SURFACE FINISH

Surface finish is a factor in determining the electrical resistance and the aging characteristics of a quartz resonator plate.

Surface Finish and Aging

If a resonator plate is left rough as it comes from a finish lapping process, it will gradually lose small particles of quartz from its surface, and increase in frequency with time (upward aging). Consequently it is common practice to etch unpolished blanks. The amount of etch is expressed in terms of upward shift in frequency in kilocycles which results from the etch. The minimum value varies from 0.04 to 0.30 F^2 (F in mc) according to the abrasive used in the last lapping process. Some manufacturers apply a light etch to polished plates, and it is generally regarded as desirable to etch whenever a plot of frequency change vs. time in a standard etch solution shows that the change of frequency is more rapid at the beginning of the etching process.

It is also to be observed with reference to surface finish and aging that a cleaning process is likely to be more efficient when applied to a smooth surface than when applied to a rough surface.

Surface Finish and Resistance

The effect of a rough surface upon resistance increases with the frequency of the plate. In order to meet the specifications most commonly used, it is customary to begin polishing at the upper end (40 mc or higher) of the usual 3rd harmonic frequency range. ["Polish" here means a surface no worse than that indicated by the middle curve in Figure 47, produced by an abrasive finer than 5 microns, by some special process differing from standard "lapping" processes, and usually employing lapping plates of a material which can be charged with abrasive.] Some manufacturers are able to meet common resistance specifications up to 50 or 60 mc without polishing. It is possible, but not practical, to produce units above 60 mc with less than 60 ohms resistance, by etching a good 5 micron finish.

Estimating the Quality of Surface Finish

Defining a surface finish by the abrasive used to produce it, is of very limited usefulness. Not only are the characteristics of the lapping or polishing machine and of its use important factors, but the commercial grading of abrasives is also too uncertain to permit accurate definition by this means.*

The average surface finish of a plate can be measured by optical means, by a profilometer, or by the rate at which frequency changes when the plate is etched in a standard etch solution. A definition of an adequate polish can be obtained from a family of etch rate curves. If Δf is plotted on the ordinate and the etch time in a standard solution is plotted on the abscissa, the poorest surface finish will be represented by the curves nearest the top of the graph. Selecting some convenient and sufficient time, a value is selected for this time, safely below the etch rate curve for the first group of units to show increased resistance. Differences between the effects of "good" and "excellent" polishes are often obscured by other variables.

