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# X-BAND BEACON REFERENCE CAVITIES

REPORT
972

**RADIATION LABORATORY**
**MASSACHUSETTS INSTITUTE OF TECHNOLOGY**
**CAMBRIDGE - MASSACHUSETTS**

NDRC
Div. 14
OEMsr-262

Radiation Laboratory

Report 972 January 15, 1946

# X-BAND BEACON REFERENCE CAVITIES

## Abstract

The purpose of this report is to summarize the present status of X-band beacon reference cavities. The general construction is described, but other than critical electrical dimensions, no detailed mechanical description is made. Electrical performance characteristics, and especially frequency stability are discussed. A number of miscellaneous calculations concerned with possible frequency errors are made.

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Title page
7 numbered pages
5 pages of figures

# X-BAND BEACON REFERENCE CAVITIES

## 1. Introduction

The purpose of this report is to summarize the present status of X-band beacon reference cavities. The general construction is described, but other than critical electrical dimensions, no detailed mechanical description is made. Electrical performance characteristics, and especially frequency stability are discussed. A number of miscellaneous calculations concerned with possible frequency errors are made.

## 2. Characteristics

There are at present two rather distinct types of cavities, the 1Q22, 23, 24, 25 series made by Westinghouse, and the 1Q26 made by C. E. These differ widely in appearance and in fundamental design. The 1Q22 (this number will be used to designate the whole series) and 1Q26 are shown pictorially in Fig. 1 and schematically in Figs. 2 and 3.

Both cavities are hermetically sealed by means of glass windows placed over the coupling apertures and are designed to have relatively small variations in resonant frequency due to temperature changes, vibration and mechanical shock, and variations in external atmospheric pressure.

The nominal resonant frequencies of the various cavities are as follows:

| | |
|---|---|
| 1Q22 | 9250 Mc/sec |
| 1Q23 | 9280 Mc/sec |
| 1Q24 | 9310 Mc/sec |
| 1Q25 | 9375 Mc/sec |
| 1Q26 | 9280 Mc/sec |

The 9250 and 9280 Mc/sec cavities are intended for use with receivers of 60 and 30 Mc/sec i-f respectively as standards against which to tune the local oscillator to receive the X-band beacon located at 9310 Mc/sec. The 9310 Mc/sec cavity is intended to monitor the beacon transmitter, and the 9375 Mc/sec cavity is used to tune the local oscillator of the beacon receiver. In this last application, the local oscillator is frequency modulated to hunt over the aircraft radar band. At present only 9250 and 9280 Mc/sec cavities are used in AFC circuits, while the 9310 and 9375 Mc/sec cavities are used as monitors for manual control. The applications of beacon reference cavities to AFC circuits have been discussed by Pound in R.L. Report 694, by Farr in R.L. Reports 886 and 905, and by Durand in R.L. Report 337.

Examination of Fig. 2 indicates that the 1Q22 is a copper cavity with a copper diaphragm attached to an Invar strut that is fixed at its upper end to the copper cylinder. As the temperature of the cavity is increased, it expands, tending to reduce the resonant frequency. However, the Invar rod remains relatively unchanged in length and is pulled up by the copper cylinder, thus pulling up the diaphragm and reducing the capacity loading. This effect tends to increase the resonant frequency. The cavity frequency is changed about 9 Mc/sec by a displacement of the diaphragm of .001". By proper design, the two

