Research on Novel Loop Antenna in Microwave Cavity Measurement of Permittivity

Hai Zhang, Baoqing Zeng, Lei Ao, Nannan Li, Jing Guo, Zhiwei Peng, and Ping Wang

***Abstract*—Electromagnetic coupling effects on a novel loop antenna in a TE_{011} circular cavity are studied theoretically and experimentally. This novel loop coupling antenna is developed for avoiding and suppressing the spurious modes in the TE_{011} circular cavity of the microwave permittivity measurement system. The operating principles and impedance of the novel loop antenna are investigated. This method has the advantage of simple setting and fast tuning of the system. The experimental results are compliant with simulations.**

***Index Terms*—Cavity, couple, loop antenna, resonator.**

I. Introduction

Application of materials in the design of microwave modules and components, microelectronics and communication industries requires the exact knowledge of material parameters such as permittivity, conductivity and permeability. Couplers are the key component in the microwave permittivity measurement system. In the conventional TE_{011} mode circular cylindrical cavity measurement system, several coupling methods such as:1) two coupling loops in the middle of the cavity wall [1]-[2] and 2) two coupling holes at the upper end plate of the cavity [3]-[4], and etc, have been adopted in order to excite the TE_{011} mode.

It is important to guarantee the cavity have a clear resonant mode in the measurement. In most of these methods, the grooves, gaps or the absorbing material in the lower end plate of the cavity is introduced to avoid or suppress the degenerate TM_{111} mode. The dimensions of the grooves should be calculated exactly and machined accurately. On the other hand these additional designs may introduce errors because of the inflection of the field configurations especially in the region of grooves or gaps.

To solve this problem, we design a novel loop coupling antenna in TE_{011} mode circular cavity measurement system. As shown in Fig. 1(a), we applied a novel loop antenna in a circular cylindrical cavity of TE_{011} mode. The loop antenna is located in the center of upper end plate. It consists of two parts: 3 half circle loops and 3 feed traces. The half loops, each shorted on its one side, has been associated to a wire fed by a 50 ohm Type-N connector. The configuration is shown in Fig. 1(b) and (c).

Manuscript received September 14, 2012; revised December 19, 2012.
Hai Zhang, Baoqing Zeng, Nannan Li, Jing Guo, Zhiwei Peng, and Ping Wang are with the National Key Laboratory of Science and Technology on Vacuum Electronics, University of Electronic Science and Technology of China, Chengdu, Sichuan, 610054, P. R. China (corresponding author to provide phone: 86-028-83200158; e-mail: bqzeng@uestc.edu.cn).
Lei Ao is with School of Physics Electronics, University of Electronic Science and Technology of China (e-mail: al20060608@126.com).

