C-12

RESONANCE IN MICROWAVE CIRCUITS

The properties of a microwave resonant cavity are explored using several of the common microwave instruments.

A solid state, electrically tunable X-band oscillator is the source of signal power. Its power and frequency are measured with power meter and wavemeter and the directional coupler to be used later is calibrated. A section of rectangular waveguide with a sliding short circuit and coupling iris is provided to form a tunable resonant cavity. Resonance in the cavity is observed by sweeping the frequency of the oscillator and mapping out the cavity response on an oscilloscope. Subsequently the impedance of the cavity is matched to the source and the Q of the resonance is measured. The field pattern in the cavity is mapped out using a perturbation technique and the actual value of the electric field in the cavity at resonance is measured. Finally, a double balanced mixer is used as a phase detector to measure the phase shift across the cavity as it is swept through resonance, displaying the basis for phase locked oscillators.

References

1. Ginzton, E.L., Microwave Measurements, McGraw Hill
2. Ramo, S., Whinnery, J. and Van Duzer, T., Fields and Waves in Communication Electronics, John Wiley & Sons

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Introduction

The objective of this experiment is to measure the properties of a microwave resonator. The resonator or cavity in this case is comprised of a section of waveguide with a pattern of holes for probing the field in the resonator, a short waveguide block with a built in field probe and a sliding short circuit with micrometer adjustment for changing the resonant frequency of the cavity. Referring to Figure 1, G is the coupling iris which governs the strength of the coupling between the cavity and the oscillator. There are a number of excellent references [1,2,3] on the quantitative and qualitative aspects of microwave cavity behavior.

The oscillator[4] is the source of microwave power. Its frequency can be varied electrically by imposing a positive voltage on the terminal marked FM. This voltage changes the capacitance of a reverse biased diode or "varactor" which changes the resonant frequency of the oscillator's tank circuit. There is also a mechanical adjustment. It should not be used. For its protection from reflected power and to limit the power incident on the instruments that may be used down stream, the oscillator output is connected to the combination of a 3 dB attenuator and ferrite isolator[5]. Following is a cavity wavemeter[6] for measuring the frequency of the oscillator output. Next down stream (direction away from the oscillator) is a broadwall directional coupler[7] which samples the forward power flowing down stream and the reflected power or reverse power flowing upstream. Beyond is a slotted line[8] which permits accurate measurement of the down stream impedance via its voltage standing wave ratio (VSWR). The resonator mentioned above completes the assembly.

To explore the properties of the resonator quantitatively we will begin by measuring the power incident on the directional coupler and its forward and reverse coupling constants. With these measured we can then monitor the power as needed without disturbing the circuit. Subsequently the resonance of the cavity should be observed both in transmission and in absorption, the resonant frequency measured and the cavity matched to the generator impedance. The Q_0 of the cavity will then be measured as will the field profile in the cavity and the field intensity. Finally the phase shift across the resonator as a function of frequency near the