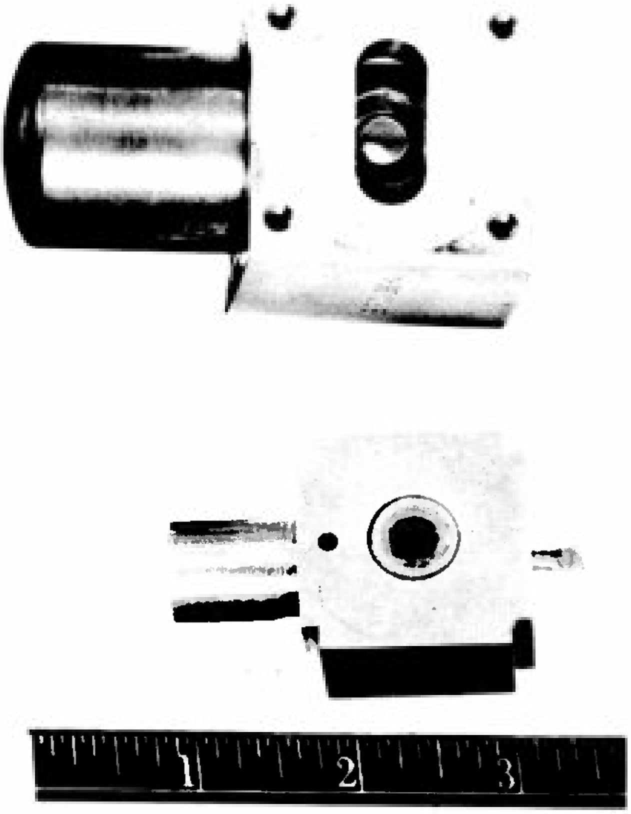
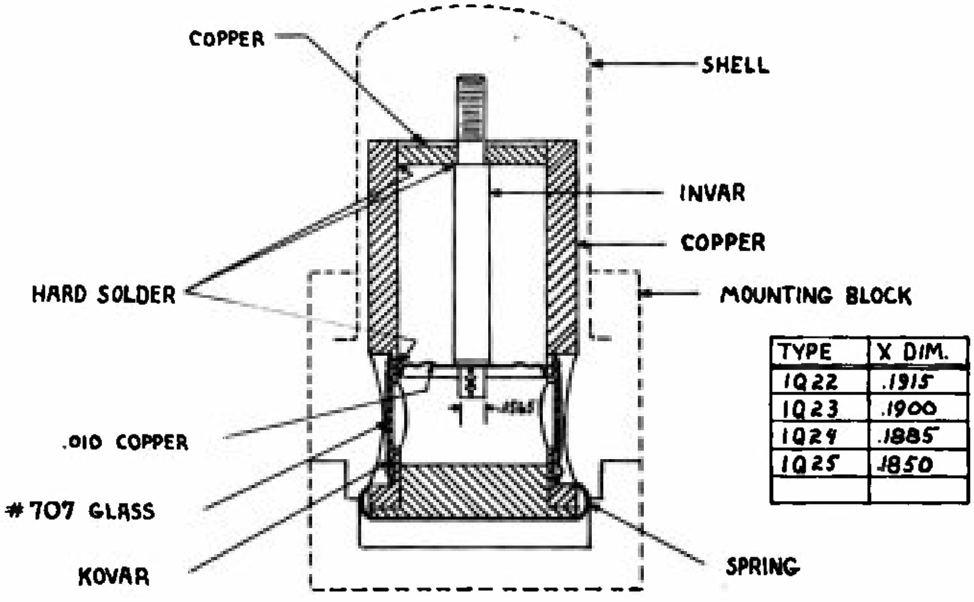


FIG. 1. X-BAND BEACON REFERENCE CAVITIES
TOP: 1Q22
BOTTOM: 1Q26



| TYPE | X DIM. |
|---|---|
| 1Q22 | .1915 |
| 1Q23 | .1900 |
| 1Q24 | .1885 |
| 1Q25 | .1850 |
| | |

FIG. 2 1Q22

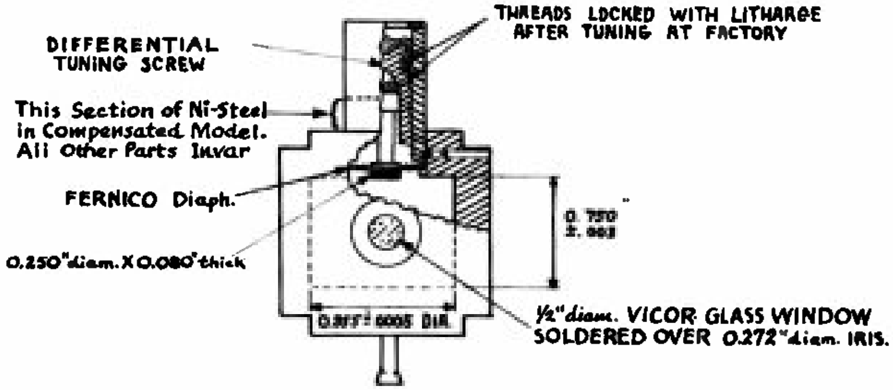


FIG. 3. 1Q26

effects can be made to compensate each other, and in practice a high order of compensation is achieved over a temperature range from -50° C to 100° C. The cavity is shock mounted within an aluminum block, which clamps between standard 1" x 1/2" waveguide with UG-40/U chokes.

