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MEASUREMENT OF QUARTZ MICROSTRIP AT 22 GHz AND 110 GHz

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ABSTRACT

The losses of microstrip lines (gold-chrome on quartz) used in the construction of millimeter wave mixers were determined by measuring the unloaded Q of a $n\lambda g/_2$ cavity. The losses are approximately 30% higher than the theoretical values. It was also shown that short term heating of the microstrip and use of cyanoacrylic glue for mounting purposes should not cause any significant loss increase.

MEASUREMENT OF QUARTZ MICROSTRIP AT 22 GHz AND 110 GHz

1. Measurement of Losses at 22 GHz

The 22 GHz measurements were carried out on half-wavelength resonators using a loss test mount designed by S. Weinreb. The cross sections of the mount are shown in Figure 1. The half-wavelength TEM resonator forms a transmission type cavity, which is coupled to the outside microwave circuit by two small antennas terminating two movable OSSM connectors. The measurement set-up is shown schematically in Figure 2.

In this circuit the resonant frequency f_o, the loaded Q-factor Q_L, and the transmission loss T_o of the cavity at the resonant frequency were measured. This allowed the computations of the unloaded Q-factor Q_u, under the assumption of symmetrical coupling. The latter condition was assured by the geometrical symmetry of the resonator and was also (for larger couplings) checked by measuring the power reflected from the cavity at both ports (with other port terminated) with the help of directional coupler. The following relations between loaded Q-factor Q_L, unloaded Q-factor Q_u, 3 dB bandwidth Δf, resonant frequency f_o, coupling coefficient β, and loss T_o were used[9]:

$$Q_L = \frac{f_o}{\Delta f}, \quad Q_u = Q_L\,(1 + 2\beta), \quad T_o = \frac{4\beta^2}{(1+2\beta)^2} \tag{1}$$

The attenuation factor α and effective dielectric constant ε_{eff} were computed from the following relations:

$$\alpha = \frac{\pi}{Q_u \lambda_g} \quad (2), \qquad \sqrt{\varepsilon_{eff}} = \frac{cn}{2\,f_o\,(L+\Delta L)} \quad (3)$$

where

- λ_g is the wavelength in the TEM line (in this case $\lambda_g = 2(L+\Delta L)$),
- L is the resonator length,
- ΔL is the correction factor due to the effect of the fringing capacitance of microstrip open circuits,

- c is the speed of light in vacuum,

- n is the number of half-wavelengths along the resonator.

Every resonator was measured several times for different coupling coefficients varying between 0.007 and 0.055. This corresponds to the transmission loss values being in the range T_o = 20 to 37 dB. Corresponding 3 dB bandwidths varied between 260 MHz and 220 MHz. The maximum error of the Q factor measurement was estimated to be 10%. The accuracy of the resonant frequency measurement was better than 0.5%.

The results of the measurement are summarized in Table I. All the samples had a length of 184 mils. and a cross section as shown in Figure 1. Samples 1 to 3 are made of fused quartz*. Samples 4 and 5 are made of crystalline quartz*. The bottom piece of dielectric for all samples is crystalline quartz. The values of $\sqrt{\varepsilon_{eff}}$ were corrected for the effect of the fringing capacitance of microstrip open circuit using theoretical data presented in [1].

Samples 1 to 3 were mounted using wax. Sample 2 was heated to 500°F for 15 minutes before mounting. The comparison between measured data for sample 1 and 2 shows that the short exposure to heat should not cause a significant change of the microstrip loss factor. Somewhat lower Q-factor for sample 3, as compared with samples 1 and 2, is connected with the defects in the metalization pattern, which could have been observed under a microscope. There were no observable differences between samples 4 and 2.

Sample 4 was mounted using wax, while sample 5 was mounted using cyanoacrylic glue. No difference in Q-factor was observed. The slight difference in the resonant frequencies of these two resonators is probably caused by the effect of gaps between the quartz substrate and the walls of the mount.

2. Measurement of Losses at 110 GHz

A sample mount, suitable for the Q-factor measurement of the TEM resonators at the frequency of 110 GHz, was not available. Therefore, the

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*There is a possibility that samples 1 to 3 and 4 to 5 were reversed when cut into strips. This is of little consequence since the attenuations were approximately equal. Samples 1 to 3 have gold like color when viewed through the quartz; samples 4 to 5 have a chrome like color. Manufacture of samples 4 and 5 is described in an appendix.

following method was used. The sample of quartz with the metallic strip was placed in the center of the bottom wall of the WR8 waveguide, as shown in Figure 3a. The structure, terminated with a movable short (as shown in Figure 3b), operated as a reflection type cavity. The cavity coupling could be varied from zero to the coupling slightly greater than critical, by the change in the position of movable short. The properties of the cavity formed in this way were measured in the experimental set-up, which is shown in Figure 4.