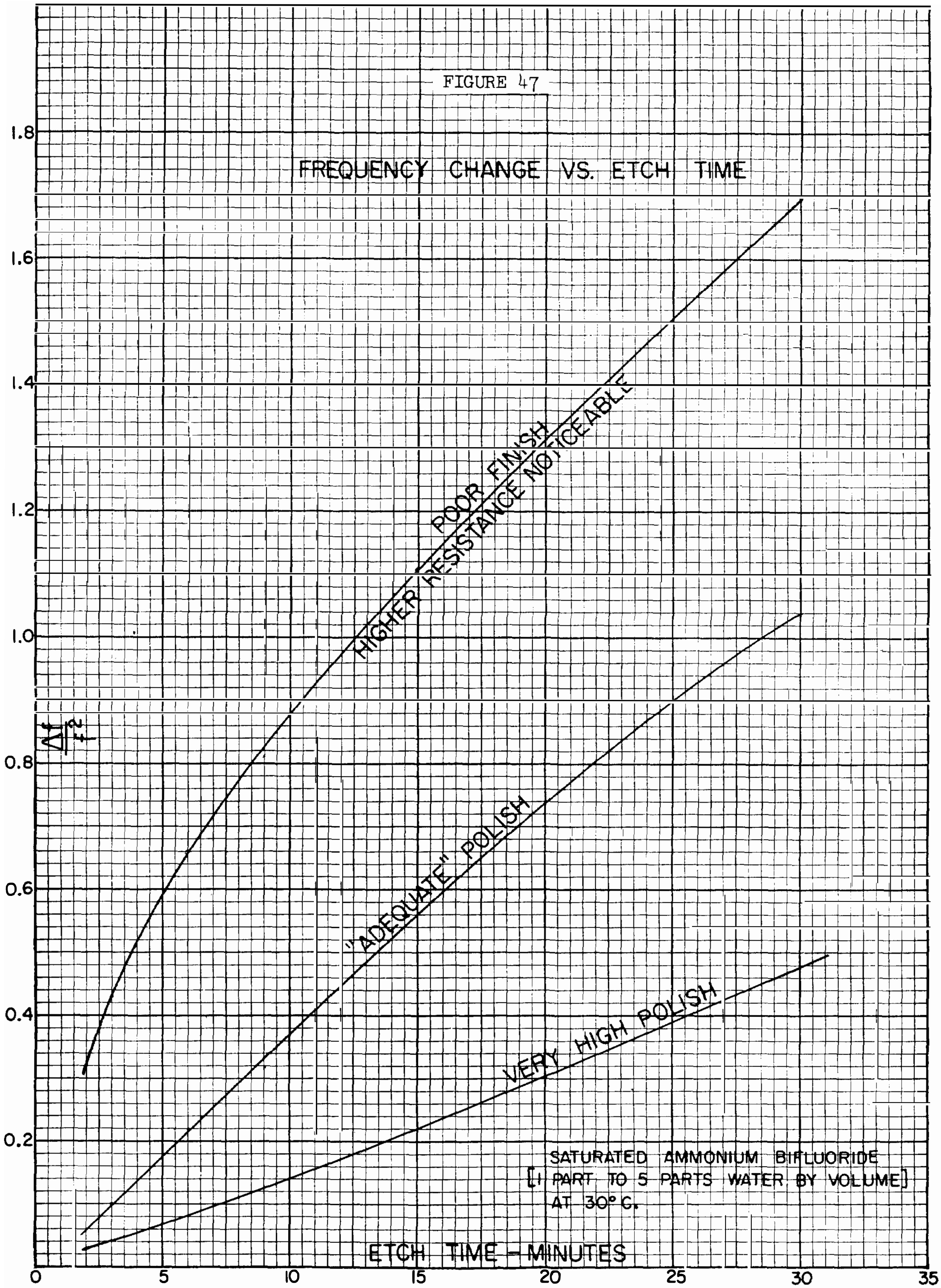
Etching is being considered here as a destructive test, not as a part of the surface preparation.

The following two etch rate curves were prepared from measurements made by Mr. Mulvihill of the U. S. Army Signal Research and Development Laboratories. The curve marked "Very High Polish" not only shows a relatively slow rate of change of frequency, but after about 7 minutes in the etch solution the rate of change increases, indicating that the finish produced by a short etch is inferior to the original finish. The curve marked "Adequate Polish" shows no significant decrease in rate of frequency change for the first few minutes, although the rate of change is greater than for the units with a very high polish. Possibly, if other variables were under very good control a corresponding difference in resistance would be noticeable. The upper curve shows a quite rapid change in frequency during the first few minutes of etch and then a decrease in rate of change, indicating that etching is improving an originally poor surface. Units with such surfaces, if etched, may show a decrease in resistance. With or without etch they are likely to have higher resistances than those with surfaces such as those which produced the middle curve.**

* See Union Thermoelectric Corporation, Abrasive Grading and the Lapping of Quartz Oscillator Plates, Special Report (15 April, 1958), on Contract DA36-039-sc-71061.

** For a detailed study of etch-rate vs. abrasive size and lapping and polishing processes, as well as other methods of measurement, see Seymore S. Brody, A Study of the Surface Structure of Quartz Crystals, Signal Corps Engineering Laboratories, Engineering Report No. E-1133 (30 September, 1953).

