

A Compact High-sensitivity Tangential E-Probe With Resonator and Coupled Balun

Shang Zhang¹, Zhen-Guo Liu¹, Zhipeng Chen¹, Mengzi Li¹, and Weibing Lu¹

¹Southeast University

April 15, 2022

Abstract

A compact high-sensitivity probe for sensing up tangential E-field is proposed and measured in this paper. The probe is consisted of an electric dipole with patches used to induce the tangential E-field, a resonator made up of open circuit stubs (capacitor) and short circuit stubs (inductor), for achieving a specific resonance, and a compact coupled balun for transforming the differential- mode voltage into the single output voltage and impedance matching. The probe is fabricated on five-layer dielectric lamina. Compared with the referenced broadband probe, the measured $|S_{12}|$ of the probe is enhanced by 18.81 dB. The proposed probe in this paper is validated with simulation and measurement.

A Compact High-sensitivity Tangential E-Probe With Resonator and Coupled Balun

Shang Zhang^{1,2}, Zhenguo Liu^{1, 2, 3}, Zhipeng Chen^{1, 2}, Mengzi Li^{1, 2}, Weibing Lu^{1, 2, 3}

¹ *State Key Laboratory of Millimeter Waves, Southeast University, Nanjing China.*

² *School of Information Science and Engineering, Southeast University, Nanjing, China.*

³ *Purple Mountain Lab., Nanjing, China.*

Email: liuzhenguo@seu.edu.cn

A compact high-sensitivity probe for sensing up tangential E-field is proposed and measured in this paper. The probe is consisted of an electric dipole with patches used to induce the tangential E-field, a resonator made up of open circuit stubs (capacitor) and short circuit stubs (inductor), for achieving a specific resonance, and a compact coupled balun for transforming the differential- mode voltage into the single output voltage and impedance matching. The probe is fabricated on five-layer dielectric lamina. Compared with the referenced broadband probe, the measured $|S_{12}|$ of the probe is enhanced by 18.81 dB. The proposed probe in this paper is validated with simulation and measurement.

Introduction: With the increase of operating frequency modern radio frequency (RF) integrated circuits have become more and more miniaturized, which results printed circuit board (PCB) has become more dense. Thus, unexpected electromagnetic radiation coupling between some sensitive components will affect the normal operation of RF integrated circuits, resulting in very serious electromagnetic compatibility (EMC) issues [1]. To improve the performance of RF integrated circuits, a proper electromagnetic analysis model is needed to determine the location of interference source in the RF integrated circuits, which is the key to solve EMC issues.

In recent year, the near-field scanning technology for detection location of interference sources has been developed rapidly [2-3], which play significant role in EMC problems. The probe used to sample E-field component is the key part of the near-field scanning measurements. Much effort has been devoted to studying the normal E-field probe [4-6], such as how to design the miniaturized probe and improve the

working frequency band of probe for wideband measurements, but less attention has been paid to the probe detected the tangential component of E-field. Yan proposed a broadband tangential E-probe loaded with electric dipole and integrated balun for the near-field measurement covering the GPS band [7]. However, for integrated circuits working in narrowband, the high-sensitivity probe detected tangential E-field can convey more power to the instruments, therefore, a weaker electric field can be detected. A resonant tangential E-probe [10] has high sensitivity for sensing up the weak electric field, compared with it, the structure of the resonator in the probe proposed in this work is simpler and the coupled balun without via fence has more concise structure. Moreover, the performance of this probe is better.

In this paper, a compact high-sensitivity probe for capturing tangential E-field with resonator and coupled balun is suitable for locating the noisy sources or the electromagnetic interference sources of circuits working in narrow band. The proposed probe has been fabricated and measured.

Probe structure: Fig. 1 shows the overall structure of the probe with resonator and coupled balun based on 4-layer PCB. Fig. 2(a) exhibits the layout of the probe with physical dimensions. The structure from top to bottom is the top layer, the middle layer 1, the middle layer 2 and the bottom layer. Both the top and bottom layers are copper planes, which can provide the currents return paths and shield the external field. The middle 1 layer is the metal grounding plane of coplanar waveguide. In the middle 2 layer, the folded electric dipole and the resonator composed of open- and short-circuit stubs as well as the coupled balun are cascaded in turn. Fig. 2(b) shows the stack-up of the resonator probe, which is made up of three layers of 0.254-mm thick Rogers4350B and two layers of 0.2 mm thick Rogers4450F.

