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by

AN ULTRA-BROADBAND PROBE FOR RF RADIATION MEASUREMENTS

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A72-38993

Recent awareness to the problem of harmful exposure to microwave radiation has stimulated the search for convenient and accurate methods of measuring the intensity of this radiation. Although much has been accomplished so far, there remains much to be done. In particular, the aspect of broadbanding a given probe design is crucial if exposure to multi-frequency radiation fields is to be anticipated. This paper deals with this question and describes the design and performance of a probe built in accordance with the principles developed in the theoretical portion of the paper.

Evidently, in order to measure the radiation intensity over a wide band of frequencies, the fraction of power absorbed by the probe must remain constant with frequency. This condition of presenting a constant effective aperture to the radiation field is not achievable with metallic transducers of the conventional antenna variety. On the other hand, it is possible to achieve this result, or come very close to it, by letting the field directly interact with a properly chosen resistive screen.

Consider a plane wave at normal incidence on an infinite screen of zero thickness and of surface resistance R_0, normalized to that of free space. Any unit square of that screen can be characterized by an equivalent absorptive cross section A_a, and a reflective cross section A_r, given by

$$A_a = \frac{4R_0}{(1+2R_0)^2} \qquad [1]$$

and

$$A_r = \frac{1}{(1+2R_0)^2} \qquad [2]$$

Although A_a and A_r are seen to be independent of frequency, the use of a homogenous resistive film does not lead to a practical design of a radiation probe. Consider thus a very long resistive strip of width W, as shown in figure 1.

If the normalized resistance per unit square area of side a is R, and the associated inductive reactance is X_L, then the above expressions for a plane wave polarized along the strip as shown in figure 1 becomes

$$A_a = \frac{4R}{(1+2R)^2+4X_L^2} \qquad [3]$$

and

$$A_r = \frac{1}{(1+2R)^2+4X_L^2} \qquad [4]$$

Although the above expressions show a frequency dependence on account of X_L, it is seen that this change is within 10% if

$$X_L \leq 0.16+0.32R \qquad [5]$$

Now in order to satisfy [5], as well as other practical constraints, the unit square dimension cannot be arbitrarily chosen. Thus, from the standpoint of good sensitivity, low reflectivity and compatible noise level, it becomes evident that R should be chosen somewhere between 1 and 2, corresponding to absorptive cross sections of 44.5% and 32%, respectively, and to reflective cross sections of 11% and 4%, respectively. Furthermore, if the effect of the absorbed power is detected by thermoelectric means, then it is highly desirable to limit oneself to surface resistances not in excess of 50 ohms/□, corresponding to values of $\frac{a}{w} \geq 8$ for R = 1.

Now the inductance (in nanohenries) of the strip of length a is approximately given by

$$L = 2a\left\{\ln\frac{2\pi a}{W} - .75\right\} \qquad [6]$$

where a is in cm. Thus, for the case of R = 1, a/w = 8, and operating through X band with less than 0.5 dB of degradation in sensitivity as in [5], a = 0.145". Having thus determined the unit square dimensions, it is now possible to represent the resistive homogenous screen by a set of parallel strips of width W, separated by a distance a, and of resistance R per unit square. Obviously, the above equivalence is only true for a plane wave polarized as in figure 1. To remove this restriction, one resorts to two orthogonal sets of strips as shown in figure 2.

Consider now an array of strips as in figure 2, but of finite overall dimensions. In this case, the constant current distribution of the unbounded array must be somewhat modified in consideration of the current discontinuity at the boundary. While this effect is very difficult to compute, it is evident that it decreases as R is increased. Since the actual current distribution should be approximately expressable by a constant term and a dipole type of distribution, one should expect the latter to have its greatest effect when the length of the strip is approximately $\lambda/2$. At higher frequencies, the integrated value of the absorbed energy should converge to that of the constant term. This general behavior is shown in the data of figure 5 for $R_0 = 0.865$. For $R_0 = 1.25$, the deviations from the response given by equation [3] are seen to be considerably smaller, as expected.

In practice, the integrated power absorbed by an array as discussed above is most conveniently indicated by utilizing the thermoelectric effect to generate directly an output voltage. In order to accomplish this, each strip of the array consists of alternating segments of bismuth and nichrome films, suitably heat sinked at alternate junction points. Finally, the array is interconnected in order to properly sum all the generated thermal emf's. Figure 3 shows the superposition of two orthogonal arrays on two substrates together with their interconnections. Figure 4 shows two boron nitride disks between which the arrays of figure 3 are sandwiched. Notice the heat sinks provided in figure 4.

Figure 5 is a plot of measured sensitivity versus frequency. The data relating to a film with $R_0 = 0.865$ were taken at the facilities of RADC, Rome, New York. The calibrated points at 1 kHz are in excellent agreement with the measured sensitivity at 1 GHz.

Further details relating to the theoretical and experimental aspects of the directional properties, the thermal properties, the housing and cable design of the probe will be fully discussed.

The work reported in this paper is supported by RADC under Contract No. F30602-71-C-0276.