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Effect of Varied Probe Length on the Resonant Frequency of a Circular Cross-Sectional Cavity

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ABSTRACT

A simple design of a metallic circular cross-sectional air-filled cavity is presented. Two probes of varied lengths are used to excite TE_{112}-mode wave into the cavity to give a resonant frequency of 5.86 GHz. The experiments show that the resonant frequency of the cavity resonator decreases as the lengths of the probes are increased. The shortest probe in the range of study gives the closest resonant frequency to the one desired.

***Keywords**: Circular cavity, Probe*

Introduction

An electromagnetic cavity is a volume filled with air or other dielectric, limited by walls of electrical type (interfacing with a conductor) or of magnetic type (interfacing with a dielectric of higher permittivity). The cavity can have, in principle, any geometrical form but in practice, it has a cylindrical form with rectangular or circular cross-section. If, with an appropriate method, an electromagnetic field is introduced into the cavity, a standing wave will be produced whenever the conditions of resonance exist. A certain electromagnetic energy is than said to be stored in the

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cavity. The study of the conditions of resonance of the cavity allows defining the resonant modes as well as the resonant frequencies of a cavity [1]. Cavities find applications in filters (in satellite, radar, wireless communications etc.) for their special characteristic of having very high quality factor (Q) (up to few thousands) when combined with high permittivity dielectric resonator [2]. The importance of cavities goes well away from their utilization as a resonant element or as a frequency-meter in the hyper-frequency circuits. They are, in fact, used for the determination of the complex permittivity of gases or of small dimension material samples. They are also used to fix the resonant frequency of solid-state or tube oscillators (such as klystron).

A number of techniques can be used to excite electromagnetic wave into a cavity, such as the use of probe coupler, aperture (slot) coupler by mean of a waveguide, and the use of loop coupler [3]. A probe – the stub contact panel socket, feeds the cavity presented in this paper. Being easily found in the market, the probe (shown in Figure 1) can be connected to the most commonly used semi-rigid microwave cables.

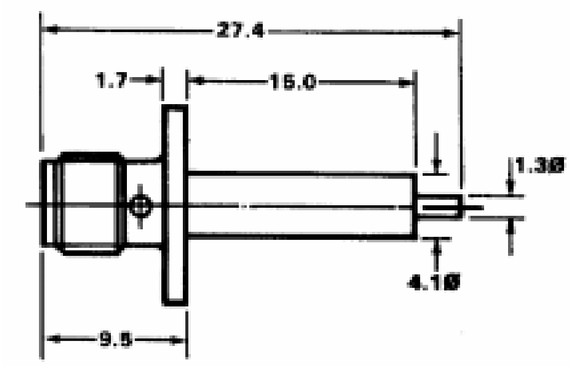

Figure 1: Stub Contact Panel Socket

A circular cross-sectional cavity of metallic walls is designed to resonate at 5.86 GHz and two probes (the stub contact panel sockets) are introduced at the input and output port of the cavity, respectively, to excite and collect the TE_{112}-mode wave. The length of the probes is varied to allow observation on its effect on the resonant frequency.

The Cavity

The design starts with the equation relating the resonant frequency to the dimensions of the circular cross-sectional cavity for a mode chosen, as given below [4]:

$$\left(f_r\right)_{mnp}^{TE^z} = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{\chi'_{mn}}{a}\right)^2 + \left(\frac{p\pi}{h}\right)^2} \tag{1}$$

where,

f_r : resonant frequency of TE_{mnp}-mode
χ'_{mn} : the mth root of Bessel function derivative of nth order.
a : radius of the cavity
h : half-length of the cavity
p = 1, 2, 3 …..
μ : permeability of the dielectric filling the cavity
ε : permittivity of the dielectric filling the cavity

For the chosen TE_{112}-mode and air-filled cavity, the values of *p*, χ'_{mn}, ε and μ are automatically fixed to 2, 1.8412, 8.854 × 10^{-12} F/m and 4π × 10^{-7} H/m respectively. Fixing the resonant frequency f_r at 5.86 GHz leaves us with the last two values *a* and *h* to be determined. A good combination of these values of *a* and *h* to give an optimal size of the cavity is found to be 25.00 mm and 31.965 mm respectively.The conductor chosen to be the wall of the cavity is aluminum. Considered as cheap, aluminum is also categorized as a good conductor with conductivity up to 3.54 × 10^7 S/m to reduce conductor loss in the cavity.

The probes are inserted into the cavity at the regions that has strong field component along the directions of the field solution [3]. For the chosen TE_{112}-mode, the field form is shown in Figure 2.

Figures 3 and 4 show the cavity layout and the complete cavity with the insertion of two probes.