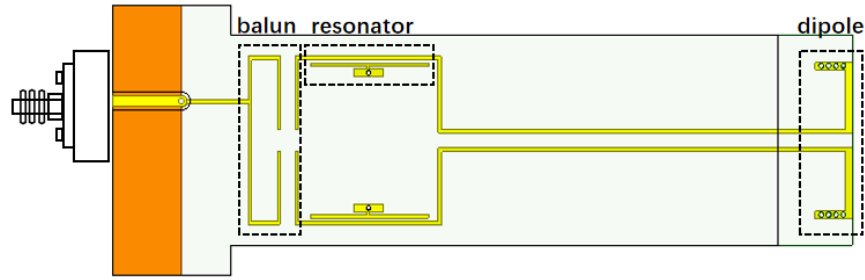


Fig. 1 Overall top view of the E-probe

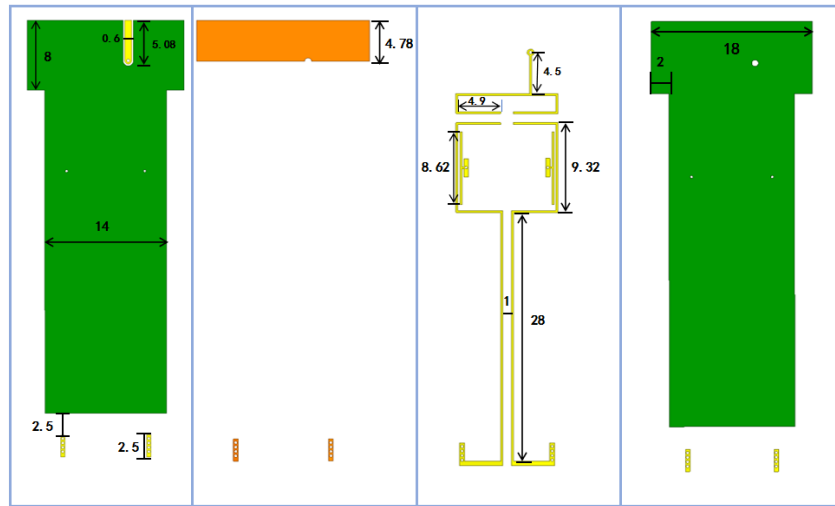


Fig. 2(a) Top view and layout of each layer with physical dimensions (unit: mm)

The E-probe is mainly divided into improved dipole, resonator and coupled balun. The folded dipole arm connected with three patches [10] through hole vias is used

Top Layer	0.017mm
Rogers 4350B	0.254mm
Mid1 Layer	0.017mm
Rogers 4450F	0.2mm
Rogers 4350B	0.254mm
Rogers 4450F	0.2mm
Mid2 Layer	0.017mm
Rogers 4350B	0.254mm
Bottom Layer	0.017mm

Fig. 2 (b) Stack-up of the probe

as the induced end in the front of the probe, mainly to increase the contact area with the tangential electric field to enhance the sensitivity of this probe. The end of the resonator is connected with the dipole and the other end is connected to the coupled balun which converts the differential mode voltage into the common mode voltage. The other end of the coupled balun is connected with the strip line which is connected to conductor-backed coplanar waveguide CB-CPW through a signal via. The current generated at the probe tip through the electromagnetic field to be measured, and then flows to the SMA connector through the resonator, the coupled balun, the signal via and the CB-CPW.

A. Resonator: Compared with the broadband probe, the electric field probe with resonator has higher sensitivity working at narrow-band frequency [8]. The capacitor and inductor are the parts of the resonator, open-circuited and short-circuited transmission line can be used for the resonator which has a high quality factor. The resonator shown in Fig. 3 is loaded into the probe designed in the paper, the function of open-circuited stub is equivalent to capacitor, and the function of short-circuited stub is equivalent to inductor. The length of open-circuited stub and short-circuited stub can be used to tune the resonant frequency. Fig. 3 shows the specific dimensions of open-circuited stub and short-circuited stub when the probe works at 1.320 GHz resonant frequency. The initial value is set to be less than $\lambda/8$ and the specific values can be obtained by sweeping parameters to achieve specific resonance in HFSS.