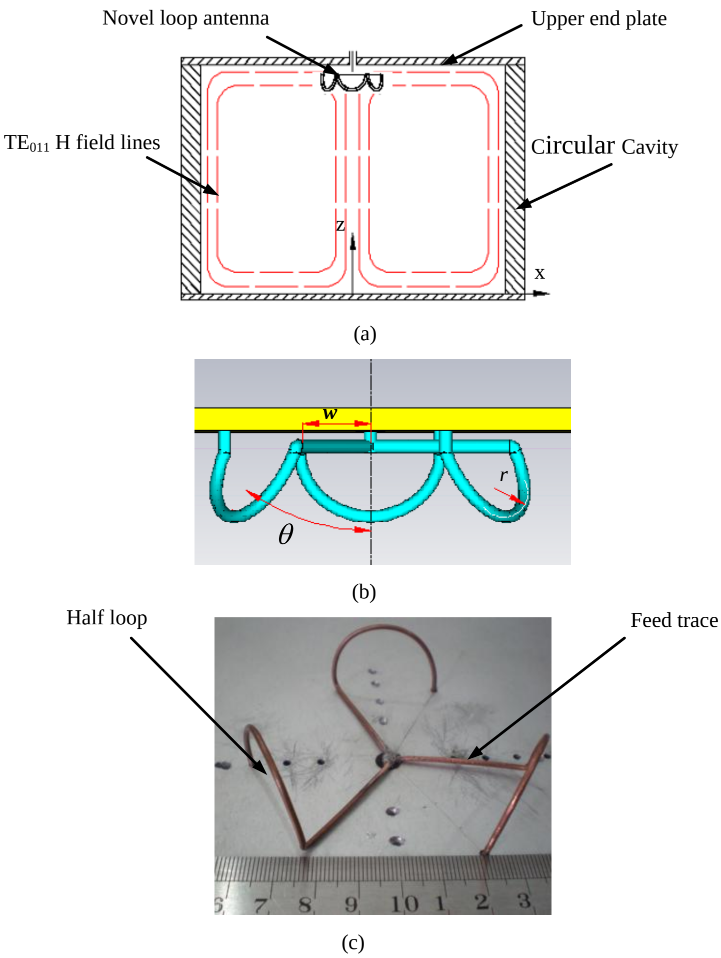

Fig. 1. (a) Structure of the cavity resonator (b) Geometry of the loop antenna (c) Photograph of the loop antenna

The theoretical coupler performances have been computed with CST Microwave Studio Software and compared to the measured results. Regarding this part of study, we propose a physical explanation of the loop behavior. Then parametric studies give additional information and help us to increase our knowledge of this design.

Description of the loop antenna as shown in Fig. 1(b): r is the loop radius, w is the length of the feed trace, and θ is the angle between the loop and the axes of the cavity.

Results: The radius of the circular cylindrical cavity presented here is 230 mm, and its height is 328 mm. By an optimized choice of the above parameters, it is possible to achieve a clear TE_{011} mode solution presented in Fig. 2. The return loss has been computed and measured.

For the case of simple one loop [5](radius ≈ 15 mm, located at about 115mm from the axis of the cavity), two TM_{111} polarization degeneracy modes and TE_{011} mode can be excited simultaneously as shown in Fig. 3. The circles on the $|S_{11}|$ curves represent the resonant frequencies of the

DOI: 10.7763/IJIEE.2013.V3.343

measurement cavity.

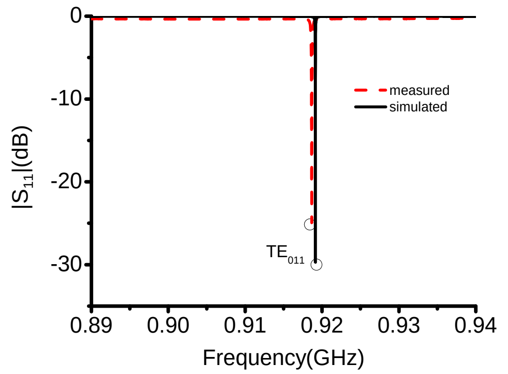

Fig. 2. Return loss of novel loop (---) measured (—) simulated

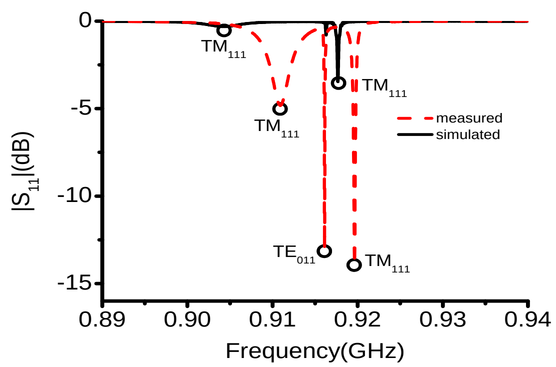

Fig. 3. Return loss of simple one loop (---) measured (—) simulated

For the case of novel loop ($r \approx 20$ mm, $w \approx 40$ mm, $\theta \approx 40$ º), the shape of the $|S_{11}|$ curves shows only one TE_{011} prominent resonance. It is easy to distinguish between the TE_{011} and TM_{111} mode by means of Q factor, because the Q factor of the TE_{011} mode is much larger than that of TM_{111} mode. The spurious TM_{111} modes have been suppresses consumedly. We have investigated this and concluded to the following assumption. We thread the 3 half loops in the symmetrical direction generating the symmetrical surface current. This kind of current distribution will excite the same symmetrical magnetic flux as the TE_{011} mode magnetic field.

II. Parametric Studies

To increase our understanding of this coupling effect, we proceed to theoretical parametric studies. We investigate the dimension of r, w and θ. We show the influence of parameters on resonance curves. As noticed in [6]-[8] the input impedance of the coupling loop antenna can be calculated

$$Z = R_0 + j\varpi L_0 + \sum_a \frac{2\pi i f M_a^{\ 2}}{\frac{\pi V}{c^2}\left(f_a^{\ 2} - f^2 + i\frac{f f_a}{Q_a}\right)}. \quad (1)$$

Varying these parameters thus enables an optimum of power transfer to be achieved by adjusting real part of the impedance to equal the characteristic impedance of the coaxial line and introducing a suitable reactance to tune out the reactance.

