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Improved Loaded Quality Factor of Cavity Resonators with Cross Iris Coupling

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The performance of circular, rectangular and cross irises for the coupling of microwave power to rectangular waveguide cavity resonators is discussed. For the measurement of complex permittivity of materials using cavity perturbation techniques, rectangular cavities with high Q-factors are required. Compared to the conventional rectangular and circular irises, the cross iris coupling structure provides very high loaded quality factor for all the resonant frequencies. The proposed cross iris coupling structure enhances the accuracy of complex permittivity measurements.

ELECTROMAGNETIC scattering through apertures is of great importance in microwave technology. Large number of theoretical and experimental investigations have been done in this field[1-5]. Modification of coupling mechanism of microwave power to the cavities is essential for improving the loaded quality factor of cavity resonators. Different coupling techniques such as probe (electric coupling), loop (magnetic coupling) and open guide (electric coupling) are used to couple power to the cavities. The simplest among them is the open guide coupling. In this category, generally circular/rectangular irises are employed. When a resonant cavity is coupled to an external load, its characteristics are considerably modified by the coupling element. For the investigation of the dielectric and magnetic properties of materials, microwave cavity resonator techniques are widely used[6,7]. Resonators of high Q-factor are used for the measurements. Hence the coupling mechanism of a cavity resonator has important role in improving the loaded Q-value. In the present investigation different types of iris coupling structures are analysed. A new coupling mechanism - cross iris coupling - for enhancing the loaded quality factor of the cavity resonator is proposed.

THEORETICAL ASPECTS

A cavity is considered to be a closed volume. The coupling system radiates power and this lowers the loaded Q-value of the resonator. The losses that usually occur in a cavity resonator are (1) dielectric loss (2) wall loss and (3) coupling loss. Let P_{Ld}, P_{Lw} and P_{Lc} are the time average power losses of a resonator, the total quality factor of the resonator is given by

$$Q_t = \omega_r \frac{W_s}{P_{Ld} + P_{Lw} + P_{Lc}} \tag{1}$$

or

$$\frac{1}{Q_t} = \frac{1}{Q_d} + \frac{1}{Q_w} + \frac{1}{Q_c} \tag{2}$$

Where ω_r is the resonant frequency and W_s is the energy stored in the cavity. The unloaded Q-value is given by

$$\frac{1}{Q_0} = \frac{1}{Q_d} + \frac{1}{Q_w} \tag{3}$$

For a cavity with given medium, Q_0 is constant. So the total loaded quality factor Q_t depends on the value of Q_c. The total loaded quality factor Q_t and unloaded quality factor Q_0 are related by the coupling parameter [8]

$$K = \left[\frac{Q_t - Q_0}{Q_t + Q_0} \right]^2 \tag{4}$$

The lower the value of K, the higher is the loaded Q-factor

From (2) and (3)

$$\frac{1}{Q_c} = \frac{1}{Q_t} - \frac{1}{Q_0} \tag{5}$$

Also the coupling coefficient[9]