Fig. 3 shows the construction of the 1Q26. It is an all Invar cavity, tuned by a variable capacitance on a flexible Fernico diaphragm, adjusted by a differential tuning screw. All the temperature compensation is achieved by virtue of the low coefficient of expansion of Invar. A more recent development utilizes a section of nickel-steel in the outer tuning cylinder to obtain a differential expansion and thus get a higher degree of temperature compensation. The 1Q26, like the 1Q22, mounts between UG-40/U chokes on 1" x 1/2" waveguide.

The sealing windows of the 1Q22 are similar to those in the 1B24 TR tube. They are Kovar rings with 707 glass sealed inside; the whole assembly is soft soldered into the copper cavity. The 1Q26 uses Corning Vicor glass windows with a metallized ring near the outer edge. These glass windows are soft soldered directly to the Invar.

The cavities are evacuated to a pressure of a few mm Hg and are thus unaffected by changes in the dielectric constant of the atmosphere due to changes in pressure or humidity. The pressure is chosen so that if the cavity is exposed to the magnetron pulse, a glow discharge will be established within it, thus indicating whether the cavity has leaked air or not.

The limits of frequency errors for the 1Q22 and 1Q26 allowed by the present Army-Navy specifications are given below.

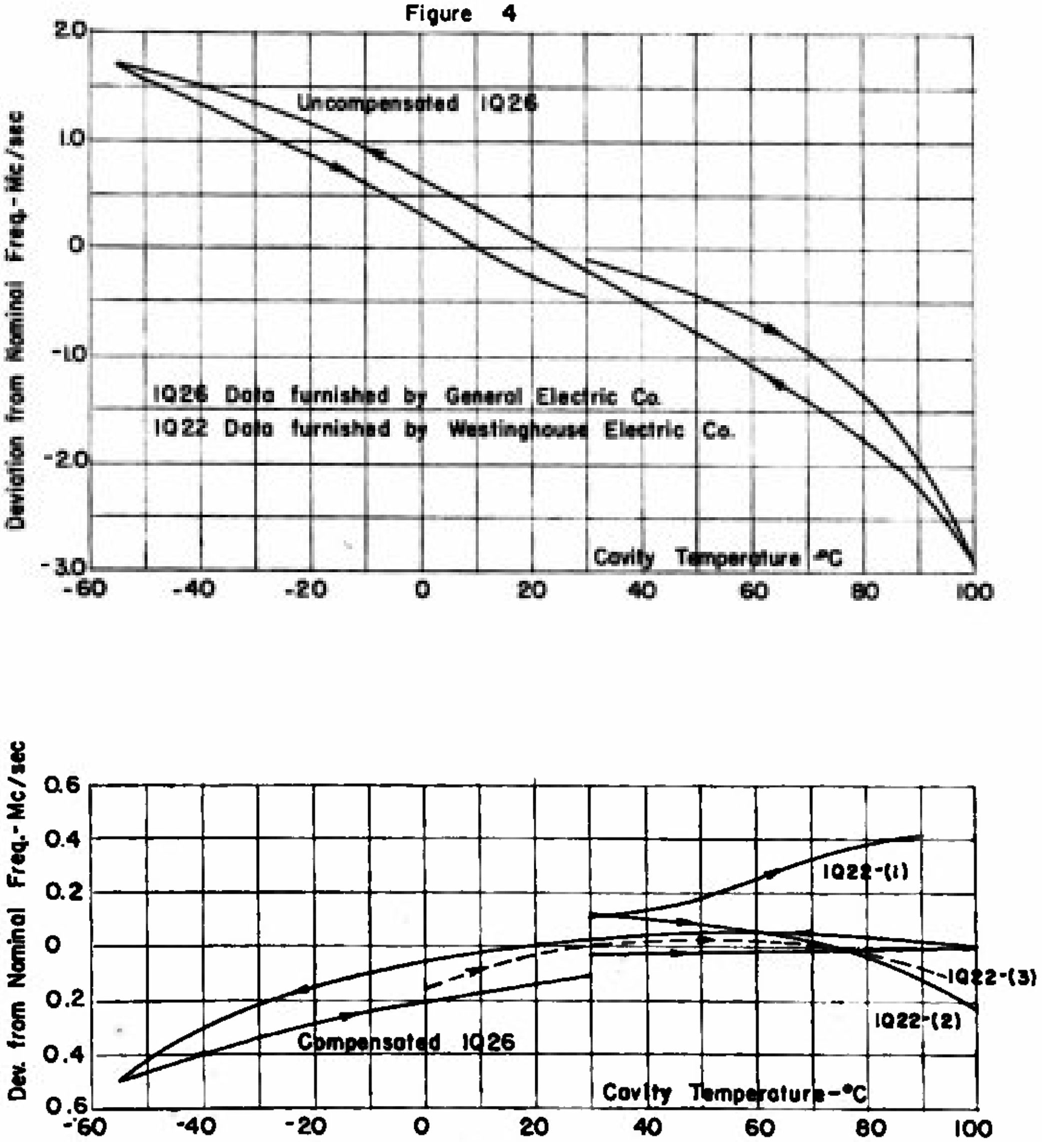
| | 1Q22 | 1Q26 |
|---|---|---|
| Vibration | ± 0.10 Mc/sec | ± 0.10 Mc/sec |
| Shock, mounting | ± 0.10 | Not specified |
| Atmospheric pressure | ± 0.15 | ± 0.15 |
| 20° to 100° C | ± 0.30 | ± 1.80 |
| 0° to -55° C | ± 0.30 | ± 1.80 |
| Hysteresis | ± 0.30 | Not specified |
| Q | 1900-2400 | 1000-1500 |
| Insertion loss | 4-6 db | 5-8 db |