The following observations assured that the observed resonance was a TEM mode $n\,{}^{\lambda}g/_2$ resonance in the quartz microstrip:

1) No resonance was observed when the samples were turned upside down. This excludes the possibility of the excitation of a dielectric surface wave resonance.

2) No detectable difference within the accuracy of available instruments ($\overset{\sim}{\leq}$ 0.2 dB) was observed in the transmission through the waveguide with and without sample far from its resonant frequency. To explain this it is enough to notice that the cross section of the sample is very small as compared with the cross section of the waveguide, and also that the metallic strip does not affect in any way the TE_{01} mode propagation, as it is perpendicular to the electric field lines.

3) Two samples of the difference in length being equal to $\frac{\lambda_{TEM}}{2}$ (according to the microstrip analysis of this structure) had almost the same resonant frequency.

4) No change in the properties of the resonator was observed, when the short was moved by the distance of half wavelength in the waveguide.

The following relations were used to compute the unloaded Q-factor of the cavity[9]:

$$Q_u = (1+\beta)\ Q_L, \quad Q_L = \frac{f_o}{\Delta f}\ , \tag{4}$$

$$\beta = \frac{1}{VSWR_o} \qquad \text{for undercoupled cavity}$$

$$\beta = VSWR_o \qquad \text{for overcoupled cavity}$$

and $VSWR_o = \dfrac{1 + |\Gamma_o|}{1 - |\Gamma_o|}$

where

- $VSWR_o$, Γ_o are voltage standing wave ratio and reflection coefficient at resonant frequency, respectively.
- Δf is half power bandwidth measured between the frequencies for which the magnitude of the reflection coefficient is given by

$$\left|\Gamma_{\frac{1}{2}}\right|^2 = \frac{1 + |\Gamma_o|^2}{2} \tag{5}$$

The attenuation factor α and effective dielectric constant ε_{eff} were then computed from the equation (3)

The samples have been measured several times for nearly critical coupling. The results of the measurements are summarized in Table 2. The value of $\sqrt{\varepsilon_{eff}}$ was corrected for the open circuit fringing capacitance using the theory presented in [1]. The maximum error of the resonant frequency and Q-factor measurement was estimated to be 1% and 30%, respectively.

3. The Comparison Between Theory and Experiment

3.1 K-Band Structure

There are no analytical expressions available from which the losses of the structure of Figure 1 could have been computed. Therefore, the following method of theoretical losses estimation have been adopted. It was known from the previous analysis by Greenberg, that the characteristic impedance for the quasi-TEM line shown in Figure 1 should be $z_o = 104\ \Omega$. Assuming $z_o = 104\ \Omega$, substrate permittivity $\varepsilon_r = 4.0$ and the width of the strip w = 3 mils., the equivalent microstrip line can be defined, for which the losses can be computed using theory and design data presented in [2], [3], [4]. Similarly, assuming $z_o = 104\ \Omega$ $\sqrt{\varepsilon_r} = 1.55$ (comp. Table I) and w = 3 mils. the equivalent symmetric strip line can be defined for which the losses can be also computed[5]. The results of computations done in these ways are summarized and compared with experimental data in Table III. For all computations the resistivity of bulk gold $\rho = 2.3$ μohm · cm was assumed. The chromium adhesive layer, 100 Å thick, should not introduce any significant loss increase (gold layer is of the order of 2.5 μm), according to the theory by Sobol and Caulton[6].

The best agreement between theoretical and experimental data is obtained for the equivalent symmetric strip line model. This is expected as this model approximates the real structure much better, as compared with microstrip model.

There are two factors which must be taken into account in an attempt to explain the discrepancies between the measurement and the theory:

1) The presence of side walls in the real structure, which causes greater current density to flow along the edges of the metallic strip, than it is predicted by the model. This increases the losses as shown by Yamashita and Atzuki[7].

2) The surface roughness. This effect should play a minor role, as the surface roughness of RMS value $\delta = 2$ μinch = 0.08 μm would cause only 4% loss increase, as predicted by the theory of Morgan[6].