$$k = \frac{Q_0}{1 + Q_t} \tag{6}$$

From (4) and (6) we get

$$K = \left[\frac{k}{2 + k} \right]^2 \tag{7}$$

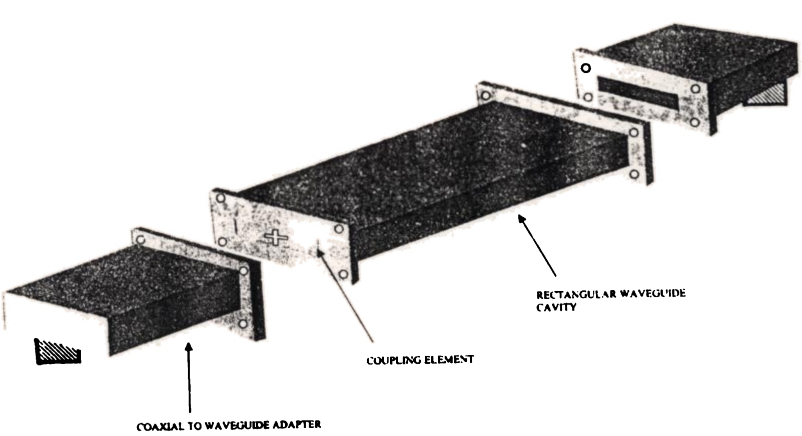

Fig 1 Rectangular waveguide resonator with iris coupling structure

In order to get higher loaded quality factor, coupling parameter K and hence coupling coefficient k should be low. The motivation of the present work is to design a coupling iris which will give higher loaded quality factor for all the resonant frequencies of a resonator.

EXPERIMENTAL DETAILS AND RESULTS

X-band transmission type rectangular waveguide cavity of length 13.5 cm is employed for the study. The iris is made on conducting metallic sheets. Since thick irises adversely affect input impedance and Q-value power should be coupled into or out of the cavity through irises in thin conducting sheets. In the present case sheets of thickness 0.1 mm are used for the fabrication of iris coupling elements. The iris coupling structure is held between the coaxial to waveguide adapter and the cavity (Fig 1). The cavity is connected to the two ports of the S-parameter Test Set and is excited in the TE_{10n} mode. Figure 2 shows the experimental set-up.

Different types of irises designed for the study are shown in Fig 3. Loaded Q-factor of the cavity with each coupling structure is determined from the amplitude response of the cavity ($Q_l = f_r / \Delta f$, where f_r is the resonance frequency and Δf is the 3dB bandwidth). Table 1 shows the loaded quality factor of the cavity with different iris structures. Rectangular irises of width 1 mm and lengths 5 mm, 6mm, 7mm, 8mm, and 9mm are selected for the study. The loaded quality factor of the cavity for each rectangular iris is measured. It is observed that, for each resonant frequency, the Q-factor varies with the length of the rectangular iris. Thus rectangular iris of 7 mm length gives comparatively high Q-factors.

Most commonly used type of iris structure is circular. Circular irises of diameters 5mm, 6mm, 7mm, 8mm and 9mm are taken for the measurement. From the Table 1, it can be seen that circular iris of 6 mm diameter gives high loaded quality factor at the resonance