Curves of tuning vs temperature for the 1Q22, 1Q26 and the compensated 1Q26 are given in Fig. 4. It will be noted that the 1Q22 curve is not linear nor has it the same shape for different cavities. The 1Q22 tends to be overcompensated at the ends of the temperature range.

The phenomenon of tuning-temperature hysteresis occurs in the 1Q22 series of cavities. If a cavity is taken from room temperature to any other temperature and then returned to room temperature, its final resonant frequency will, in general, be different than its initial frequency. The cause of this phenomenon is not fully understood. However, it is believed to be associated with the elastic properties of the diaphragm since the effect was reduced by changing from a .005" to a .010" thick diaphragm. There is also some evidence that unequal heating of the cavity during the brazing operations leaves residual strains in the cavity, and thus contributes to the hysteresis. It has been

## TUNING-TEMPERATURE CHARACTERISTICS of 1Q22 and 1Q26 CAVITIES

Figure 4



observed that if a cavity is carried through a number of temperature cycles between $100^\circ$ C and $-40^\circ$ C, the hysteresis is large on the first few cycles, and gradually reduces in amplitude until it reaches some stable value. It has also been observed that if the cavity is held at the extreme temperatures for only a short time (of the order of 60 minutes), the stable value reached after a number of cycles will be upset if the holding time is later increased to 8 hours at the extreme temperatures. After a number of cycles with the longer holding time, a new equilibrium will be set up. At present all 1Q22 cavities are given a number of long temperature cycles that presumably reduce the hysteresis to a stable value of less than $\pm$ 0.30 Mc/sec. Fig. 5 is a plot of the resonant frequency at room temperature after alternate hot and cold temperature cycles.