FIGURE 47


FREQUENCY CHANGE VS. ETCH TIME
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
$\frac{\Delta f}{f^2}$
POOR FINISH
HIGHER RESISTANCE NOTICEABLE
"ADEQUATE" POLISH
VERY HIGH POLISH
SATURATED AMMONIUM BIFLUORIDE
[1 PART TO 5 PARTS WATER BY VOLUME]
AT 30° C.
ETCH TIME - MINUTES
0
5
10
15
20
25
30
35

It is also to be noted that if the thickness at the center of a contoured plate is used in calculating C_e, the result will be less than the actual capacitance.

Because of the many variables involved when calculating the shunt capacitance, it is advisable, whenever possible, to rely upon precision measurements and upon extrapolations of those measurements.

Over limited ranges, such as 1/2 or 2/1 change in frequency (unshaped plates with relatively large diameter to thickness ratios), of a 6/7 or 7/6 change in capacitance at the same frequency, it is possible to extrapolate from a known situation to an unknown with an accuracy of the order of ±0.2 μμf.

If it is desired to maintain the same C_o value at a new frequency:

$$d_e1 = d_e2\sqrt{\frac{f2}{f1}} \quad ,$$

where: d_e1 is the new electrode diameter,
d_e2 is the diameter of the electrode which results in a known value of C_o.
f1 is the new fundamental frequency,
f2 is the fundamental frequency for which the C_o value for d_e2 is known.

If it is desired to change the capacitance at the same frequency:

$$d_e1 = d_e2\sqrt{\frac{C_o1}{C_o2}} \quad ,$$

where C_o1 is the new value, and C_o2 is the known value for d_e2. This equation can be made somewhat more accurate by subtracting the holder capacitance from C_o2 and C_o1.

At frequencies below 100 mc normal specifications insure that the ratio of the reactance of C_o to the measured resistance of the unit is large. For new and experimental units, especially at frequencies above 100 mc, it is necessary to note that the ratio X_{C_o}/R may become too small.