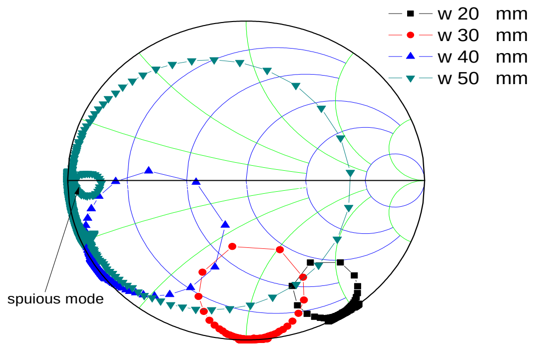

Fig. 4. Measured input impedance versus w

A. Length w

In Fig. 4, we present input impedance curve versus w. The shape of resonance curve shows only one prominent resonance.

The w varies between 20 and 50 mm. Note that there are no modifications on the other pair loop parameters ($r \approx 15$ mm, $\theta = 0$ º). In the TE_{011} mode field, the flux linkage thread through the loop mostly depends on the radial component of the H field. If we set the loop coupler in the location of half radius, the magnetic flux through the loop is the maximum. However, with the increment of w, the distribution of the surface current will be more complex, the higher order modes effect and the loss in the surface of the loop coupler become obvious.

The w does not have a lot of influence on the shape of impedance curve. The resonance of the system remains and the frequency of resonance changes little. But the resonance circles rotate clockwise towards the generator with the increase of w. The match situation will be improved at first, and the better case is for about $w \approx 40$ mm. When $w \approx 50$ mm, the TE_{011} mode of the cavity decreases obviously, and there is an obvious spurious resonance circle of TM_{111} mode.

In the view of feeding, w affects the mutual inductance deeply. When $w \approx 50$ mm, the distribution of the surface currents will be more complex and cannot be assumed as uniform. The effect of spurious modes becomes obvious. The variations demonstrate that the magnitude of resonance is sensitive w.

B. Radius r

In Fig. 5, the input impedance has been measured for different values of r. This parameter varies from 5 mm to 40 mm. Note that there are no modifications on the other loop parameters ($w \approx 20$ mm, $\theta = 0$ º).

The resonance condition of the cavity firstly is improved with the increase of radius. And the change of the input impedance is accord with (1), if we think of the influence of the r on the phase. The resonance circles also rotate clockwise towards the generator with the increase of r.

When the size of the loop is small compared with a wavelength, saying r less than $0.1\lambda_g$, the current in the loop may be assumed uniform. The best case is for $r \approx 25$ mm. The radius greatly affects the magnitude and phase of the resonance curve. When the radius of the loop increases to 40 mm, the coupler cannot be regard as a small loop coupler. The relative magnitude of the spurious modes will be added. The distribution of the surface current will be more complex

and the spurious TM_{111} modes appear. A little resonance circle of TM_{111} mode appears as shown in Fig. 5.

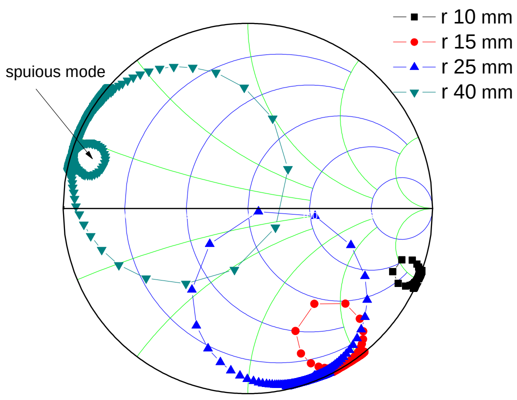

Fig. 5. Measured input impedance versus *r*

C. Angle θ

In Fig. 6, we present the input impedance curve versus θ. The angle varies between 0 ° and 50 °. Note that there are no modifications on the other pair loop parameters ($r \approx 20$ mm, $w \approx 40$ mm).