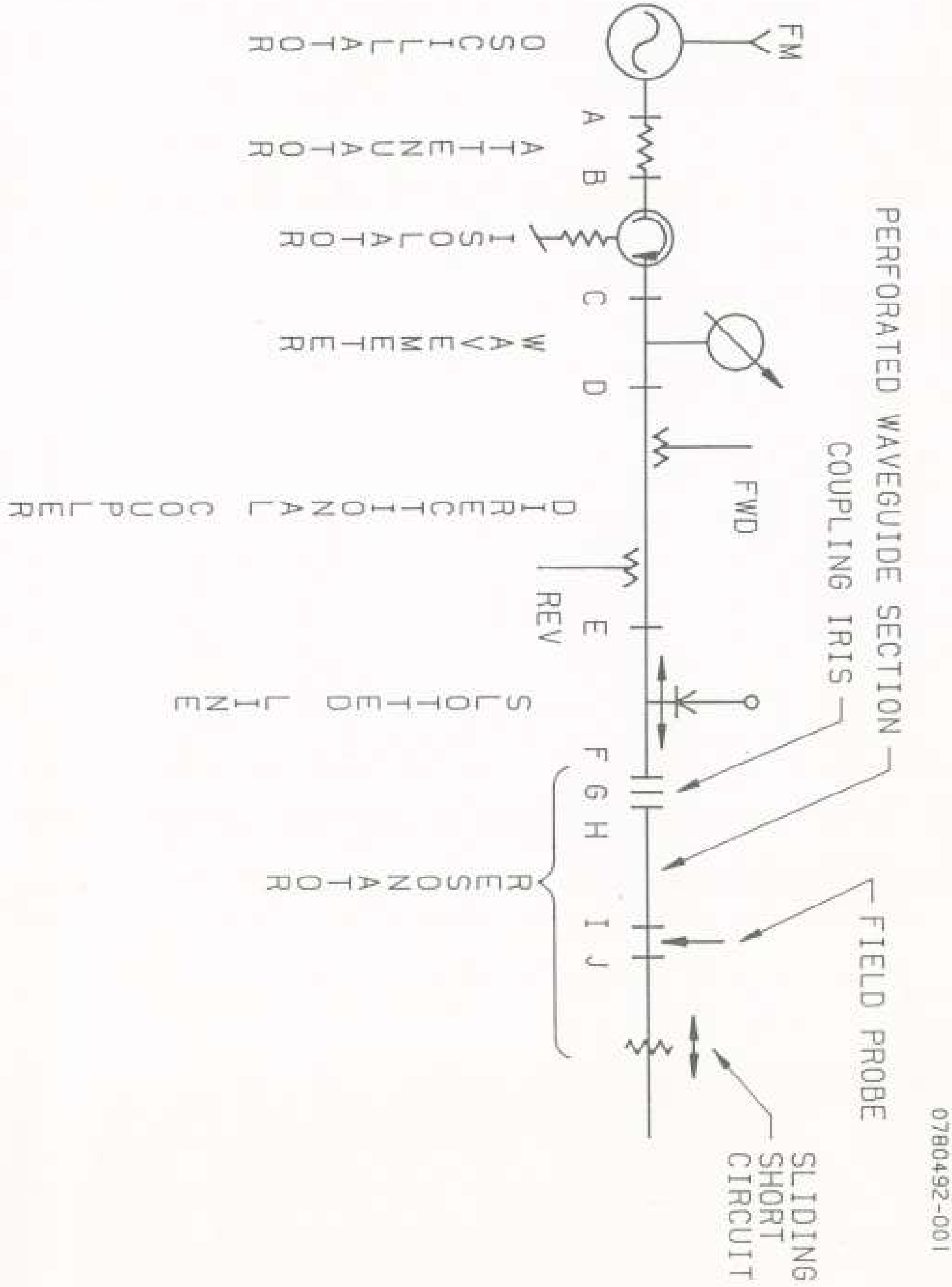
FM
OSCILLATOR
A
ATTENUATOR
B
ISOLATOR
C
WAVEMETER
D
FWD
DIRECTIONAL COUPLER
REV
E
SLOTTED LINE
F
G
H
I
J
PERFORATED WAVEGUIDE SECTION
COUPLING IRIS
RESONATOR
FIELD PROBE
SLIDING SHORT CIRCUIT
0780492-001

Fig. 1

resonance will be displayed using a double balanced mixer as a phase detector. The apparatus available for performing the measurements is listed below.

Equipment for C-12

1. Resotech X-band solid state oscillator and power supply†
2. Waveguide 3db attenuator
3. Ferrite isolator
4. Absorption wavemeter†
5. Bi-directional broadwall coupler
6. Slotted line, FXR
7. Waveguide section with holes for field measurements
8. A selection of waveguide irises for varying the coupling
9. Waveguide probe section
10. Waveguide sliding short with micrometer adjustment
11. Sapphire rod (0.060 inch dia.), e= 9.56 VERY BRITTLE
12. VSWR meter, HP†
13. Power meter with waveguide bolometer mount, HP†
14. Modulator/Sweeper generator
15. Pin diode attenuator, Anaren 61538†
16. Double balanced mixer, Anaren 7A0128†
17. Crystal detectors, FXR, HP
18. Waveguide phase shifter
19. Waveguide to coax adapters (50 ohm)
20. Waveguide termination, Airtron 52970
21. 50 ohm coaxial terminations
22. Oscilloscope