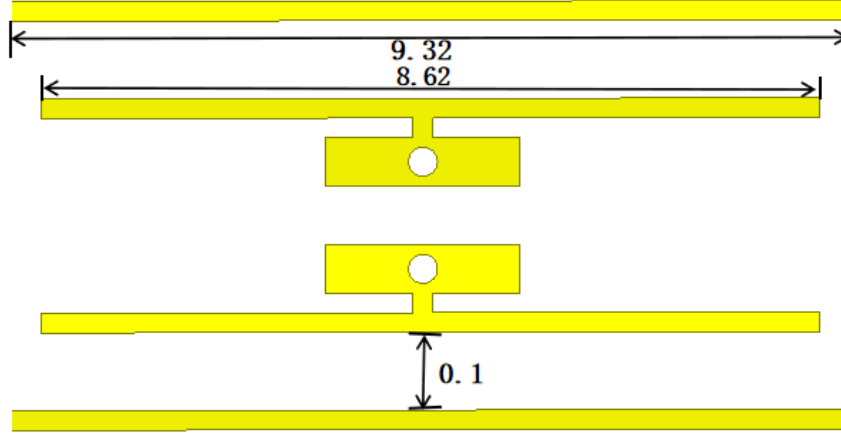


Fig. 3 The resonator with physical dimensions (unit: mm)

B. Coupled balun: The function of the coupled balun is to achieve the transition from balanced transmission line to unbalanced transmission line. Since the electric dipole at the front of the probe is the balanced transmission, but the output port of CB-CPW is unbalanced port, thus, a balun is needed to achieve the transformation from balanced to the unbalanced. Fig. 4 shows the coupled balun and its specific dimensions adopted by the probe in this paper. The coupled balun is used to transform the differential-mode voltage induced by the electric dipole into the common-mode voltage and the transformation of the input impedance at the resonator to the matched 50Ω impedance is obtained [9].

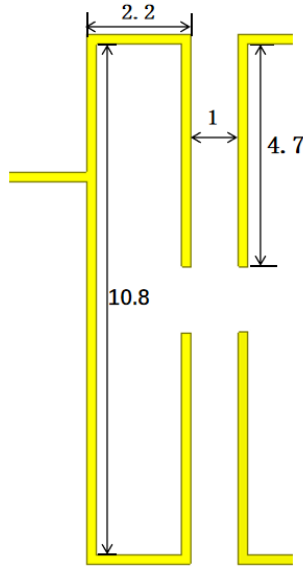


Fig. 4 The embedded balun with physical dimensions (unit: mm)

Experiments and analysis: In order to demonstrate the performance of the tangential E-probe with resonator and coupled balun proposed in the paper, a conventional broadband tangential E-probe published in [7] is used to compare. Fig. 5(a) is the physical picture of this probe. The measurement setup is shown in Fig.

5(b), and the distance between the tip of the probe and the microstrip line is 1 mm. In the measurement, it should be noted that in order to obtain the maximum electric field component, the probe was placed away from the center of the standard microstrip line. After HFSS optimization simulation, it is found that the peak value of the electric field of the microstrip line is at 2 mm away from the center of the microstrip line. The comparison between simulated results and measured ones is shown in Fig. 5(c). As show in Fig. 5(c), measured results agree well with simulated ones except for a little deviation in frequency between them. The simulated result of the peak value captured by the probe is -24.39 dB at 1.320 GHz, while the measured one is -24.75 dB at 1.334 GHz. The possible reasons is that there are machine tolerances in the manufacturing process and at same time it is difficult to accurately control the gap between the microstrip line and the tip of probe. Compared with the traditional broadband probe, the value of $|S_{12}|$ is improved by improved by 18.81-dB at 1.334 GHz.

Conclusion: To improve the measurement sensitivity in narrow band, a compact high-sensitivity tangential E-probe with resonator and coupled balun is proposed and tested in this paper. The resonator composed of open-circuited and short-circuited transmission line can enhance the sensitivity. The coupled balun is to complete the transition from differential-mode voltage into common-mode voltage. The $|S_{12}|$ measured by this probe is improved by 18.81 dB at 1.334 GHz. The compact high-sensitivity tangential E-probe is more suitable for weak signal measurement.