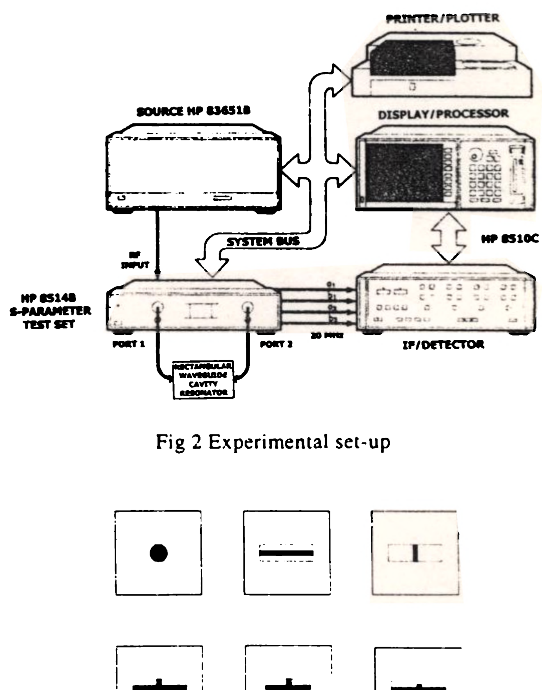

Fig 2 Experimental set-up

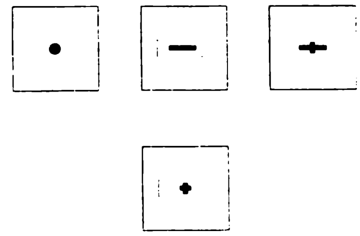

Fig 3 Different types of irises

TABLE 1 Loaded quality factor of cavity resonator for different types of irises

Frequency (GHz)	Diameter of Circular Iris						Length of Rectangular iris (width 1 mm)						Length of Cross iris (width 1 mm)					
	5mm	6mm	7mm	8 mm	9 mm	10 mm	5mm	6mm	7mm	8mm	9mm	10mm	5mm	6mm	7mm	8mm	9mm	10mm
8.5	1930	2525	720	550	425	392	452	212	1185	1015	1004	932	1912	2795	424	452	485	542
9.3	1150	1640	198	210	225	317	314	442	227	362	572	796	1805	2724	510	324	238	195
10.1	1142	925	475	368	374	288	610	598	817	646	465	302	1120	2010	185	177	162	150
10.9	810	472	342	295	285	310	525	488	785	578	394	206	1065	1740	845	589	378	246
11.8	515	1085	520	[illegible]	365	308	135	1115	792	515	265	102	1192	1362	592	410	265	192

TABLE 2 Coupling parameters and coupling coefficients of different types of irises

Frequency (GHz)	Coupling coefficient k			Coupling parameter K		
	Cross	Circular	Rectangular	Cross	Circular	Rectangular
8.5	1.6	2.1	22.3	0.05	0.13	0.84
9.3	1.8	3.1	11.1	0.08	0.25	0.69
10.1	2.6	5.7	9.4	0.19	0.49	0.65
10.9	3.1	13.2	12.1	0.25	0.74	0.72
11.8	4.5	6.1	5.5	0.41	0.52	0.48

TABLE 3 Impedance of various types of irises

Frequency (GHz)	Cross iris						Circular iris						Rectangular iris					
	5 mm		6 mm		7 mm		5mm		6 mm		7 mm		5 mm		6 mm		7 mm	
	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)	R(Ω)	X(Ω)
8.5	53.16	0.487	53.93	0.488	55.13	0.712	55.47	0.719	56.78	0.642	58.19	0.814	51.96	0.361	52.79	0.412	55.31	0.704
9.3	50.76	3.668	51.03	4.467	51.21	5.963	51.30	6.197	51.55	7.542	52.06	9.261	50.49	2.304	50.71	3.295	51.46	6.089
10.1	46.90	3.354	46.14	4.255	45.06	5.391	44.98	5.492	44.14	6.692	42.93	8.267	48.04	2.141	47.15	3.006	44.61	5.687
10.9	44.90	0.176	43.64	0.293	41.90	0.618	42.01	0.557	40.37	0.914	38.52	1.469	46.80	0.031	45.36	0.072	41.36	0.478
11.8	45.21	-3.22	43.85	-3.66	41.95	-4.74	42.31	-4.56	40.45	-5.09	38.43	-5.68	47.10	-2.14	45.64	-3.01	41.20	-4.98

frequencies 8.5 GHz, 9.3 GHz and 11.8 GHz. For 10.1 GHz and 10.9 GHz, circular iris with 5 mm diameter gives better performance.

Symmetric and asymmetric cross iris coupling elements are designed for the study. It is found that asymmetric structures show very low Q-factors and they are not taken into consideration. Symmetric cross iris of width 1 mm and lengths 5 mm, 6mm, 7mm, 8mm and 9mm are designed used as coupling elements. Cross iris with 6 mm length provides highest loaded quality factor.