† Further technical information included in this C-12 manual

1.Power, Frequency and Directional Coupler Calibration

After reading the manual for the HP power meter (included in this book), attach the bolometer head in the correct orientation at (F). Zero the meter on the 10mW scale as instructed in the manual. Switch on the oscillator and measure and record the power. Now look for the power dip as you tune the wavemeter (see wavemeter manual in this book) and record the frequency of the oscillator. Next remove the bolometer from (F) and attach the matched waveguide termination in the correct orientation. From the theory of the directional coupler predict which of the off line ports will be the forward power port. Check your prediction and calibrate the coupler by measuring the emergent power with the power meter. (Be sure to terminate the other off line port using a waveguide to coax adaptor with coax termination.) With the matched load in place at (F), there will be a measurable power emerging from the FWD port and practically none from the REF port. The ratio of the coupled out power to the power in the main line, which you measured above, will be the coupling factor for the coupler. It is usually expressed in dB. Now replace the main line matched termination with a short circuit, e.g. one of the iris plates with no hole in it, and measure the coupling factor for the REF port. With the short in place on the main line, the reverse flowing power will essentially be equal to the forward flowing power since it is almost perfectly reflected by the short circuit. (If you're interested you could measure the actual value of the reflection coefficient using the slotted line and VSWR meter. Using the slotted line is discussed later in these pages.)

2.Observe Resonance

Using one of the irises provided, reassemble the components as shown in Fig. 1. Connect the FM output of the Modulator/Sweeper chassis to the oscilloscope and observe that the output is a sawtooth. Vary its amplitude and check that it is at least 4 V peak to peak. When applied to the FM input of the oscillator f(t) for the oscillator will follow this waveform closely, i.e.

$$f(t) = f_o + a\,V(t)$$

where V(t) is the voltage from the sweeper. a V(t) will be a few 10's of MHz while f_o is about 8.5 GHz. You can measure a V(t) using the wavemeter.

Now connect the FM output of the sweeper to the FM input of the oscillator and the horizontal sweep output to the "x-axis" of the 'scope. Connect the "y-axis" of the 'scope through a crystal detector[9] to the field probe in section I-J of Fig. 1. The detector output will be a measure of the field in the resonator cavity. Off resonance most of the microwave energy from the oscillator will be reflected at (F). On resonance, the resonator will fill with energy thus producing a signal on the detector. The scope trace will then be a plot of field amplitude (y) vs. frequency (x). Provided that the sweep is slow enough so that the cavity filling time is fast compared to the time it takes the sweeper to change the frequency by one cavity bandwidth, the 'scope trace will be a faithful reproduction of the cavity resonance curve. Naturally, to see the resonance in this manner the cavity resonant frequency must lie within the band covered by the swept oscillator. If you don't see the resonance, tune the resonant frequency of the cavity by adjusting the position of the sliding short circuit at the end of the cavity until the resonance is centered on the screen. Sketch the resonance curve in your notebook. Estimate the Q of the resonator using the wavemeter absorption "blip" and the known response of the detector to find the frequency separation of the half power points on the resonance curve. Is the sweep slow enough that the 'scope trace is a faithful resonance curve?

The procedure you have just carried out displays the resonance "in transmission". Without changing any settings, connect a crystal detector to the reverse power port on the directional coupler and make its output the input for the y axis on the 'scope. Sketch the signal in your notebook and explain its relation to the transmission resonance. This is the resonance viewed "in absorption".

3. Impedance Matching

With an arbitrary iris connecting the cavity to the power source some of the microwave power incident will be transmitted through and some reflected from the iris. The transmitted power puts energy into the field in the cavity, the reflected power returns to the isolator where it is absorbed. The reflection results in a standing wave pattern in the incoming waveguide the measurement of which can be turned into a reflection coefficient or VSWR (voltage standing wave ratio). If phase information is taken as well, that complex impedance of the cavity-iris combination can be completely measured[10].