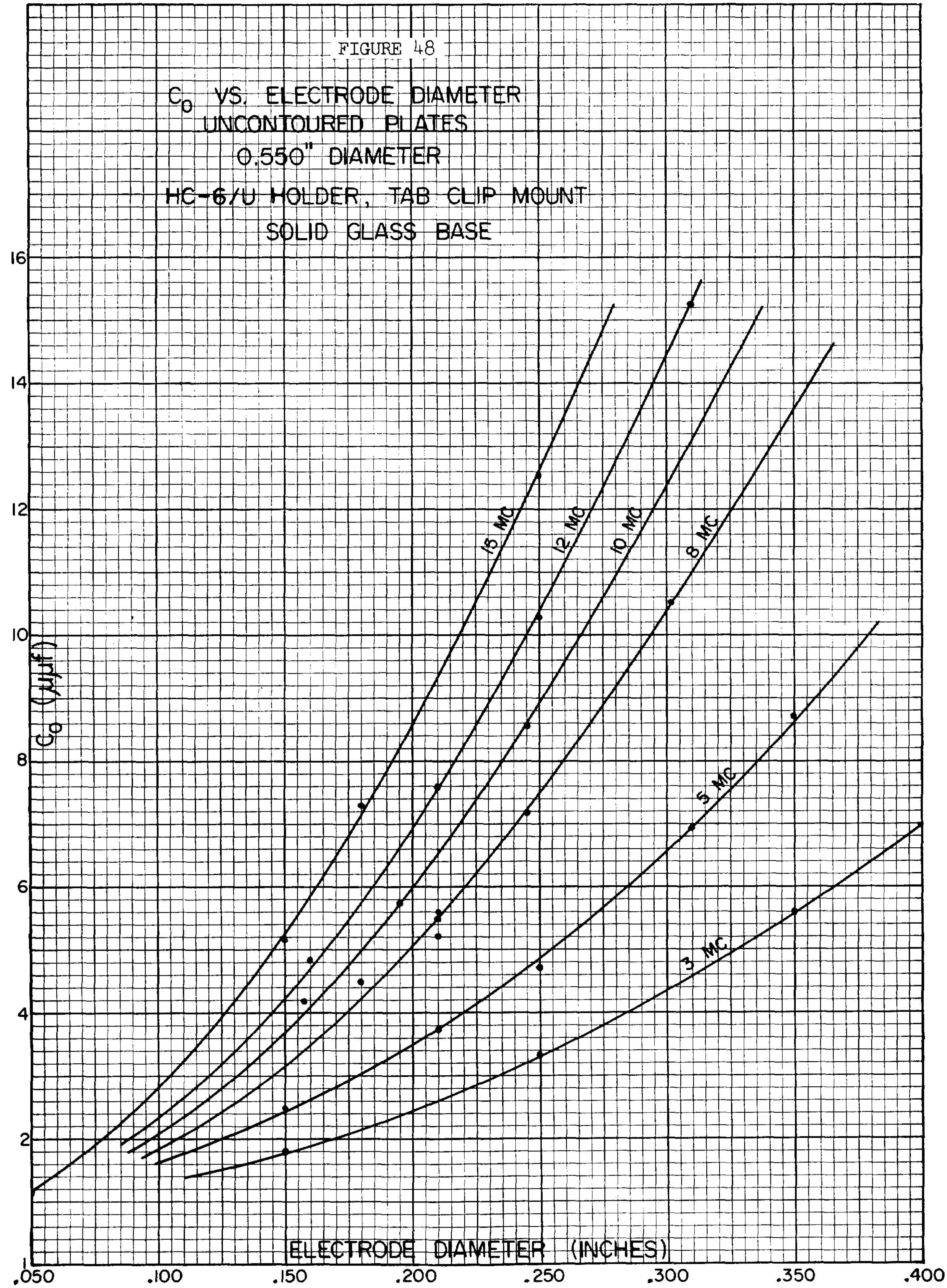