Experiments are carried out by using a Vector Network Analyzer (VNA) where the forward reflection coefficients $|S_{11}|$ are measured for different lengths of probes. The lengths of probes chosen were 25 mm, 20 mm, 15 mm, 10 mm, 5 mm, 4 mm, 3 mm, and 1.5 mm. This can be done by soldering a piece of straight metallic line to the metallic point of the stub contact panel socket to get the length desired.

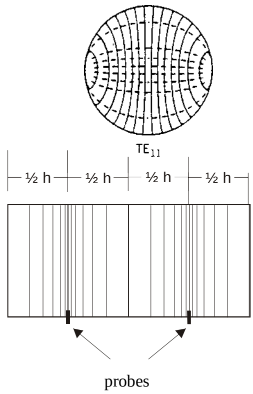

Figure 2: Electric Field Form

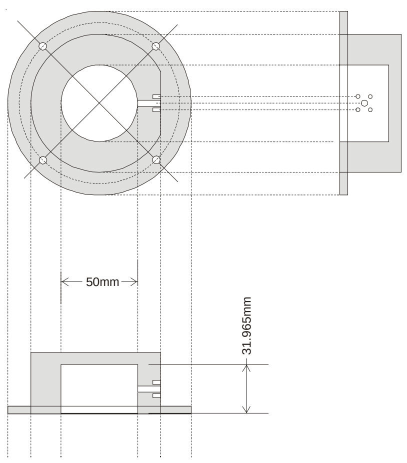

Figure 3: Cavity Layout

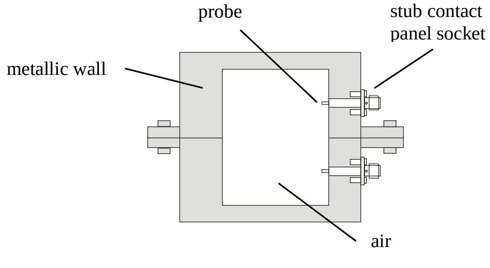

Figure 4: Complete Cavity Diagram

Experimental Results

From the results obtained, the signal is totally disturbed starting from the probe length of 6 mm and above. Observation on the resonant frequency therefore can only be done for the lengths of 5 mm, 4 mm, 3 mm and 1.5 mm and Figures 5-8 show the $|S_{11}|$ obtained respectively.