Using the iris you started with, disconnect the *fm* signal from the oscillator so that it runs at constant frequency. Connect the oscillator output to the PIN attenuator and the PIN attenuator to the coax to waveguide adapter at (A). Driving the attenuator with a 1 kHz square wave, measure the VSWR of the cavity on resonance using the slotted line [8] and the SWR meter(instruction book included in this C-12 manual). [Determine that you are at resonance by setting the frequency of the oscillator for maximum signal on the field probe located between (I) and (J) in the cavity section. To observe the signal connect a diode detector to the field probe and observe its output on the 'scope set to receive *dc* signals. Alternatively you can set for a minimum in the reflected power by connecting the detector and 'scope to the reflected power port on the directional coupler.] Now try different irises until you find one that gives a close impedance match, i.e. very small reflected power. [In practice, careful adjustment of the iris size can result in VSWR's, at resonance, of 1.01 or better. However, for the present purposes a VSWR of 1.5 or less will suffice. What fraction of the incident power is reflected at a VSWR of 1.5? and 1.01?] By comparing the VSWR measured with the cavity just off resonance to that with it on resonance you can determine whether the cavity is "overcoupled", i.e. $Z_c < Z_o$ or "undercoupled", i.e. $Z_c > Z_o$. If "undercoupled" you'll need a bigger iris to get a match and if "overcoupled" you'll need a smaller iris. Explain this in your write up. Alternatively you can measure VSWR vs iris size and find the minimum. Explain how you can use this information to determine which of the irises give "overcoupling" and which "undercoupling".

With the cavity matched at resonance, almost all of the incident power is dissipated in the cavity walls to support the field in the cavity. [Where is the remainder dissipated?] Q_L of the cavity now has a simple relation to the Q_o[11]. Measure the Q_L in the matched condition and calculate the Q_o from it. Knowing that the cavity is made mostly of Aluminum, calculate the Q you would expect at this frequency. What might be the reasons that the calculated value is not the same as the measured value?

4. Field Intensity and Field Distribution

The object of this part of the experiment is to measure the electric field in the cavity. The basic method is described quantitatively by Slater[12] and relies on the fact that a dielectric perturbation placed in the cavity, e.g. a low loss dielectric rod aligned with the electric field lines, alters the resonant frequency depending on the electric field at the position of the perturbation in the cavity. This suggests inserting a dielectric rod of known ε and cross section into the cavity along the direction of **E**. From the Δf measured, $\int E^2 \bullet dl$ can be determined in comparison with the energy stored in the cavity. The field pattern can be measured by putting the rod at various places using the predrilled holes provided. From the dimensions of the waveguide and the measured resonant frequency sketch the electric field pattern that you expect in the resonator. By making the measurements referred to above check your sketch and compute the maximum value of the electric field in the cavity. (Don't forget that you have already measured the incident power and the Q value.)

5. Measuring Phase Differences at Microwave Frequencies

A double balanced mixer such as provided with C-12 can be used as a phase detector. The output of a double balanced mixer with identical frequencies applied to its LO (local oscillator) and RF radiofrequency) ports is a dc voltage proportional to the sine of the phase angle between these two signals. By means of this device it is possible to display the phase shift across the cavity as it goes through resonance. Take a sample of the incident power from the forward port of the directional coupler and a sample of the field in the cavity and apply them to the two input ports of the mixer. Observe the output on the 'scope and the oscillator frequency is swept repetitively through the resonant frequency of the cavity. Sketch what you observe. Is this commensurate with what you expect. What is the expected phase relation between the drive and motion of a resonator driven below its resonant frequency, at its resonant frequency and above its resonant frequency.

Sketch a circuit using this mixer and the oscillator you are using to "lock" the oscillator's frequency to the resonant frequency of the cavity.

References

1. Ginzton, E.L., Microwave Measurements, McGraw Hill 1957, Ch. 7,8,9,10.
2. Ramo, S., Whinnery, J. and van Duzer, T., Fields and Waves in Communication Electronics, John Wiley 1965, Ch. 10.
3. Collin, R., Foundations for Microwave Engineering, McGraw Hill 1966, Ch. 7.
4. Resotech Data Sheet, this C-12 Manual.
5. Collin op.cit. Ch.6, Ramo et al op cit. Ch. 9
6. Ginzton, op. cit. Ch.7, Hewlett Packard Manual for 532A/B Direct Reading Frequency Meters, this C-12 Manual
7. Ramo et al, op. cit. Ch. 11, Collin, op. cit. Ch. 6.
8. Ginzton, op. cit. Ch.5 under "standing wave detectors"
9. ibid, Ch. 2.
10. ibid, Ch. 5
11. ibid, Ch. 9
12. ibid, Ch. 10