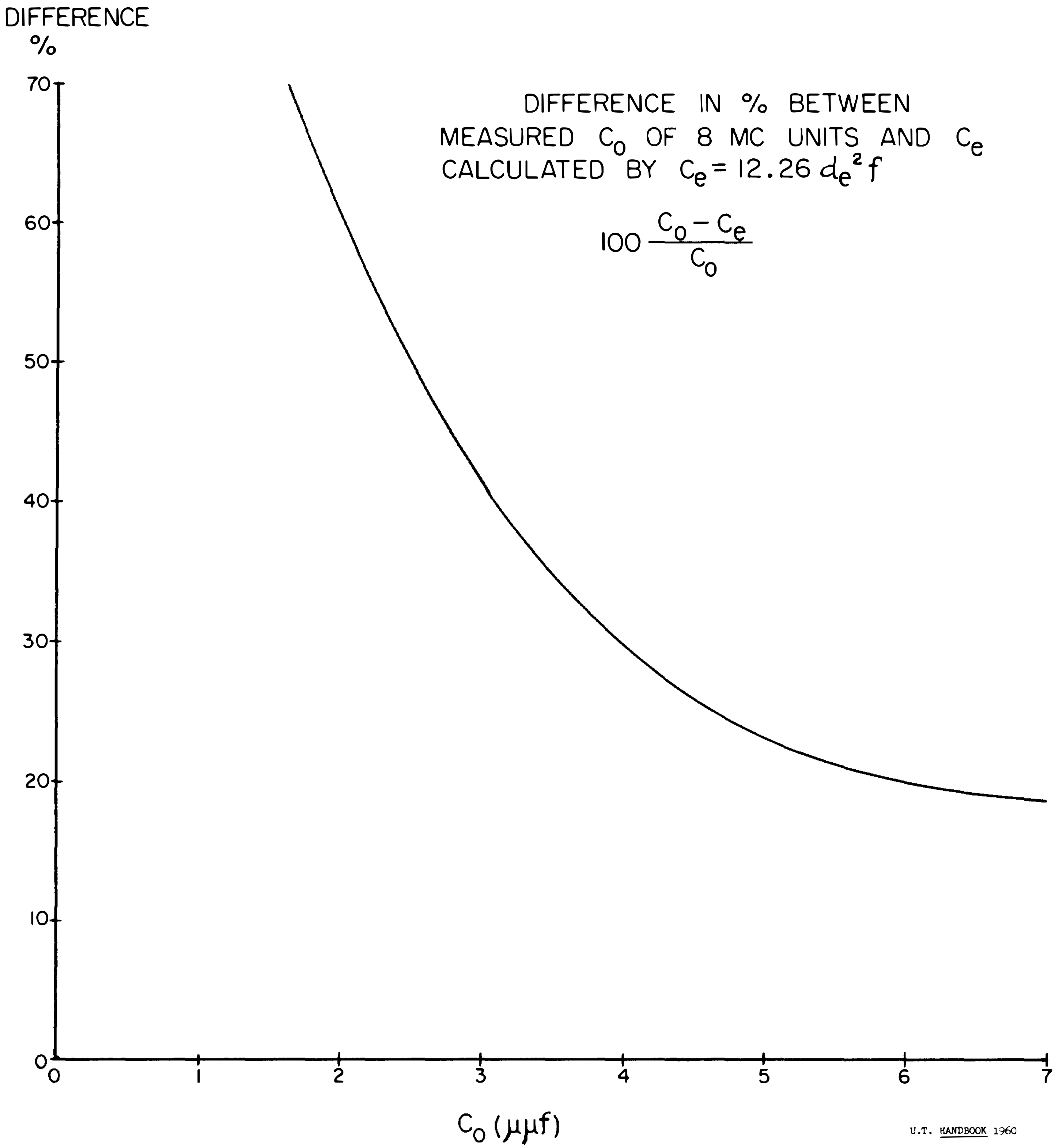


