Short Papers

Measurement of High Pulsed Microwave Power in Free Space

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***Abstract*—Resistive power heads connected to horn antennas are used to measure high pulsed microwave power density in free space. With such a unit, pulsed power densities up to 3 MW/m ^{2} have been measured in the S- and X-bands.**

I. Introduction

The electromagnetic environment is an increasing cause for concern as strong electric fields are becoming a pervasive part of it. Furthermore, there are projects to use microwave directed-energy weapons to disable or destroy enemy electronic systems [1]. System design must take all this into account due to increasing sensitivity of electronic equipment as well as growing dependence on it for our safety. It is therefore of great importance that systems such as aircraft or satellites be tested to withstand electromagnetic threats. Special test facilities generating short, high-power microwave pulses have been developed for this purpose [2]. In testing the electric field strength or RF power density must be measured at the actual location of the equipment of risk. Since the peak power density level produced by the above mentioned pulse sources is of the order of a few MW/m^2 [2], the standard commercial electric-field probes, limited to detecting a few kW/m^2 [3], [4], are of little use.

A most promising device for such measurements is the resistive power head using n-type Si for the sensor manufacturing [5]. The principal advantages requirements of such a sensor, as contrasted with Schottky or point-contact diodes also used to measure microwave pulse power, are: 1) the ability to measure high RF pulse power directly in the transmission line without directional couplers or attenuators; 2) a large available output signal (up to a few tens of volts) from the sensor; 3) high reliability and overload endurance, as is characteristic of a resistive sensor; and 4) the ability to switch off the resistive sensor's DC supply in order to assess any parasitic signal that might be induced in the measurement circuit by external electromagnetic fields.

This paper demonstrates the successful use of a resistive power head with matched load connected to a horn antenna to measure high microwave pulse power density in free space.

II. Experimental Setup

The diaphragm based resistive power head of Fig. 1 has been developed for measuring high RF pulsed power in waveguide. A rectangular parallelepiped shape piece of n-type silicon with ohmic contacts serves as a sensor. Two resistive sensors are actually placed between the waveguide broad wall and the thin metal foil which is located in the waveguide's H-plane. They are connected in series in a DC circuit together with a DC source but in parallel in a RF circuit. Because of this the spurious signals due to harmonic mixing [6] are suppressed while the useful signals are summed up.

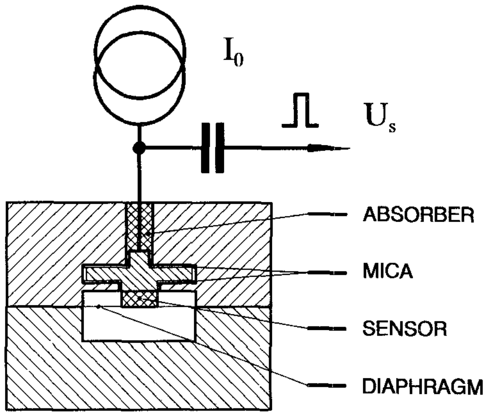

Fig. 1. Sectional view of the resistive power head.

The dimensions of the sensors and diaphragm, as well as the resistivity of the silicon are chosen to optimize frequency response, minimize perturbation of the electric field in the transmission line, and enhance the sensor's thermal characteristics. The sensor's height corresponds roughly to 1/10 of the waveguide narrow wall and resistance is about 300 Ω.

When a semiconductor is exposed to the strong electric field, electrons gain additional energy, and a new steady state occurs with a mean electron energy greater than equilibrium. As a rule heated electrons are more frequently scattered by lattice imperfections, therefore the semiconductor's resistivity increases [7]. Since the resistivity of the sensor is chosen big enough, and the microwave pulse duration is rather short, the sensor's thermal heating is negligible and may be ignored. Therefore, only the electron heating is responsible for the sensor's resistance change in the RF electric field and for a DC pulse appearance in the DC circuit. The resistance change increases with the RF electric field strength in the sensor material which in turn increases with the RF power. The DC pulse amplitude thus indicates the RF pulse power in the transmission line.

The pulse in the DC circuit was amplified five to six times by a preamplifier located close to the resistive sensor. To minimize electromagnetic interference, double shielding of the preamplifier and microwave absorbing filters in its input and output are employed. An additional temperature sensor and electronic circuitry are used to compensate the temperature dependence of the output signal. The maximum signal at the preamplifier output was 10 V.

Electron heating inertia, with a time constant in the range of a few picoseconds [5], defines the response time of the resistive sensor. This is much shorter than current rise time in the DC circuit or time constant of the preamplifier. These two delay times put the overall response time of the power head in the range of 100 ns.