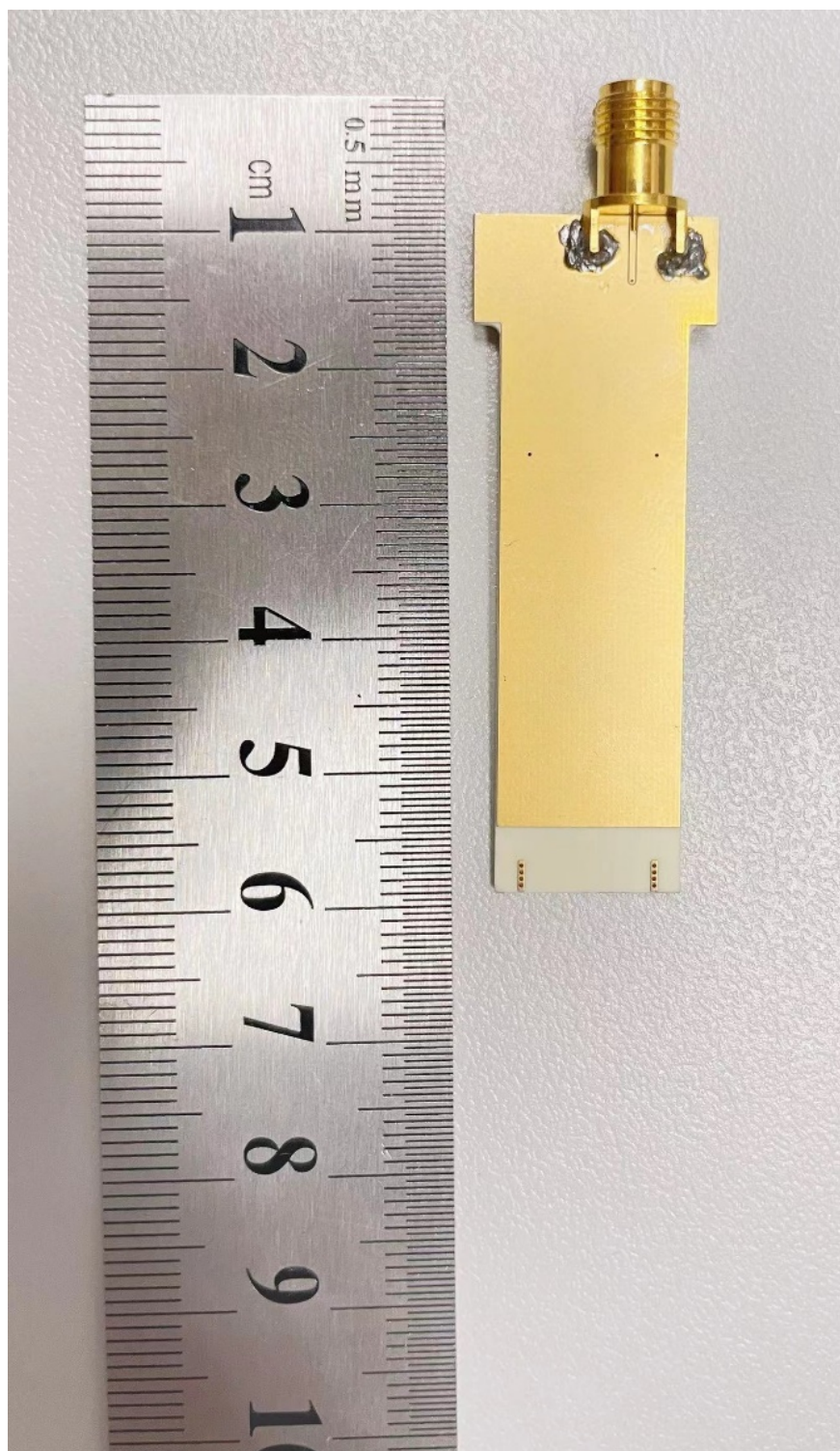


Fig. 5(a) *Photograph of the probe*



Fig. 5(b) *The measurement setup of the probe*

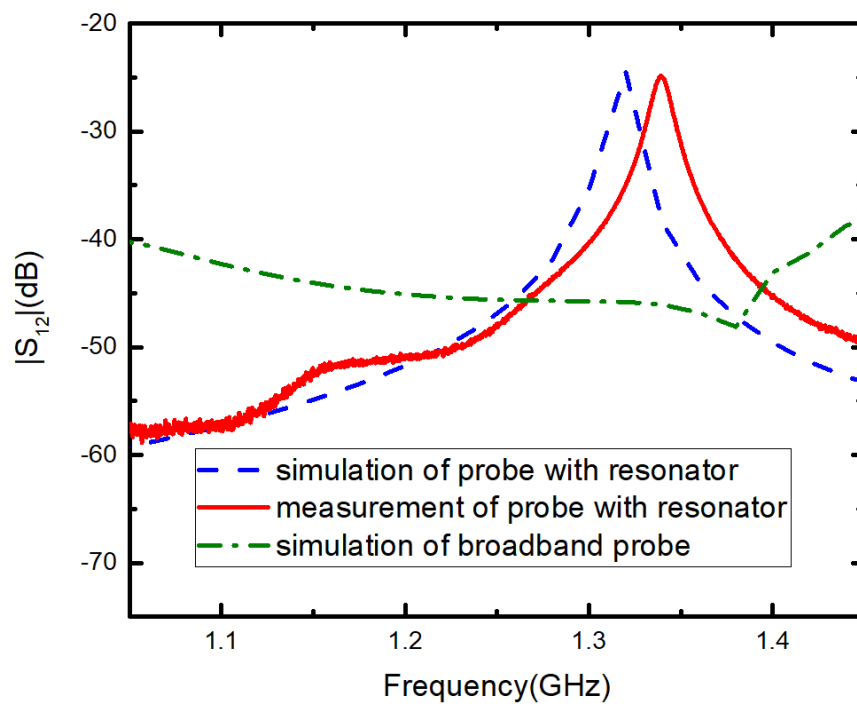


Fig. 5(c) $|S_{12}|$ comparisons with the broadband tangential probe

Acknowledgments: This work was supported by the National Natural Science Foundation of China under Grant 61671147.

References

1. M. Ramdani *et al.* , "The Electromagnetic Compatibility of Integrated Circuits—Past, Present, and Future," in *IEEE Transactions on Electromagnetic Compatibility* , vol. 51, no. 1, pp. 78-100, Feb. 2009.
2. H. Weng, D. G. Beetner and R. E. DuBroff, "Prediction of Radiated Emissions Using Near-Field Measurements," in *IEEE Transactions on Electromagnetic Compatibility* , vol. 53, no. 4, pp. 891-899, Nov. 2011.
3. H. Qiu *et al.* , "Movable Noncontact RF Current Measurement on a PCB Trace," in *IEEE Transactions on Instrumentation and Measurement* , vol. 66, no. 9, pp. 2464-2473, Sept. 2017.
4. David Baudry, A. Louis, and B. Mazari, "Characterization of the Open-Ended Coaxial Probe Used for Near-Field Measurements in EMC Applications," in *Electromagnetics Research*, vol. 60, 311-333, 2006.