FIGURE 48
C_0 VS. ELECTRODE DIAMETER
UNCONTOURED PLATES
0.550" DIAMETER
HC-6/U HOLDER, TAB CLIP MOUNT
SOLID GLASS BASE
15 MC
12 MC
10 MC
8 MC
5 MC
3 MC
C_0 (μμf)
16
14
12
10
8
6
4
2
1
ELECTRODE DIAMETER (INCHES)
.050
.100
.150
.200
.250
.300
.350
.400

FIGURE 49


DIFFERENCE
%
70
60
50
40
30
20
10
0
DIFFERENCE IN % BETWEEN
MEASURED C_0 OF 8 MC UNITS AND C_e
CALCULATED BY $C_e = 12.26\, d_e^2 f$
$100 \frac{C_0 - C_e}{C_0}$
0
1
2
3
4
5
6
7
C_0 (μμf)

Thickness of Plated Electrodes

The negative change in frequency as the thickness of plated electrodes is increased is most conveniently expressed as $\Delta f/F^2$, where Δf is the negative frequency change in kc, and F is the approximate frequency in megacycles. $\Delta f/F^2$ is directly proportional to the mass of the metal deposited on the resonator plate.

This is illustrated in Figure 50. Take, for example a filament charge of 0.2 grams. At 3 mc the frequency change produced by 0.2 grams is 0.9 kc, at 4 mc, it is 1.6 kc, at 5 mc it is 2.5 kc. Or, for this particular situation $\Delta f/F^2 = .9/9 = 1.6/16 = 1/10$.

For a point source of evaporated metal, it is possible to move from a known to an unknown situation by:

$$M_2 = \frac{M_1 d_2^2}{d_1^2} \quad ,$$

where:

M_1 = filament charge in known situation.

M_2 = filament charge required in unknown situation.

d_1 = distance between plating mask and filament in known situation.

d_2 = distance between plating mask and filament in unknown situation.

It is to be noted that graphs such as Figure 50 may not apply to both contoured and uncontoured plates. It is also to be noted that in order to meet current standards it has not been found necessary to take into account the greater actual area of a thin metal film on a rough surface.