For more detailed theoretical treatment of the losses of this structure the computer program described in [8] should be used.

3.2 W-Band Structure

The W-band structure (Fig. 3) is very similar to the open microstrip line, as the distance between the side and upper walls of the waveguide and the microstrip are sufficiently large. Therefore, the microstrip theory can be used. The comparison between measured and computed data is shown in Table IV.

The surface roughness and/or a different value of assumed resistivity of the gold can explain the difference between the measured and computed values of losses. The RMS value of the surface roughness $\Delta \cong 0.13$ μm would cause at 110 GHz the loss increase of about 30% for the gold-quartz stripline, according to the theory by Morgan[6]. This would explain the observed discrepancies.

4. Conclusions

The measured losses of microstrip used in the construction of 115 GHz mixers are measured to be about 30% greater than theoretical values. It should be investigated, if this effect is of importance for actual mixer performance. The losses can be expected to be higher for the low-impedance sections of microstrip, which have been used in the mixer low-pass filter design, due to the close proximity of the side walls.

The cyanoacrylic glue, which is used in the process of mounting of the mixer, does not cause any significant loss increase, and can be freeely used.

The short term heating of the microstrip during the soldering process also should not affect the losses of microstrip.

The method of measuring of microstrip losses by placing the sample in back-shorted waveguide was found simple and convenient in use at 110 GHz. It should be particularly useful in comparative studies of losses of different microstrip realizations.

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APPENDIX

Description of Microstrip Samples

Samples 4 and 5 are Z-cut (Z axis perpendicular to substrate surface) crystalline-quartz with a < .075 μm (3 microinch) RMS surface roughness furnished on NRAO P.O. G00755 (3/15/77) by:

Specialty Engineering
830 Charcot Avenue
Sam Jose, CA 95131
Attn: Mr. Nate Brown

These samples were metallized (evaporated) to a specification of .016 μm (160 Angstroms) or less of chrome covered with 2.5 microns or more of gold on NRAO P. O. G00802 (3/24/77) by:

G. M. Vacuum Coating Co.
882 Production Place
Newport Beach, CA 92663
Attn: Mr. Dan Coursen

Samples 1, 2 and 3 furnished by A. R. Kerr were Amersil Suprasil II fused quartz metallized (sputter, then plate) by Materials Research Corporation with 80 Angstrons chrome and 2.5 microns gold.

SAMPLE DESCRIPTION	SAMPLE №	Q_u	f_o [GHz]	$\sqrt{\varepsilon_{eff}}$	$\alpha \times 10^{-6}$ [N/mill]	$\alpha \cdot 10^{-3}$ [N/mm]
FUSED QUARTZ FROM KERR	1	95	20.40	1.55	90	3.6
	2	103	20.50	1.53	83	3.3
	3	75	20.43	1.55	113	4.4
CRYSTALLINE QUARTZ METALIZED BY GM CO.	4	95	21.61	1.46	90	3.6
	5	94	21.84	1.45	91	3.6

TABLE I. K-BAND MEASUREMENT RESULTS

SAMPLE DESCRIPTION	SAMPLE №	f_o [GHz]	n	Q_u	$\sqrt{\varepsilon_{eff}}$	$\alpha \times 10^{-6}$ [N/mill]	$\alpha \times 10^{-3}$ [N/mm]
FUSED QUARTZ FROM KERR	1	109.9	6	230	1.66	220	8.7
	2	110.3	7	260	1.68	190	7.5
CRYSTALINE QUARTZ GM.CO.	3	111.8	6	240	1.56	200	7.9

TABLE II. W-BAND MEASUREMENT RESULTS

UNITS	MEASURED	COMPUTED		
		SYMMETRIC STRIPLINE [5]	MICROSTRIP -SCHNEIDER [illegible]	MICROSTRIP -PUCEL [illegible]
$\times 10^{-6}$ N/mill	90	70	62	57
$\times 10^{-3}$ N/mm	3.6	2.8	2.4	2.2

TABLE III. COMPARISON OF MEASURED AND COMPUTED LOSS AT 21 GHz.

UNITS	MEASURED	COMPUTED -SCHNEIDER [3]
$\times 10^{-6}$ N/mill	200	150
$\times 10^{-3}$ N/mm	7.9	5.9

TABLE IV. COMPARISON OF MEASURED AND COMPUTED LOSS AT 110 GHz.