5. W. Liu, Z. Yan, J. Wang, X. Yan and J. Fan, "An Ultrawideband Electric Probe Based on U-Shaped Structure for Near-Field Measurement From 9 kHz to 40 GHz," in *IEEE Antennas and Wireless Propagation Letters* , vol. 18, no. 6, pp. 1283-1287, June 2019.
6. Z. Yan, J. Wang, W. Zhang, Y. Wang and J. Fan, "A Miniature Ultrawideband Electric Field Probe Based on Coax-Thru-Hole via Array for Near-Field Measurement," in *IEEE Transactions on Instrumentation and Measurement* , vol. 66, no. 10, pp. 2762-2770, Oct. 2017.
7. J. Wang, Z. Yan, W. Liu, D. Su, X. Yan, "A Novel Tangential Electric-Field Sensor Based on Electric Dipole and Integrated Balun for the Near-Field Measurement Covering GPS Band," in *Sensors*. 2019, no.9: 1970.
8. E. Song and H. H. Park, "A High-Sensitivity Electric Probe Based on Board-Level Edge Plating and LC Resonance," in *IEEE Microwave and Wireless Components Letters* , vol. 24, no. 12, pp. 908-910, Dec. 2014.
9. J. Yan, H. Zhou and L. Cao, "A Novel Filtering Balun and Improvement of Its Isolation Performance," in *IEEE Microwave and Wireless Components Letters* , vol. 27, no. 12, pp. 1056-1058, Dec. 2017.
10. J. Wang, Z. Yan, W. Liu, D. Su, X. Yan and J. Fan, "A High-Sensitivity Resonant Tangential E-Probe With Loaded Improved Dipole and Embedded Integrated Balun," in *IEEE Transactions on Instrumentation and Measurement*, vol. 68, no. 8, pp. 3042-3044, Aug. 2019.