

RESISTIVELY-TAPERED-DIPOLE ELECTRIC-FIELD PROBES UP TO 40 GHz

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Abstract: We have developed an electric-field probe for use as a transfer standard at frequencies up to 40 GHz. The lower frequency cutoff is below 1 MHz. The design is based on the resistively tapered dipole (RTD) probes developed for frequencies up to 18 GHz. Those probes used 8-mm tapered dipoles. In this work we have used 6-mm, 4-mm, and 2-mm dipoles to extend the frequency range. Because the new probes are isotropic, have relatively flat frequency response, and have a response which drops off outside their operating frequency range, they could also be used as hazard meters.

Design

The basic design for isotropic RTD probes is discussed in detail in [1]. The configuration of one of the three orthogonal elements of the probe is shown in fig. 1. Isotropic RTD probes with dipoles of length 2 mm, 4 mm, and 6 mm were obtained and tested. The design of each element was as shown in fig. 1, with only the antenna varying in size. The entire antenna was scaled to obtain the correct shape for each of the three lengths. A diode was bonded across the gap of each dipole to serve as the detector. The dipoles themselves as well as the transmission lines leading to the output pads were thin films of Nichrome deposited on rectangular substrates of fused quartz. The output pads and the pads to which the diodes were bonded were of gold. Fused quartz was chosen as the substrate material in order to reduce the effects of scattering from the substrate. For materials used previously, such effects led to serious degradation of the angular patterns for frequencies above about 10 GHz. The isotropic probes are formed by joining three single elements along their long edges to form a cylindrical structure of triangular cross section. No support structure was used within the triangular cylinder, again for purposes of reducing scattering effects. The transmission lines from each substrate to the high-impedance voltmeter used to read the output signals were pairs of resistive wires. As in the 8-mm RTD probe, they were made of carbon-impregnated Teflon. Because the entire probe -- sensor, packaging, transmission lines -- is either dielectric or highly resistive, there is very little scattering from it, and consequently the perturbation of the field being measured is minimal.

Test Results

The 6-mm and 4-mm RTD probes were tested from 1 MHz to 40 GHz, and the 2-mm probe was tested from 50 MHz to 40 GHz. Below 50 MHz the response of the 2-mm probe was too erratic for reliable testing. For frequencies up to 125 MHz the measurements were performed in a TEM cell; from 300 MHz to 40 GHz they were done in the NIST anechoic chamber. No measurements were done between 125 and 300 MHz. Both facilities simulate a free-space environment with a single plane wave incident on the probe. In all the measurements the output of each element was terminated in a 50-Ω resistive load at the metering unit.

The most useful quantity to know for a transfer standard probe is its transfer function. The total (or "isotropic") transfer function of the probe is defined in terms of the sum of the output voltages of the three elements,

\[ T(\theta) = 10 \log_{10} \left( \frac{V_x + V_y + V_z}{E_{inc}} \right), \]  

where \( E_{inc} \) is the magnitude of the incident electric field. In general the transfer function as defined in eq. (1) is a function of the angle of incidence of the radiation on the probe. To use the probe as a transfer standard then, one must specify its orientation. One way to do this is to rotate the probe and use the maximum response obtained. This technique has the advantage that it can also be used in the field, where the direction and polarization of the incident radiation are not known. Figure 2 plots the maximum obtained for the total transfer function for each probe as it was rotated about its axis in the orientation described above. In the range of our greatest interest, 18-40 GHz, the 4-mm probe has the flattest response. As a bonus, the response of the 4-mm probe is fairly flat, ±4 dB, over the entire frequency range measured, 1 MHz-40 GHz. Also, it appears that the 4-mm probe and especially the 2-mm probe will have a good response beyond 40 GHz.
The lineabilities of individual elements of the probes were measured and are shown in fig. 3, which plots the output voltage versus the equivalent power density at representative frequencies. If the diode is operating in the square-law region, then the curve should be a straight line. The results indicate that the response of the 2-mm probe is linear up to the highest field measured, 2 mW/cm². For the 4-mm probe departures from linearity begin to become significant at about 0.7 mW/cm², and the 6-mm probe is linear up to about 0.5 mW/cm². The nonlinearities which are present are very smooth and could be readily corrected by calibration.

The angular patterns of individual elements and the isotropy of the total response were also measured. In general, the patterns are good, except for the 2-mm probe, which sometimes has rather erratic patterns due to low signal level. The good behavior of the angular patterns persists up to about 20 or 25 GHz. The patterns begin to deteriorate between 25 and 30 GHz, and by 40 GHz they are all quite poor. Here we present only the results for the maximum anisotropy, defined as the maximum deviation from the geometrical mean of the maximum and minimum response at a given frequency.

The approximate minimum detectable electric fields of the three probes are 5 V/m for the 2-mm probe, 3 V/m for 4-mm, and 1.5 V/m for 6-mm. For comparison, the 8-mm probe has a minimum detectable electric field of about 1 V/m.

Conclusions

Because of its superior frequency response and isotropy in the 18-40 GHz range, the 4-mm probe is chosen as the optimum RTD design of those tested. Besides covering the 18-40 GHz range, it can be used down to 1 Hz and could also be used a little above 40 GHz. Its better isotropy may well be a quality control accident, but its better frequency response is a result of the dipole length. Thus a single probe would be sufficient to cover the entire range of an anechoic chamber, certainly up to 40 GHz and probably up to 45 or 50 GHz. The approximate minimum detectable electric fields of the three probes are 5 V/m for the 2-mm probe, 3 V/m for 4-mm, and 1.5 V/m for 6-mm. For comparison, the 8-mm probe has a minimum detectable electric field of about 1 V/m.

Reference


Figure 2: Maximum measured transfer functions.

Figure 3: Measured linearity of single elements of RTD probes.

Figure 4: Measured maximum anisotropies for RTD probes.