The power heads handling microwave pulse powers up to 100 kW and 5 kW in the S- and X-band waveguides, respectively, were designed and fabricated. The respective waveguide window dimensions were 7.4 × 3.4 cm^2 and 2.3 × 1.0 cm^{2}with the VSWR less than 1.1 for both heads.

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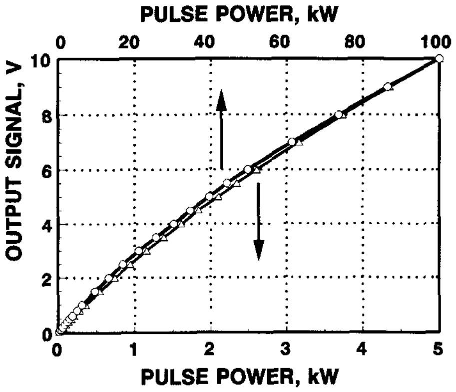

Fig. 2. Output signal dependencies on RF pulse power in the transmission line for the S-band (circles) and X-band (triangles) power heads.

TABLE I
CHARACTERISTICES OF THE HORN ANTENNAS

Band	Freq. (GHz)	VSWR	Gain (dB)	η	S (cm^2)	S_{ef} (cm^2)
S	2.86	1.15	15.2	0.73	400	292
X	9.3	1.13	21.4	0.68	169	115

The heads were calibrated using an accurate calorimetric average-power meter. The output voltage dependencies on RF pulse power for the S- and X-band heads are shown in Fig. 2. The overall measurement error of the heads is within $\pm 12\%$ over the waveguide's frequency range and over a temperature interval of -20 to $+40$ C.

The power head, proceeded by a horn antenna and followed by a matched load, comprise a unit for microwave pulse power density determination in free space. A similar horn antenna is employed to generate the electromagnetic field in free space. If the plane of the horn aperture is made perpendicular to the Poynting vector of the electromagnetic wave, and the RF power received by the waveguide is P, the microwave power density in free space can be written as

$$W_p = \frac{P}{S_{ef}} \tag{1}$$

where the effective cross-section area is

$$S_{ef} = \eta S. \tag{2}$$

Here S is a geometrical cross-section area and η is a coefficient describing the effectiveness of the horn antenna. Measuring P and knowing η thus the RF power density in free space will be determined.

III. Experimental Results

Measurements were carried out in an anechoic chamber at SAAB Military Aircraft. Calibrated horns with the characteristics listed in Table I were connected to the power heads. For the receiving horn antenna adjustment, a fully remote-control positioner was used. The measured pulse duration was 3 μs, and the repetition frequency was up to 10 Hz for both bands.

The measured value of RF power density, W_p, was compared with the calculated value according to the formula

$$W_P' = \frac{P_g G}{4\pi L^{2'}} \tag{3}$$

where P_g is RF power supplied to the transmitting antenna, G is its gain, and L is the horn spacing.

Measurement results are presented in Table II. It is seen that in the worst case, measured and calculated values differs by a factor of 1.3. The difference is not unexpected taking into account the main error of the power heads, the calibration errors of the transmitting and receiving horn antennas, and the error in the determining the RF power supplied to the transmitting antenna.

TABLE II
MICROWAVE PULSE POWER MEASUREMENT IN ANECHOIC CHAMBER

Band	P_g (kW)	L (cm)	W_p (kW/m^2)	W_p' (kW/m^2)	W_p/W_p'
S	1000	223	1030	802	1.22
2.86	3000	223	2750	2410	1.14
(GHz)	3900	223	3420	3120	1.10
	250	244	31	27.2	1.14
X	810	244	117	88	1.33
	810	214	145	114	1.27
9.3	810	122	434	352	1.23
(GHz)	810	17	3100*		

*In this case, an additional attenuator was inserted between the resistive head and the horn antenna

Switching off the DC supply of the sensors the magnitude of the parasitic signal induced in the heads by external electromagnetic fields was examined. It was determined that at the hardest conditions the parasitic signal is less that 1% relative to the direct signal.

IV. Conclusion

High levels of pulse power density in free space have been measured directly for the first time using resistive heads connected to horn antennas. It was shown that microwave pulse power densities up to 3 MW/m^2 can be measured using of such a unit in S- and X-bands. In contrast with other approaches, the described units can measure single or low repetition rate microwave pulses, and handle power densities more than three orders of magnitude greater than those to which standard commercial electric field probes [3], [4] are limited.

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