low-power 3-GHz EPR spectrometer. Comparison with the best crystal detector available confirmed the plasma detector's superiority when the modulation frequency is 100 Hz. Since the desired detector must operate at higher powers than the +15 dBm of an NE-2, a war surplus 721A TR tube was converted to a plasma detector and mounted in a waveguide cavity. The gas in the original tubes [6], a mixture of H2 and H2O, makes an inefficient detector, so other gases were introduced while observing detector operation. Comparing He, Ne, Ar, Ne+He, Hg, +He and air, the most efficient high-power detector was found to be pure helium at 25 mm pressure. The best operating range is 1 to 10 watts. No noise measurements have been made, but probably the noise temperature is not as good as those measured for neon bulbs. This is because the tips of the cones in 721A tubes, while blunt, are still too sharp and not uniform enough. Improvements could surely be made.

The 721A detector with helium was installed in a high-power EPR spectrometer which is used for saturation and dynamic polarization studies [7]. A phase-locked QK625 BWO supplies up to 200 watts CW to a reflection cavity. With 100-Hz modulation, signals are seen from standard paramagnetic samples. Since no signals at all can be seen with crystal detectors after necessary power attenuation to prevent burnout, plasma detectors represent considerable improvement.

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REFERENCES
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