The Q of the 1Q22 is considerably higher than that of the 1Q26 (2000 to 1300). The reason for this is that after the Westinghouse cavity was finished, it was discovered that the 723A/B local oscillator could not work into a load with a Q higher than about 1400 without experiencing a frequency jump of as much as 2 Mc/sec just at the resonant frequency of the cavity. Rather than change the Q of the cavity, it was decided to load it down by increasing the conductance of the output load. In the case of the G. E. cavity it was decided to reduce the Q by increasing the dissipative loss within the cavity. This was done by coating the inside of the cavity with what is essentially a Monel coating. This is applied by plating the cavity first with copper, then with nickel, after which it is fired in a hydrogen furnace. This procedure results in a simpler external circuit, since a matched load can be used. However, the figure of merit of the externally loaded 1Q22 is greater than that of the internally loaded 1Q26. The figure of merit relates the tendency of the oscillator to jump frequency to the cavity parameters and is given by

$$\frac{2/Q_1}{(1/Q_0 + 1/Q_2)^2} \gtrsim \frac{1}{C} \qquad (1)$$

where $Q_0$, $Q_1$, and $Q_2$ are the unloaded, input, and output Q's respectively, and C is a quantity related to the pulling figure of the oscillator (R.L. Report 694).

## 3. Tolerences

The frequency limits indicated in Section 2 are ideal in the sense that they assume all the errors arise in the cavity itself and none in the external circuits. The conductance plane of the 1Q22 cavity is .500" back of the face of the aluminum block. (The conductance plane is that at which the minimum of the VSWR is found at resonance). In the APS-30 type of AFC circuit, the cavity is loaded at its output by a conductance $g_e = 4Y_o$. However, this high conductance is obtained by setting up a VSWR of 4:1 of proper phase. What errors in frequency are introduced if the phase of the standing wave or the location of the conductance plane are not in their nominal positions?

# 1Q22 TEMPERATURE - TUNING HYSTERESIS

MEASUREMENTS WERE TAKEN IN ORDER FROM LEFT TO RIGHT.
EACH POINT WAS TAKEN AT ROOM TEMP. AFTER THE CAVITY HAD BEEN TREATED AS INDICATED ON THE GRAPH.

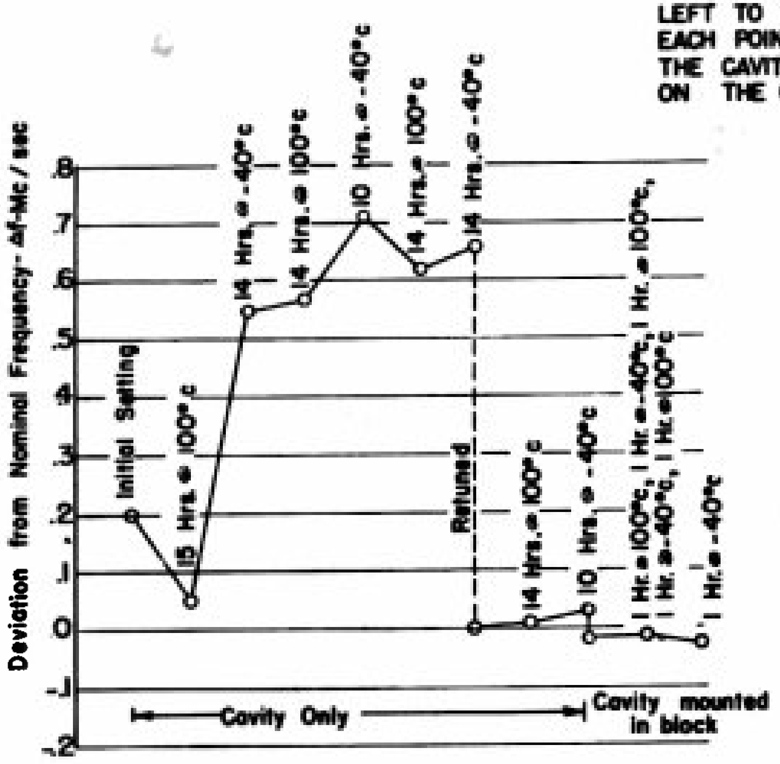


Figure 5

Data Furnished By
Westinghouse Electric Corp.

