# Design of a Novel 100MHz~60GHz Isotropic Electric-field Probe

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***Abstract*-A novel 100MHz~60GHz wideband isotropic electric field (E-field) probe, capable of accurately measuring the strength of the electromagnetic radiation, is presented in this paper. The E-field probe mainly consists of tapered resistive dipole and a low-barrier, beam-lead Schottky detector diode. The E-field probe has the ability of measuring 0.7V/m~400V/m. The frequency response of the probe is within ±3 dB（300MHz ~ 40GHz）. The isotropic response with respect to angle, guaranteed by spatial mutually orthogonal dipole configuration, is within ±1 dB.**

***Index Terms*—E-field probe, isotropic response, frequency response, Schottky detector diode.**

## I. INTRODUCTION

Along with the rapid development of the types of electronic equipment, the electromagnetic environment becomes more and more complex. A growing interest in hazard assessments of nonionizing electromagnetic emissions from electronic equipment on biological or simulated tissue has created a need for improved EM field measurements in both free space and material mediums. All these requirements lay a need for EM field sensing devices with higher frequency, broader bandwidth, smaller size, and higher accuracy. As an effective instrument of measuring the radiation strength of electromagnetic field, the electric-field probe has been studied and arouses more and more attention in recent decades.

In order to develop field probe, the precondition is to establish a standard electric-filed field generation environment for probe measurement and calibration. Standard EM fields are typically required at open-field sites, in TEM cells, in guided-wave structures, and in anechoic chambers. The requirements for establishing standard EM fields have been previously reported [1-6]. Antonio, etc. have done a lot of researches, as in [1-3], on probe's theoretical analysis, fabrication process and calibration. Correlative work has been reported in [7, 8]

In this paper, a broadband E-field probe is designed and measured in a relative standard EM field measurement environment. The probe features 1) an ultrawide useful frequency range of 100MHz~60GHz; 2) a frequency response flat to within ±3 dB from 300MHz to 40GHz; 3) a wide dynamic measurement range covering 0.7 V/m to 400V/m; 4) an isotropic response whose standard deviation (with respect to angle) is within ±1dB; and 5) a high-resistance soft film transmission line for connecting the probe's outputs to an external metering unit.

## II. DESIGN OF E-FIELD PROBE

### *A. The Tapered Resistive Dipole*

The conventional metal dipole antenna supports a standing-wave current distribution, so it is highly frequency sensitive and the working frequency band is narrow. In order to develop a broadband E-field probe, the length of the dipole must be shortened to the level of millimeter at the expense of the sensitivity. As a means of overcoming the severe size limitations imposed by natural dipole resonance, a traveling-wave dipole antenna can be realized by continuous resistive tapering of the dipole halves, as shown in Fig. 1. The heart of the E-field probe mainly consists of tapered resistive dipole, schottky detector diode and high impedance transmission line.

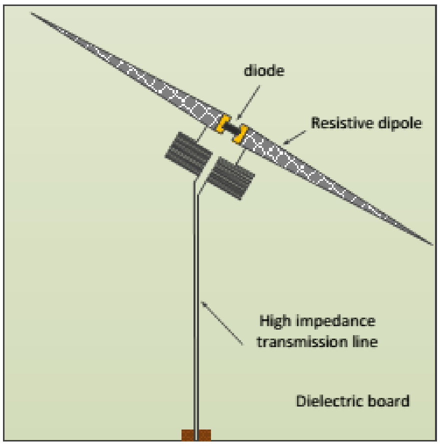


Fig.1 The tapered resistive dipole composite

Basically, it has been shown that if the internal impedance per unit length $Z^i(z)$ as a function of the axial coordinate z can be expressed as

$$Z^i(z) = \frac{60\psi}{h-|z|} \tag{1}$$

then the current distribution $I_z(z)$ along the linear dipole

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is that of a traveling wave, i.e.,

$$I_z(z) = \frac{V_0}{60\psi(1-j/kh)}\left[1-\frac{|z|}{h}\right]e^{-jk|z|} \qquad (2)$$

The symbols have the following meanings: h is the dipole's total physical length, k is the wavenumber, and $V_0$ is the driving voltage. According to the function, in order to realize a 100MHz~60GHz E-field probe, the dipole is fabricated by photoetching a thin film of tantalum nitride (TaN) with a resistivity of 10Ω/□.

*B. Detector Diode Selection*

A low-barrier, beam-lead schottky detector diodes is bonded across the dipole gap. The high sensitive detector diode used is very carefully selected from the broad range of commercially available beam-lead detector diodes. The predominant diode characteristics used in the diode selection are: 1) maximum operating frequency ($F_{max}$); 2) diode junction capacitance ($C_j$); 3) diode junction resistance ($R_j$), and 4) detection sensitivity. High $F_{max}$ dictates minimum $C_j$ and parasitic reactance such as the package capacitance ($C_P$) and diode lead inductance (L). It is also important that $C_j$ is very small because it forms a voltage divider with the driving point capacitance ($C_a$) of the dipole antenna, as shown in Fig.2. Consequently, only diodes with $C_j \leq 0.1$ pF is considered. Since $C_j$ combines with $R_j$ to form a high-pass filter, which, in turn, determines the low-frequency cutoff ($f_L$), only diodes with relatively large values of $R_j$ are considered. Also, the very wide frequency range (100MHz to 60GHz) placed high sensitivity requirements on the detecting diode. Consequently, only low-barrier diodes and zero-bias Schottky (ZBS) diodes are initially considered.