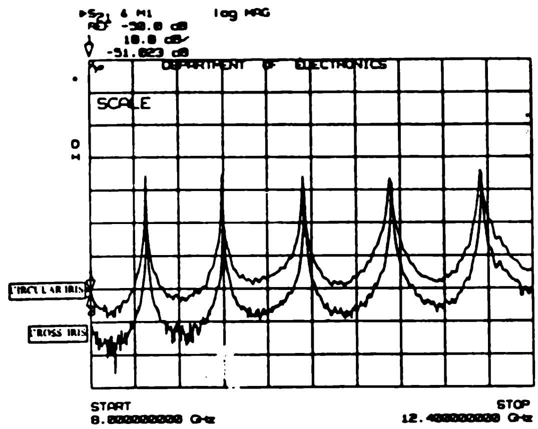

Fig 4 Amplitude response of the cavity for circular (diameter 6 mm) and cross (length 6 mm) irises

The coupling coefficient, k and coupling parameter, K of different types of irises are shown in Table 2. K and k values are lowest for symmetric cross irises, which result high loaded quality factor.

Table 3 shows the impedance variation of different irises for different resonant frequencies. It shows that the irises with different dimensions have comparatively good impedance matching with the 50 Ω source. The Q-factors are highest for cross iris compared to other irises. Figure 4 shows the amplitude response of the rectangular cavity resonator for circular iris (diameter 6 mm) and symmetric cross iris (length 6 mm). The improved loaded Q-factor may be due to the fact that the spurious modes generated at the aperture are suppressed by the peculiar structure of the cross iris. Change in the waveguide height causes field distortion and a set of non-propagating TM_{1n} modes is generated along with the dominant TE_{10} mode[10]. Similarly, the change in the waveguide width produces field distortion causing a set of non-propagating TE_{m0} modes with dominant TM mode. The cross iris may be considered as the combination of vertical and horizontal slits obtained by reducing the width and height of the waveguide. So it is reasonable to believe that the cross iris suppresses the spurious modes without perturbing the dominant mode (TE_{10}). This argument is in line with the mode suppression technique developed by Sequeria[11].

CONCLUSION

An extensive experimental study shows that cross iris coupling improves the loaded Q-factors of a cavity resonator considerably. In the case of rectangular and circular irises, highest loaded quality factor for different frequencies are obtained with different iris dimensions. But the symmetric cross iris of particular dimension provides the highest loaded Q-factor for all resonant frequencies of the given resonator. Thus the cross iris is found to be an excellent coupling element over the conventional types of irises.

REFERENCES

1. H A Bethe, Theory of diffraction by small holes, *Phys Rev*, vol 66, pp 163-182, 1944.
2. S B Cohn, The electric polarizability of apertures of arbitrary shape, *Prof IRE*, vol 40, pp 1069-1071, 1952.
3. S B Cohn, Microwave coupling by large apertures, *Proc IRE*, vol 40, pp 696-699, June 1952.
4. H A Wheeler, Coupling holes between resonant cavities or waveguides evaluated in terms of volume ratios, *IEEE Trans Microwave Theory Tech*, vol 12, pp 231-234, March 1964.
5. U Raveendranath, K T Mathew & K G Nair, Cross iris coupling for improving the loaded quality factor of cavity resonators, *IEEE AP-S symposium Digest*, vol 2, pp 1082-1085, June 1994.
6. Anand Parkash, J K Vaid & Abhai Mansigh, Measurement of dielectric parameters at microwave frequencies by cavity perturbation method, *IEEE Trans Microwave Theory Tech*, vol 27, pp 791-794, 1979.
7. K T Mathew & U Raveendranath, Waveguide cavity perturbation method for measuring complex permittivity of water, *Microwave and Optional Technology Letters*, vol 6, pp 10-106, October 1993.
8. W Ho & W F Hall, Measurement of the dielectric properties of sea water and NaCl solutions at 2.65 GHz, *J Geoph Research*, vol 78, pp 6301-6315, 1973.
9. Samuel Y Liao, *Microwave devices and circuits*, Prentice-Hall, p 106, 1987.
10. Peter A Rizzi, *Microwave engineering - passive circuits*, Prentice - Hall, New Jersy, 1988.
11. H B Sequeria, Extracting ε_r and μ_r of solids from one-port phaser network analyser measurements, *IEEE Trans Instrum Meas*, vol 39, pp 621-627, 1990.

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