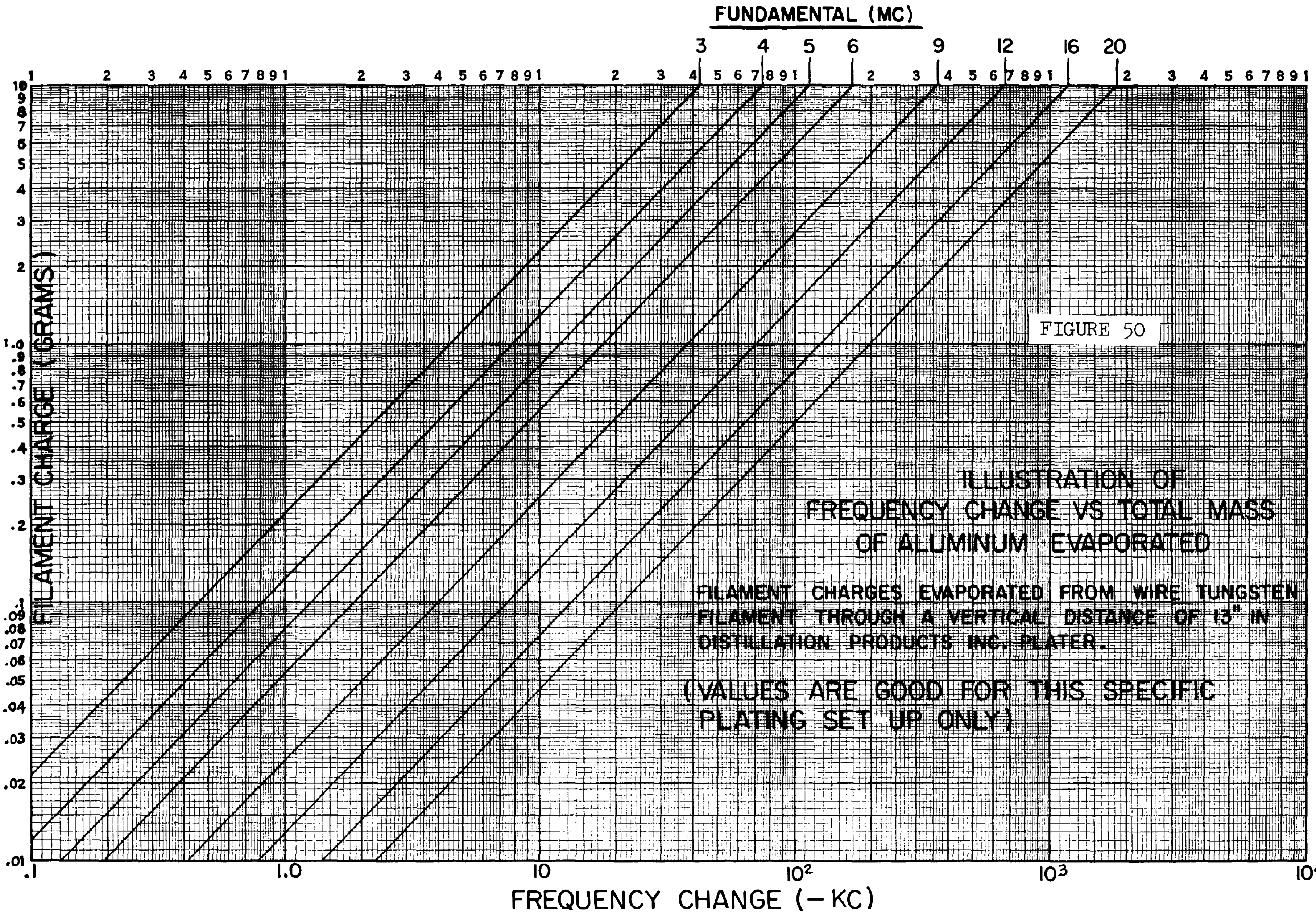
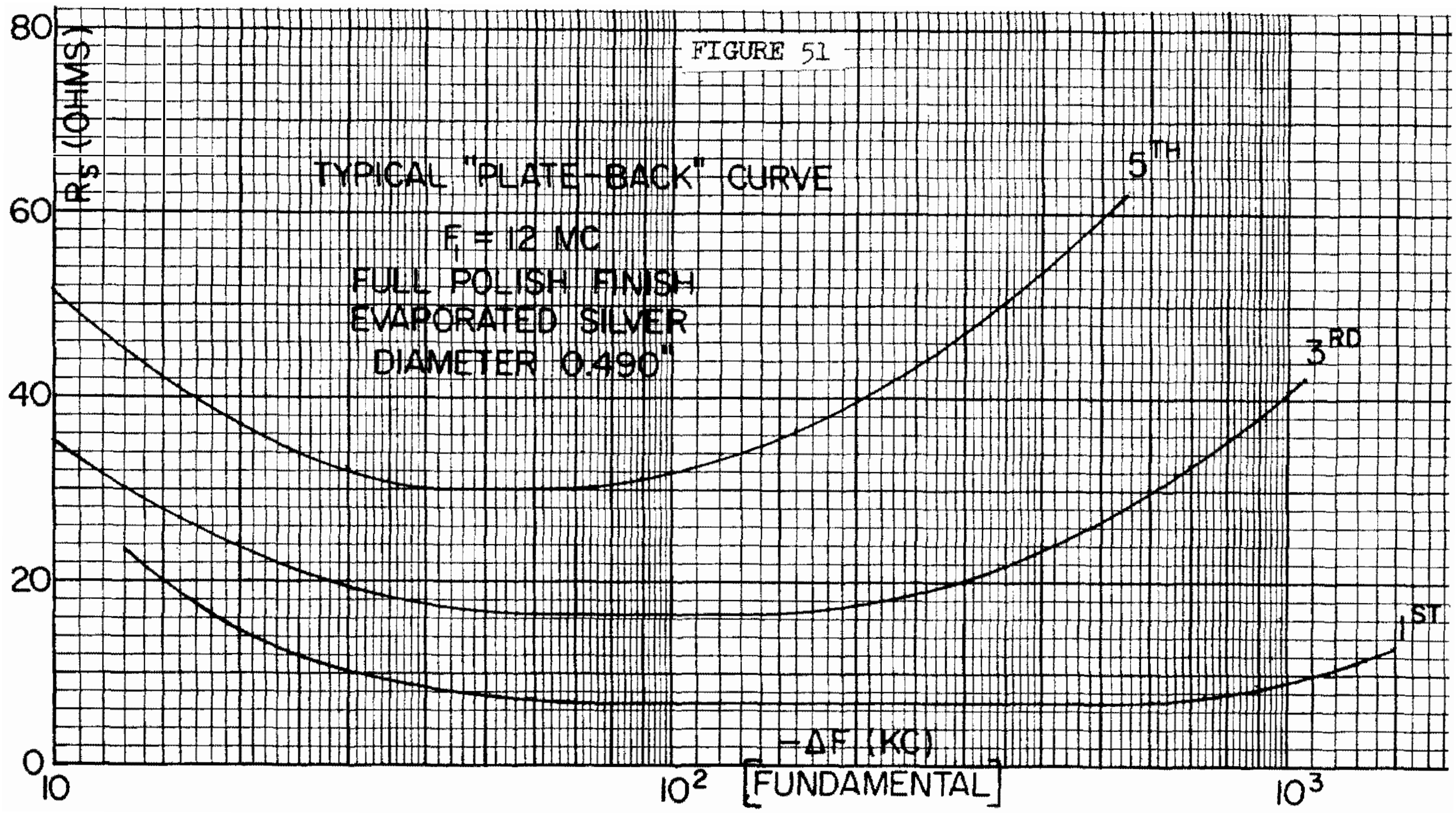