Report 972

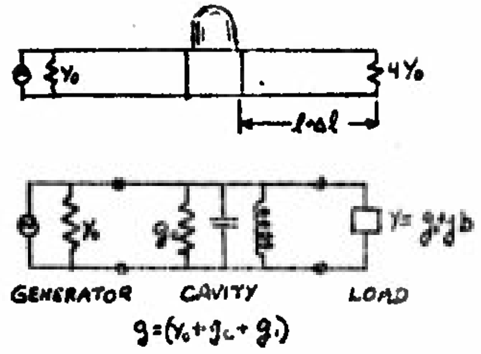


Fig. 6

In Fig. 6 the loading due to the standing wave is $Y = g_l + jb$. If the phase is correct, $Y = 4 + j0$. However, as the phase changes, b will become different from zero.

$$b = \frac{-15 \tan \theta}{1 + 16 \tan^2 \theta} \approx \frac{-30\pi \Delta \ell/\lambda_g}{1 + (8\pi\Delta\ell/\lambda_g)^2} \qquad (1)$$

Where θ is the phase shift of the standing wave in radians, and Δℓ is the phase shift in centimeters.

Near resonance, $\Delta b = 2gQ \frac{\Delta f}{f_o}$

$$\Delta f = \frac{\Delta b f_o}{2gQ} \qquad (2)$$

Where $f_o$ is the nominal resonant frequency, g is the total loading on the cavity, Q is that corresponding to g, and Δf is the resultant change of resonant frequency of the cavity. Between matched load and generator, the cavity has a $Q_{L2} = 2000$, $g = 3.5$, and $f_o = 9310$ Mc/sec.

$$\Delta f = \frac{\Delta b \; 9310}{2 \times 3.5 \times 2000} = .668 \; \Delta b \text{ Mc/sec} \qquad (3)$$

Fig. 7 is a plot of frequency shift (Δf) against phase shift (Δℓ) using Eqn. (1) and (3).

In the case of a cavity mounted between nominally matched loads, we can calculate the maximum possible frequency error due to any given mismatch. The maximum susceptance (b) for any given standing wave ratio (r) is

$$|b_{max}| = \frac{r^2 - 1}{2r} \qquad (r \geq 1) \qquad (4)$$

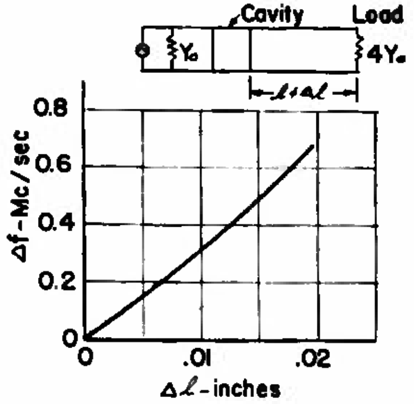
and the corresponding frequency error for the 1Q23 is

$$\Delta f_{max} = .334 \frac{r^2 - 1}{r} \qquad (5)$$

and for the 1Q26, where g = 4, Q = [illegible]

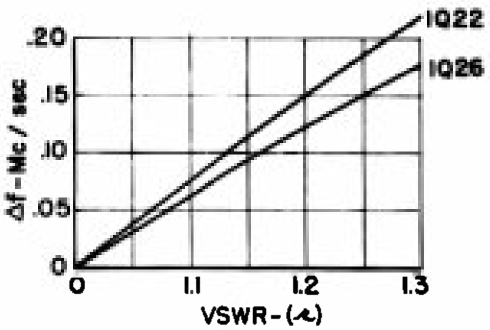
## DETUNING of 1Q22 vs PHASE of LOAD SWR

Fig. 7



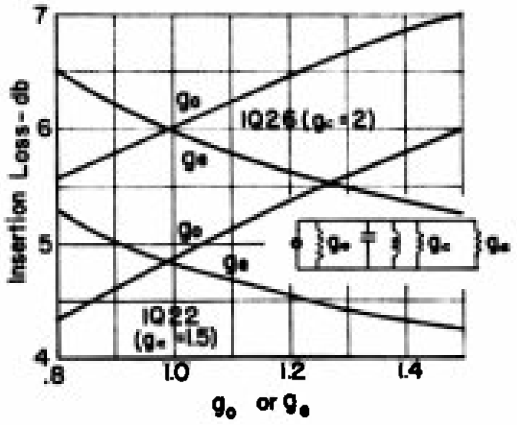
## MAXIMUM DETUNING CAUSED by MISMATCHED GENERATOR or LOAD