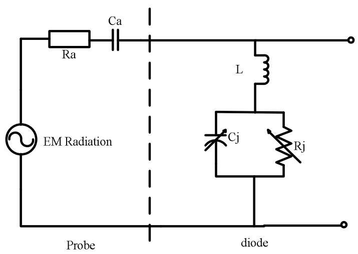


Fig.2 The dipole-diode equivalent circuit model

*C. Spatial mutually orthogonal configuration*

An isotropic response of a field probe could be achieved, if three dipoles are arranged perpendicular to each other. Then the total electric field strength is the result of the addition of the electric fields tangential to each dipole. In the design of the 100MHz~60GHz broadband E-field probe, a spatial mutual orthogonal configuration is adopted to achieve a better isotropic performance, as shown in Fig.3. The angle between each dipole and the probe axis equals to 54.7. Three dipoles of this type mounted in a triangle arrangement result in an isotropic behavior of the whole system, if the influence of the dielectric substrate could be neglected. Beside for this arrangement, some others are used in special cases [6].

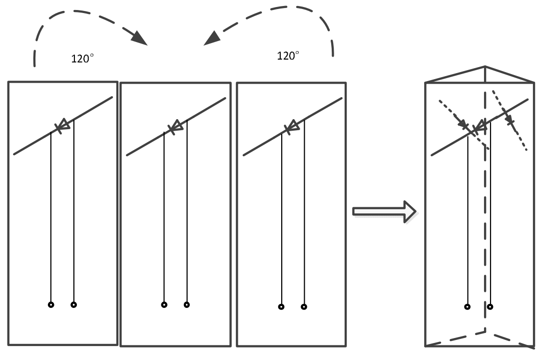


Fig.3 Configuration of the isotropic E-field probe

The induced voltage at the midpoint of each dipole can be transformed into a DC-voltage using a schottky diode at the midpoint. The transformed signal could be measured via an external metering unit through a high impedance transmission line.

## III. FABRICATION AND CALIBRATION

Fig. 4 Photograph of the 100MHz~60GHz dipole

Fig. 4 shows the photograph of the 100MHz~60GHz dipole. The dipole consists of tapered resistive TaN film. A high sensitive schottky diode is bonded in the middle of the dipole to transform the radiation signal into a DC-voltage, which is transmitted to an external metering unit through a high impedance transmission line.

(a) inside view (b) side view

Fig. 5 Photograph of the 100MHz~60GHz E-field probe

The photograph of the 100MHz~60GHz isotropic E-field probe is shown in Fig.5. The mutually orthogonal configuration of three dipoles is mounted on the customized foam, which will support the dipoles without any influence to the measured EM radiation environment.

The 100MHz~60GHz isotropic E-field probe is calibrated and measured using a transferred-standard probe in an GTEM cell and anechoic chamber, as shown in Fig.6. The power amplifier used in the measurement system is AV387XX series solid power amplifiers fabricated by The 41st Institute of CETC.

(a) GTEM cell (b) anechoic chamber

Fig. 6 Photograph of E-field probe calibration

Fig.7 shows the measured dynamic range of the E-field probe. It can be seen that the sensitivity of the E-field probe is less than 0.7V/m and the maximum value of the measured E-field strength is more than 400V/m.

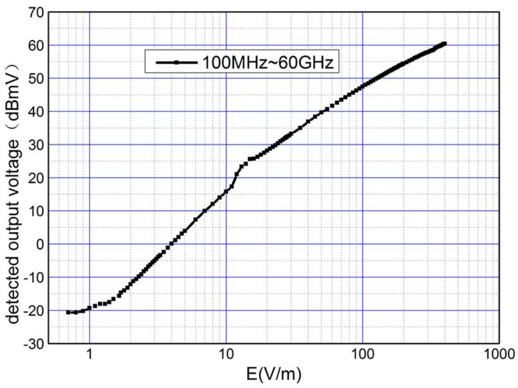


Fig. 7 Measured dynamic range of the E-field probe

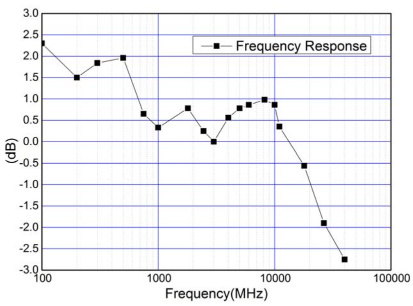


Fig. 8 Frequency response of the E-field probe

Fig. 8 presents the frequency response of the E-field probe. The frequency response of the probe, which is determined by the nonlinear circuit equivalent model in Fig.2, is within ±3dB from 100MHz~60GHz.

Fig.9 shows the isotropic response of the E-field probe. Measurements are made and recorded as the probe is rotated through 360° about the handle's longitudinal axis. The isotropic response with respect to angle, guaranteed by spatial mutually orthogonal dipole configuration, is within ±1 dB.

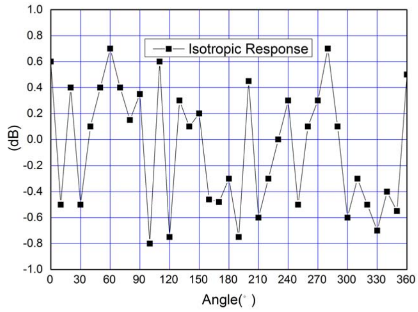


Fig. 9 Isotropic response of the E-field probe

## IV. Conclusions

In this paper, a 100MHz~60GHz isotropic E-field probe with exponential distributed lumped resistors described. Facilities of realization and necessary design steps during development are discussed. This probe is suitable for E-field radiation strength measurements and, consequently, for diagnosis of EM environment. The measurement ability is from 0.7V/m~400V/m from 100MHz~60GHz. The configuration of the spatial mutually orthogonal dipoles achieves the isotropic response within ±1dB. The broad-band isotropic E-field probe is designed to serve as measuring equipment for EM environment diagnosis.

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