6-23. DESIGN OF SERIES OSCILLATORS, 1 KC TO 100 KC

Below 90 KC the resonance resistance of crystal units is so large that the grounded grid amplifier circuit is no longer suitable because of the excessive attenuation that would occur between the crystal unit input and the amplifier input terminals. A more suitable oscillator configuration then consists of a grounded-cathode amplifier and a phase-inverting feedback network as shown in Figure 6-26. In this circuit the grid leak resistor R_g is usually the major part of the crystal unit output terminating resistance and can be selected to provide a suitable terminating level without incurring an excessive attenuation.

The major disadvantage of this circuit is the large tuned circuit component values required at the lower frequencies which may make the alternative circuits presented later more desirable. This does not apply at the higher frequencies, and this circuit may perhaps be used advantageously up to 500 KC.

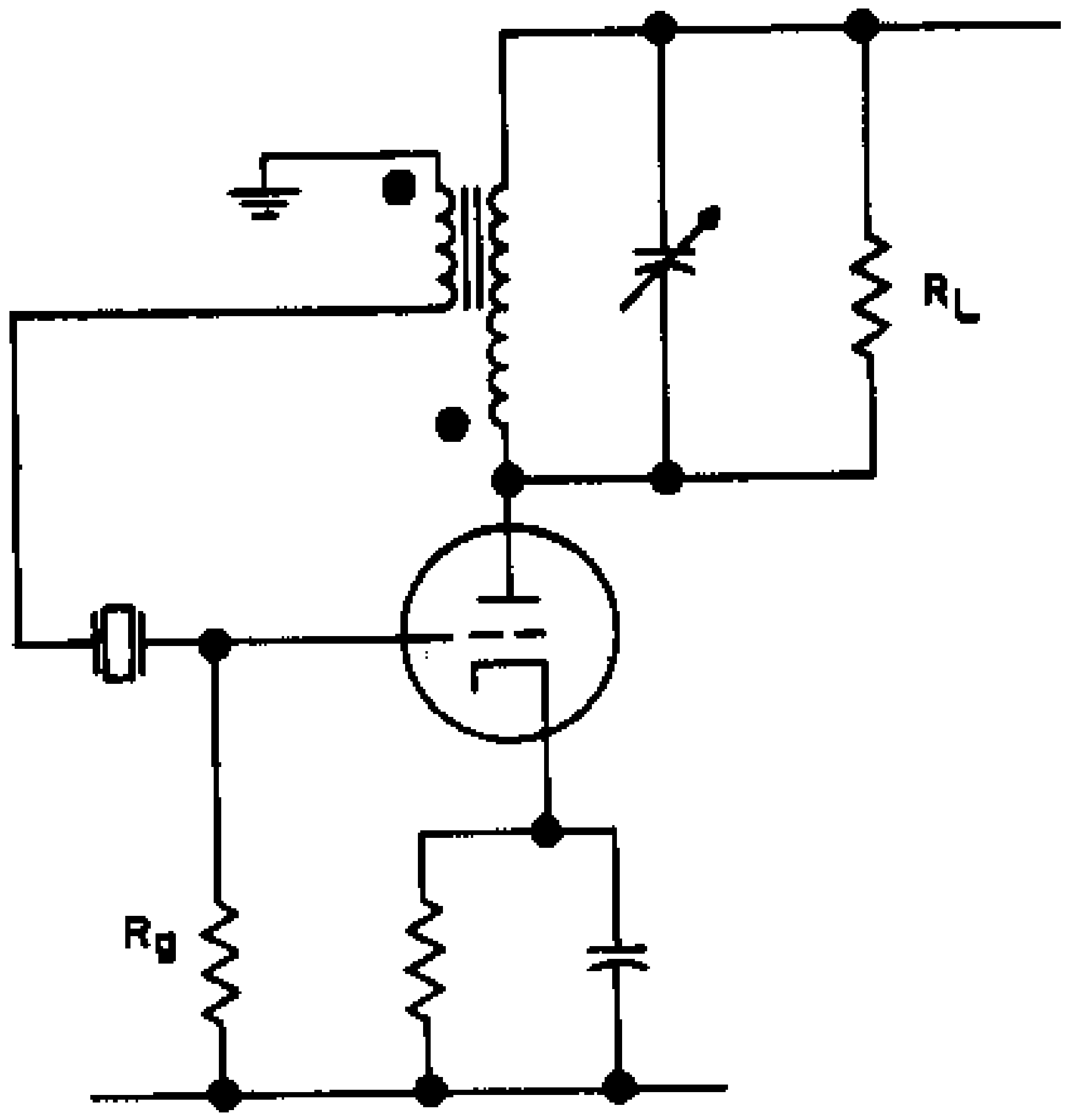

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Figure 6-26. Oscillator Circuit For Use Below 90 KC