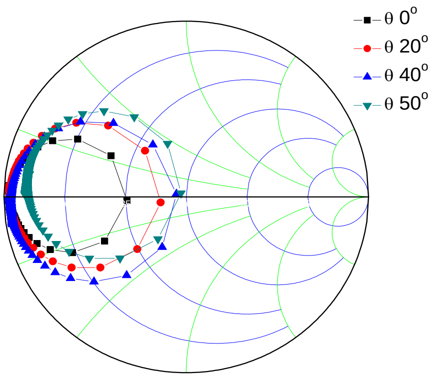

Fig. 6. Measured input impedance versus θ

When $\theta = 0$ °, the coupling depends on the radial magnetic field. As the angle increases in this range, the axial flux line can also thread through the face of loops. The electromagnetic coupling between the loop coupler and the cavity field affects the impedance behavior. By adjusting θ, the flux through the loop face can be changed and we assume the loss remains constant. And Fig. 6 shows the resonance circles do not rotate with the change of θ, because the distance from the measured plane to the end of loop does not change with the increase of θ.

When the angle adjusts from 0 ° to 50 °, the mutual inductance increases first and it has a maximum at about 45 °. In this case the magnetic field line almost perpendicularly passes through the loop face. The field and currents distribution of the resonator are almost unaffected by the presence of the loop. Hence a good impedance match can be obtained. The spurious TM_{111} mode almost completely disappears. When tuning the coupler, we can use this method to decrease the effect of the local higher order fields and guarantee that the cavity has a clear TE_{011} resonant mode.

III. Conclusion

Compared with the parameter *w* and *r*, the resonance changes gently with θ. This is convenient for us to tune the system. We can firstly tune the parameters *w* and *r* to get the approximately match then tune the θ to get exact match and suppress the spurious modes.

A novel loop antenna has been proposed. A clear TE_{011} mode has been obtained in our cavity resonator for measuring the complex permittivity. The operating principles and the coupling effects are investigated. We have seen through parametric studies that the cavity has a clear TE_{011} mode when the *w*, *r* and θ of the novel coupler modify the resonance curve of the system. This method has the advantages of simple setting of the apparatus and fast tuning of the coupling. Simulation and experimental results show a reasonable agreement.

References

[1] X. Y. Fang, D. Linton, C. Walker, and B. Collins, "A Tunable Split Resonator Method for Nondestructive Permittivity Characterization," *IEEE Trans. Instrumentation and Measurement*, vol. 53, pp. 1473-1478, Dec. 2004.

[2] H. Yoshikawa and A. Nakayama, "Measurement of Complex Permittivity at Millimeter-Wave Frequencies With an End-Loaded Cavity Resonator," *IEEE Trans. Microwave theory and techniques*, vol. 56, pp. 2001-2007, Aug. 2008.

[3] L. En, Z. Nie, G. Guo, and Q. Zhang, "Broadband measurements of dielectric properties of low-loss materials at high temperatures using circular cavity method," *Progress In Electromagnetics Research*, vol. 92, 103-120, 2009.

[4] K. Chang, *Encyclopedia of RF and Microwave Engineering*, Hoboken, pp. 591, N.J, 2005.

[5] H. Zhang, B. Q. Zeng, L. Ao, and Z. Zhang, "A novel Dual-loop Coupler for One-port Cylindrical Cavity Permittivity Measurement," *Progress In Electromagnetics Research*, vol. 127, pp. 537-552, 2012.

[6] Y. Huang, R. M. Narayanan, and G. R. Kadambi, "Electromagnetic Coupling Effects on the Cavity Measurement of Antenna Efficiency," *IEEE Trans. Antennas and Propagation*, vol. 53, pp. 3064-3071, Nov. 2003

[7] E. C. Robert, *Foundations for Microwave Engineer*, New York, pp. 523-525, 1992,

[8] E. U. Condon, "Forced Oscillations in Cavity Resonators," *Journal of Applied Physics*, vol. 12, pp. 129-132, Feb. 1941.

H. Zhang received the bachelor degree (material science and engineering) in 2000 from Heifei University of Technology, Heifei, P. R. China, and the master degree (physical electronic) in 2006 from University of Electronic Science and Technology of China, Chengdu, P. R. China and has worked toward his PhD (physical electronic) from University of Electronic Science and Technology of China, Chengdu, P. R. China since 2009. He researches the measurement technology of the electromagnetic properties by a wide range of techniques and at frequencies ranging up to millimeter wave.