Fig. 8



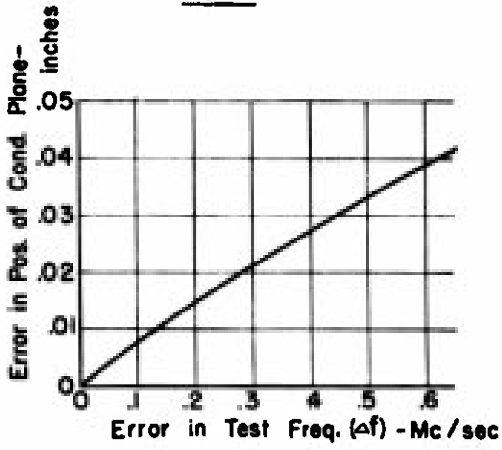
## INSERTION LOSS of 1Q22 & 1Q26 vs GEN. & LOAD CONDUCTANCE - $g_o$ & $g_e$

Fig. 9



## LOCATION of CONDUCTANCE PLANE of 1Q22 vs FREQUENCY NEAR RESONANCE

Fig. 10



$$\Delta f_{max} = .413 \frac{r^2 - 1}{r} \text{ Mc/sec} \qquad (6)$$

These two functions are plotted in Fig. 8. It should be noted that these are the maximum errors due to a VSWR in _either_ the load or generator.

Since the insertion loss tolerances are moderately severe, let us calculate the effect of mismatched loads or generators on the transmission (T)

$$T = \frac{g_e}{(g_o + g_c + g_e)^2}$$

where $g_e$ is the load conductance, $g_o$ the generator conductance, and $g_c$ the cavity conductance, all referred to a common reference plane. Fig. 9 is a plot of the effect of varying $g_o$ and $g_e$ on T for the 1Q23 and 1Q26, assuming that $g_c = 1.5$ for the 1Q22, and $g_c = 2$ for the 1Q26.

Since the loaded Q is specified to a tolerance of about ± 12-1/2 per cent, the instrumental errors should be held to the order of ± 5 per cent overall, and the contribution to this error caused by mismatched load and generator should be less than 2 per cent. Therefore, the total mismatch of generator and load should not exceed 1.07. In other words, $.93 \leq g_o + g_e \leq 1.07$. Thus, the restriction imposed by the need for an accurate Q value are much more severe than those imposed by the need for an accurate transmission value.

4. Measurements

The resonant frequency and loaded Q of these cavities are measured with a "Q-Meter", frequency standard, and interpolation oscillator. These equipments are described in the following R.L. Reports: Frequency Stds; 9250 Mc/sec, Report M-207; 9280 Mc/sec Report M-208; 9310 Mc/sec Report M-209; Interpolation Oscillators; Report 55.5-8-21-45; Q meter 55.5-9-12-45. Briefly, the measurement is as follows: A variable electron-coupled oscillator at about 5 Mc/sec is calibrated against an absolute frequency standard (WWV). Its output is multiplied up to 1857 Mc/sec in conventional vacuum tube circuits. The 1857 Mc/sec output is used to drive a 1N23 crystal mounted in 1" x 1/2" guide. The non-linear characteristic of the crystal results in a rich harmonic content, and the power at 9250 Mc/sec is about $10^{-7}$ watts. A high Q cavity is used to reject all the harmonics, but the one required. The output can be varied a few Mc/sec by tuning the electron coupled oscillator, and the absolute frequency can be easily held to ± 5 or 10 kc.

A frequency modulated 723A/B is used to feed the cavity under test. If sufficient padding is used and the 723 is centered in its mode, the output of the cavity, feeding a matched crystal, will accurately plot the response curve of the cavity; this is plotted on a cathode ray tube in the conventional manner. Simultaneously, a portion of the FM signal is mixed with the absolute frequency standard and detected in an amplifier with a variable intermediate frequency ($f_i$). As the FM signal sweeps through the standard frequency ($f_o$), the i-f amplifier will respond when the f-m signal is at $f = f_o \pm f_i$. The output of the amplifier is used to intensity modulate the cathode ray tube (usually as a pair of bright spots). These spots may be centered on the cavity response characteristic by varying $f_o$. The value of $f_o$ required to symmetrically locate the spots on the base is equal to the resonant frequency of the cavity. If $f_1$ is varied, the spots will move up and down the trace, remaining symmetrical about the center. In particular, if they are located at the point of half-power response, the Q of the cavity will be given by $f/2f_1$.