6-24. Crystal Unit Characteristics

The only military type series resonance crystal unit applicable in this frequency range is the CR-50A/U covering the range from 16 to 100 KC. The major characteristics of this crystal unit are:

Frequency Range:	16 to 100 KC, inclusive
Overall Frequency Tolerance:	±0.012 percent
Operating Temperature Range:	-40 to +70°C
Rated Dissipation:	0.1 MW
Maximum Resonance Resistance:	16 to 30 KC: 100 K
	30+ to 50 KC: 90 K
	50+ to 70 KC: 80 K
	70+ to 90 KC: 70 K
	90+ to 100 KC: 60 K
Crystal Holder:	HC-13/U

There are no military type crystal units applicable at frequencies below 16 KC, but crystal units are manufactured for operation at frequencies from below 1 KC to 16 KC. Typical manufacturer's data for these give the following major characteristics:

Overall Frequency Tolerance:	±0.015 percent
Operating Temperature Range:	-40 to +70°C
Rated Dissipation:	Values ranging from 10 to 100 UW
Maximum Resonance Resistance:	Values from 100 to 200 K
Physical Configuration:	The resonator in these units is in the form of a relatively long quartz bar, and usually the holder is a cylindrical glass bulb 3 to 4 inches in length mounted on an octal tube base, although at the higher frequencies crystal holders of the HC-13/U type may be available.

As discussed in detail in Paragraph 6-6 , the permissible drive voltage V_{max} applied at the crystal unit input terminal depends on the relative values of the crystal unit resonance resistance R_r and the amplifier input resistance R_{in}. When R_{in} is less than or equal to $R_{r\ max}$, the relationship is:

$$V_{max} = 2\sqrt{P_{CMAX} \cdot R_{in}} \qquad (6\text{-}34)$$

Denoting the relationship between R_{in} and R_{r} max as

$$R_{in} = k\, R_r \max \qquad (6\text{-}35)$$

where k is less than 1, enables V_{max} to be calculated as a function of k. For the given crystal characteristics, these calculations result in the values contained in Table 6-7. The double values of V_{max} given for the frequency range of 1 to 16 KC take into account the spread in crystal dissipation rating quoted by manufacturers. It is thought probable that 10 UW is the more desirable rating, and this will be subsequently employed.

Relating the values of V_{max} in Table 6-7 to the plate signal levels at which amplifier self-limiting can be readily obtained shows that the voltage ratio of the feedback transformer need not be very large. Amplifier voltage gain requirements are therefore not too demanding.

TABLE 6-7. CRYSTAL CHARACTERISTICS, 1 TO 100 KC

Frequency (KC)	R_r max (Kilohms)	P_{CMAX} (UW)	V_{max} (RMS)		
			k = 0.33	k = 0.5	k = 1
1 to 16 KC	200	100	5.2	6.4	9
		10	1.6	2	2.8
16 to 30 KC	100	100	3.6	4.5	6.3
30+ to 50 KC	90	100	3.5	4.3	6
50+ to 70 KC	80	100	3.2	4.0	5.6
70+ to 90 KC	70	100	3.0	3.8	5.3
90+ to 100 KC	60	100	2.8	3.5	4.9

6-25. Amplifier Characteristics

The voltage gain of a grounded-cathode triode amplifier, when the plate circuit is tuned to resonance or when the plate circuit reactance is negligibly large compared to the plate load resistance, is:

$$G_V = \frac{\mu R_T}{R_T + R_p} \qquad (6\text{-}36)$$

The amplifier input resistance consists of the grid-leak resistor R_g and the grid-cathode capacitance C_{gk} in parallel with two impedance components due to feedback via the grid-plate capacitance C_{pg}. This subject is discussed in detail in Section 9 where it is shown that, provided the phase shift between the grid and plate is small, these components are:

$$C_M = (G_V + 1)\, C_{pg} \qquad (6\text{-}37)$$

$$R_M = X_{C_M}/\phi \qquad (6\text{-}38)$$

where ϕ is the phase angle of the plate signal relative to the grid signal in radians. The amplifier input impedance therefore consists of R_g, R_M, C_M, and C_{gk} all in parallel.