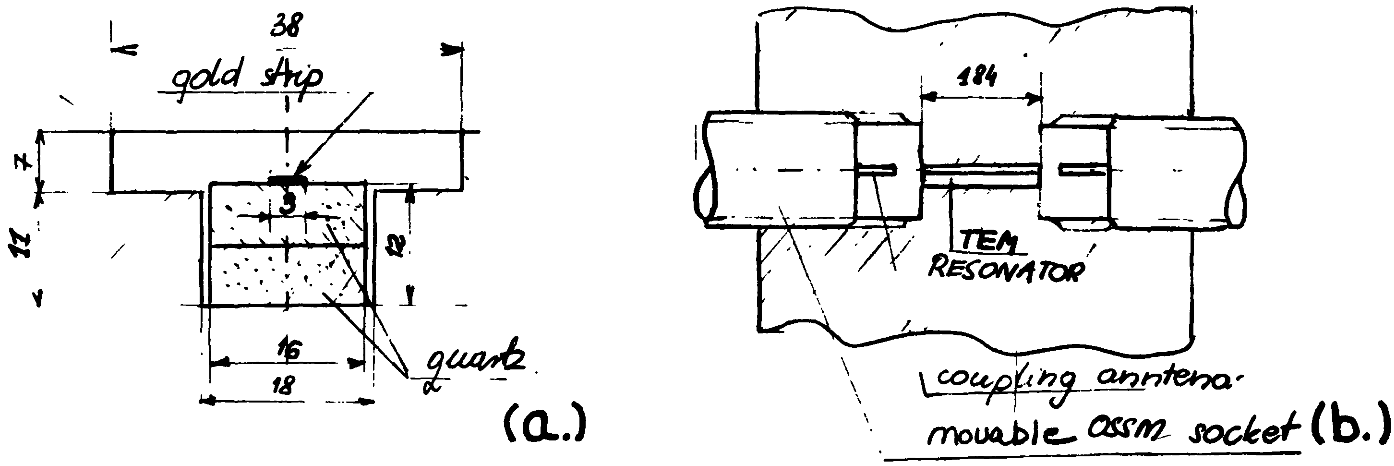

Figure 1.a. The Cross Section of the TEM Resonator.

1.b. The Cross Section of the Measuring Mount (dimensions in mils.)

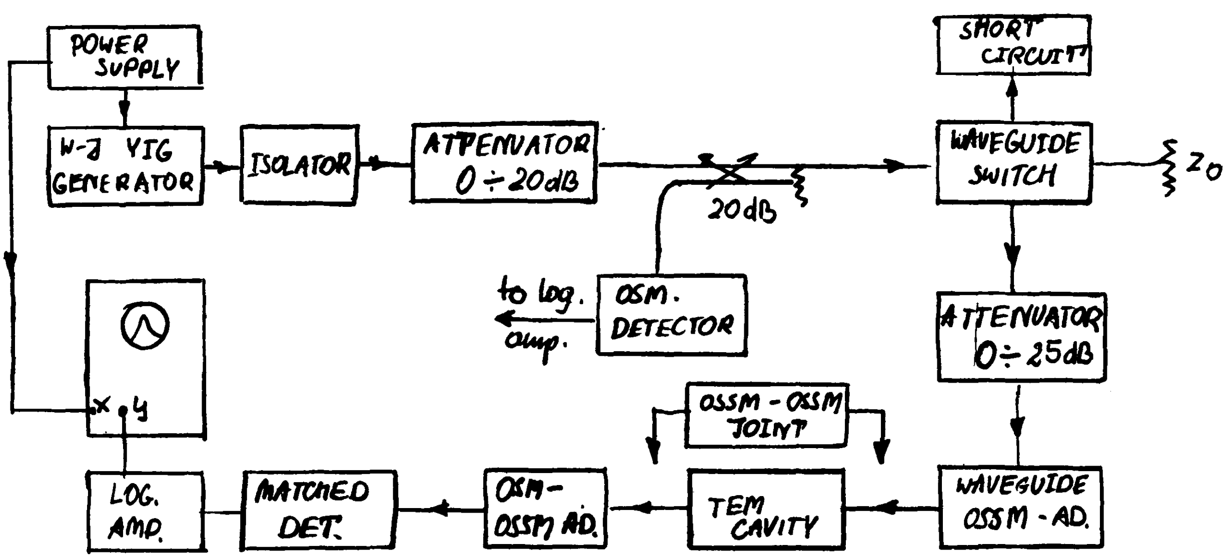

Figure 2. The Measurement Set-Up for 22 GHz Measurements.