In order to check this electronic equipment, the Q of a 1Q23 was carefully measured by plotting VSWR as a function of frequency. The standing wave ratio corresponding to the half-power points is given by

$$r = \frac{1 + \beta + \sqrt{\beta^2 + 1}}{1 + \beta - \sqrt{\beta^2 + 1}}$$

where β is the standing wave ratio at resonance (also the minimum standing wave ratio). Frequency differences were measured with a TFX-16 wavemeter that had been modified by adding a vernier tuner with a least count of .05 Mc/sec, and standing wave ratios were measured with an X-band spectrum analyzer TSX-4SE.

A stabilized 723A/B using an r-f discriminator and d-c feed back amplifier was used as a signal source (R.L. Reports 662, 815). With all these precautions, the Q value obtained from a number of measurements had a probable error of ± 1 per cent. The same cavity was then measured on the Q-meter at Westinghouse. The agreement of the two measurements was of the order of 1 per cent. The response of two cavities may be compared visually by means of an instrument TFX-29RL that alternately plots the response of each cavity on a cathode ray tube. With this instrument the Q, tuning, and insertion loss of an unknown cavity may be compared to a standard calibrated cavity.

The measurement of the location of the conductance plane of the cavity can be made in several ways. If the test oscillator can be set exactly to the resonant frequency of the cavity under test, then the location of the minimum of the input standing wave can be measured directly. This is not generally practical since different cavities may differ in frequency by as much as 0.6 Mc/sec, and if the test frequency differs from the resonant frequency, the measurement will be in error by the amount indicated in Fig. 10. However, a plot of phase as a function of frequency (Fig. 11) indicates that far from resonance, the standing wave will have almost the same phase as at resonance, and that the rate of change of phase with frequency is much slower than at resonance.

Therefore, one can measure the phase at $f_o$ ± 100 Mc/sec and the average of these two measurements will be very nearly equal to the phase at resonance (to about ± .001"). Since a tolerance of ± .010" is allowed in the location of the conductance plane, and present manufacturing techniques requires this wide a tolerance, the measurement itself must be accurate to about ± .001".

## 5. Summary

There are now available two types of X-band beacon reference cavities, the 1Q22 series made by Westinghouse and the 1Q26 made by G. E. The 1Q22 series have greater frequency vs temperature stability than does the 1Q26. Both have excellent stability against shock, vibration, and handling. The problem of sealing the differential screw against further rotation in the 1Q26 is a difficult one, and a number of different cements and sealing compounds have been tried with varying degrees of success. The higher unloaded Q and loaded Q of the 1Q22 gives it a better figure of merit than the 1Q26. However, the accuracy required in the phase of the 4:1 standing wave introduced by the crystal load and the tolerance in the location of the conductance plane of the cavity make the actual frequency errors greater than those expected for operation between matched load and generator.

A few thermally compensated 1Q26's have been built, and these are apparently as well compensated as the 1Q22.

The 1Q26 is considerably smaller in volume than the 1Q22. For aircraft use, the weight is also important. The 1Q22 weighs 12.1 oz. as compared to 6.6 oz. for the 1Q26.

L. D. Smullin

November 28, 1945

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ABSTRACT:

The present status of X-Band beacon reference cavities is summarized. There are now available two types, the 1Q22 series made by Westinghouse, and the 1Q26 made by G.E. Both have excellent stability against shock, vibration, and handling. The higher unloaded Q and loaded Q of the 1Q22 gives it a better figure of merit than the 1Q26. However, the accuracy required in the phase of the 4:1 standing wave introduced by the crystal load and the tolerance in the location of the conductance plane of the cavity make the actual frequency errors greater than those expected for operation between matched load and generator.

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