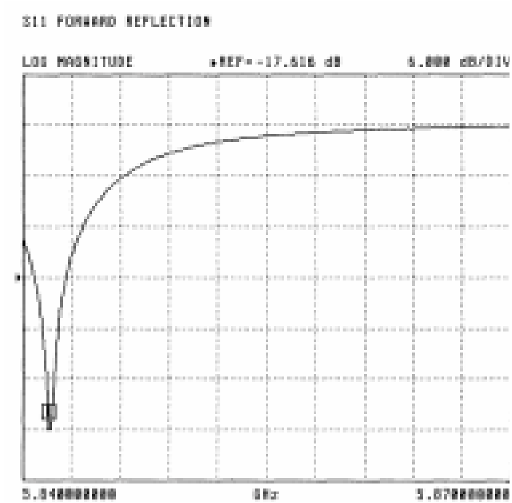

Figure 5: $|S_{11}|$ of Cavity with 5 mm Probe Length

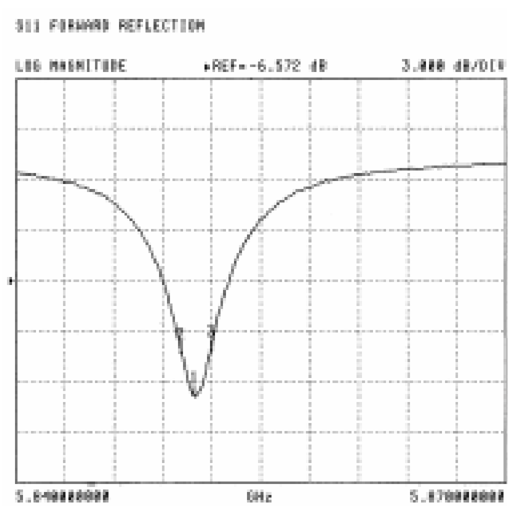

Figure 6: $|S_{11}|$ of Cavity with 4 mm Probe Length

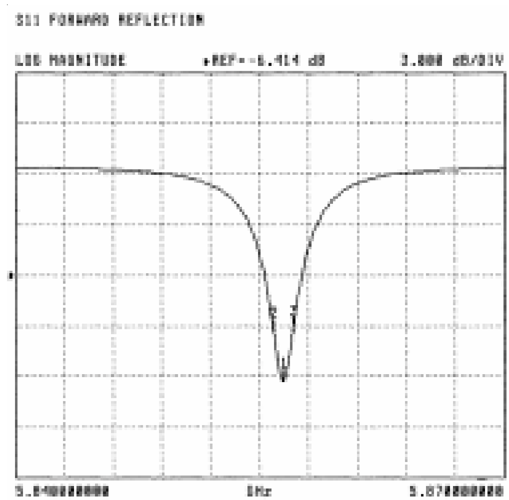

Figure 7: $|S_{11}|$ of Cavity with 3 mm Probe Length

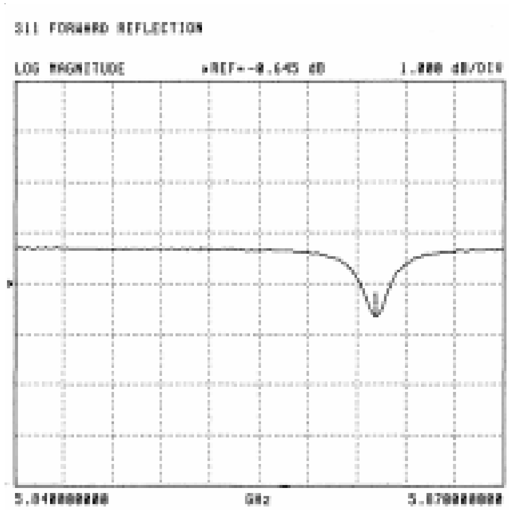

Figure 8: $|S_{11}|$ of Cavity with 1.5 mm Probe Length

It can be seen from the results that the resonant frequency of the cavity resonator decreases as the lengths of the probes are increased, as summarized in Table 1 and Figure 9.

Table 1: Resonant Frequency with Respect to Probe Length

Probe length (mm)	Resonant Frequency (GHz)
5	5.84165
4	5.85095
3	5.8565
1.5	5.8622

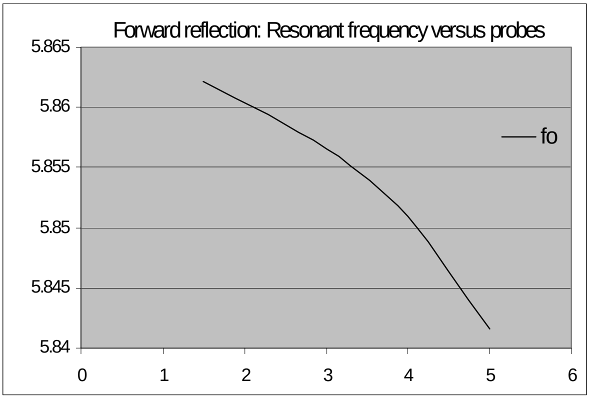

Figure 9: Resonant Frequency versus Probe Length

Amongst the lengths of probe studied, the shortest probe (1.5 mm) gives the closest resonant frequency to the one calculated, 5.86 GHz. However, the signal strength is found to be the lowest in this case, as shown by its $|S_{11}|$ which is only around 1.5 dB at the resonant frequency, whilst the value goes up to 36 dB for the case of 5 mm probe length.

Figure 10 shows the $|S_{11}|$ measured for the 1.5 mm probe length over a wider range of frequency. Other resonant frequencies are also found in the cavity. These resonant frequencies are all of other higher modes generated in the cavity.

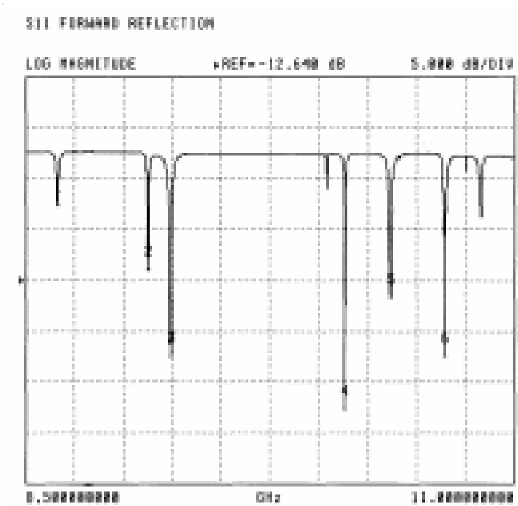

Figure 10: Measured $|S_{11}|$ over Wider Range of Frequency for 1.5 mm Probe

Conclusion

An air-filled circular cross-sectional cavity of metallic wall has been designed and tested to give a resonant frequency at 5.86 GHz for the fundamental mode TE_{11}. Two probes of varied length have been used to excite the wave and the experimental results show that the resonant frequency is shifted away from the calculated value as the length of the probes is increased, giving the best choice of length to be applied to the probe in order to obtain the most precise resonant frequency, which is the shortest probe (1.5 mm in this case of study).

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