FUNDAMENTAL (MC)
3 4 5 6 9 12 16 20
FILAMENT CHARGE (GRAMS)
FREQUENCY CHANGE (– KC)
.1 1.0 10 10^2 10^3 10^4
ILLUSTRATION OF
FREQUENCY CHANGE VS TOTAL MASS
OF ALUMINUM EVAPORATED
FILAMENT CHARGES EVAPORATED FROM WIRE TUNGSTEN
FILAMENT THROUGH A VERTICAL DISTANCE OF 13" IN
DISTILLATION PRODUCTS INC. PLATER.
(VALUES ARE GOOD FOR THIS SPECIFIC
PLATING SET UP ONLY)

FIGURE 50

Amount of Plating and Resistance

When the resistance of the oscillating unit is measured between pins for various thicknesses of plating the resistance first decreases rapidly, then less rapidly, levels off, and begins to increase, at first slowly, and then more rapidly, as more plating is added.



The dominant component of the decreasing values of resistance on the left is the resistance of the metal film. The dominant component of the increasing values of resistance on the right is the motional resistance created by the mechanical loading by the metal film. There is also a constant component resulting from factors not effected by plating, such as: damping by the mount, resistance of the mount, atmospheric loading, and internal friction losses.

Except in the case of heavy metals, such as gold, at very high frequencies, the almost horizontal portion of the curve of resistance as a function of plate-back (in kilocycles) is quite long. Consequently, it is not necessary to prepare or know these curves with very high precision, and a manufacturer has considerable latitude in which to allow for the spreads and uncertainties of his finishing processes.

For practical purposes the following system is sufficiently accurate:-

All frequencies and frequency changes (F in mc, and Δf in kc) are on the fundamental. Thus if a given amount of plating causes a 5th overtone unit to change in frequency from 100 mc to 99.7 mc, $\Delta f/F^2$ = 60/400 = 0.15. (The change is always negative. So the negative sign may be omitted for convenience.)

For each metal and for each harmonic order, the point on the left at which the descending resistance curve approaches within about one ohm of the minimum, is defined in terms of $\Delta f/F^2$, that is, the frequency change in kilocycles on the fundamental, divided by the square of the approximate fundamental frequency in megacycles. This value may be called Δf minimum.

For each metal and each harmonic order the point on the right at which the ascending resistance curve is about one ohm above the minimum, is located and defined in terms of $\Delta f/F^2$, and is called Δf maximum.

Thus for 3 metals, the fundamental, and 3rd and 5th harmonic orders, we have 9 minimum values and 9 maximum values.

In the table which follows there are only 8 maximum values and 8 minimum values because complete gold plating is not recommended for high frequency 5th harmonic units. When gold is used, activity dips usually occur.

Data for the table was collected for 3rd harmonics in the frequency range 20 to 60 mc, and for 5th harmonics in the frequency range 60-100 mc.

The maximum and minimum plate-back table does not claim to high precision, and makes no recognition of such variables as surface finish. It is, however, important to note that the tolerances are very wide for all but 5th harmonic units, and that when it becomes necessary to make very low resistance units to operate on the fifth harmonic at very high frequencies, it will be found that differences in resistance created by the amount of frequency plating added to the base plating and by the method of frequency plating are much more important than any inaccuracies of this table.

TABLE 5

MINIMUM AND MAXIMUM PLATE-BACK *

Multiply Square of Fundamental Frequency in Megacycles by $\Delta f/F^2$
to Find Plate-Back on the Fundamental in Kilocycles

OVERTONE ORDER	METAL	$\Delta f/F^2$ MINIMUM	$\Delta f/F^2$ MAXIMUM
1	AL	0.26	3.5
1	AG	0.45	3.4
1	AU	0.84	3.0
3	AL	0.20	1.0
3	AG	0.37	1.0
3	AU	0.42	0.8
5	AL	0.16	0.4
5	AG	0.28	0.5

* Values have not been tested for contoured blanks.