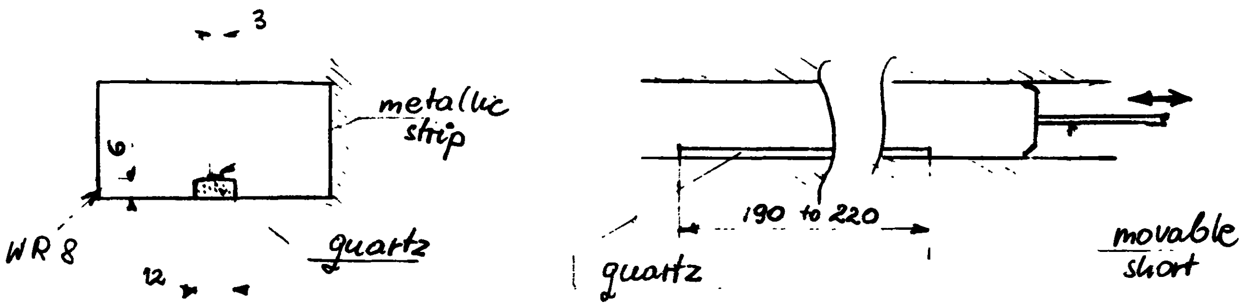

Figure 3. The Cross Section of the Mounting Structure for 110 GHz Measurement.

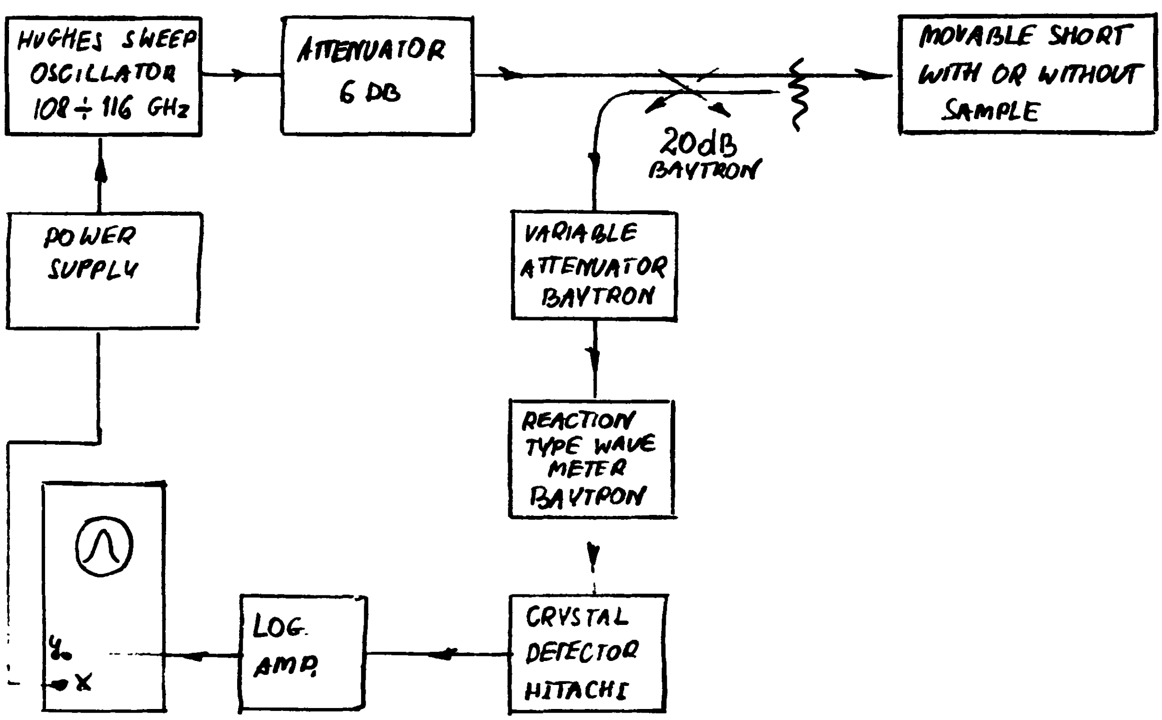

Figure 4. The Measurement Set-Up for 110 GHz Measurement.