Frequently, the reactance of C_M and R_M are negligibly large compared to R_g and have little influence on the amplifier input impedance. In some cases, however, an appreciable phase shift can occur due to C_M. Figure 6-27 illustrates the effect at the crystal unit resonance frequency. The phase angle of V_2 relative to V_1 is:

$$\phi = -\tan^{-1} \frac{k}{1+k} \cdot \frac{R_{r\,max}}{X_{C_M}} \qquad (6\text{-}39)$$

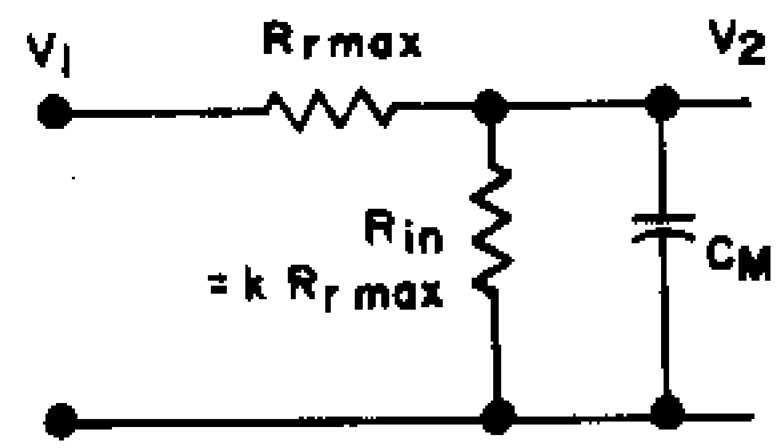

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Figure 6-27. Effect of C_M on Loop Phase Angle

It is apparent that for the likely range of k values an undesirably large phase lag of V_2 relative to V_1 can occur if the reactance of C_M approaches $R_{r\,max}$ in value. A phase lag of up to 10 degrees will not upset the circuit performance unduly, and this is considered a suitable maximum allowable value. Substituting 10 degrees into Equation (6-39) then gives as a limiting condition:

$$\frac{k}{1+k} \cdot \frac{R_{r\,max}}{X_{C_M}} \leq 0.18 \qquad (6\text{-}40)$$

If this relationship is satisfied, the effects of X_{C_M} can be neglected. If not, it will be necessary to provide a correction. This can be conveniently introduced using a neutralizing capacitor. The object is to provide a current flowing to the grid point equal in magnitude and opposite in phase to that flowing through C_{pg}. Since the output signal of the impedance transformer is in phase opposition to the plate signal voltage, a capacitor connected from this point to the grid will provide a current of the required phase. To provide the correct current magnitude requires the capacitance to be related to C_{pg} and the voltage ratio of the impedance transformer T_{V_o} by the expression:

$$C_n = C_{pg} / T_{V_o} \qquad (6\text{-}41)$$

It is not necessary to achieve complete neutralization, and the value of C_n is not critical. The nearest 5 percent standard value to that calculated should suffice.

Provided that the plate phase lag is not more than 10 degrees, values of X_{C_M} satisfying Equation (6-40) will result in values of R_M sufficiently large that its effect on the amplifier input resistance can be neglected. And when X_{C_M} does not satisfy Equation (6-40) and neutralizing is required, R_M will not, of course, be present. Under normal circumstances R_M can therefore be neglected and R_{in} is then equal to R_g.

The amplifier output impedance insofar as the feedback network is concerned consists of the parallel combination of R_p, the oscillator load R_L, and the capacitance from the plate to all other electrodes.

6-26. Loop Gain Relationships

For the oscillator circuit of Figure 6-26, the loop gain relationships can be conveniently divided into three factors. These are:

(a) The amplifier voltage gain G_V from the grid to the plate circuit

(b) The attenuation A_{V_C} from the crystal unit input terminal to the tube grid

(c) The voltage ratio T_{V_o} of the impedance transforming network between the tube plate and the crystal unit input terminal.

The oscillator loop voltage gain is then:

$$G_{V_L} = G_V \cdot A_{V_C} \cdot T_{V_o} \qquad (6\text{-}41)$$

where:

$$A_{V_C} = \frac{R_{in}}{R_{r\,max} + R_{in}} \qquad (R_{in} = R_g) \qquad (6\text{-}42)$$

T_{V_o} is a design variable which must be large enough to provide adequate loop gain but must also be sufficiently small as to prevent crystal unit overdrive. That portion of the feedback network input resistance due to the transformation of the series combination of the amplifier input resistance and the crystal resonance resistance is related to T_{V_o} as:

$$R_{FB} = \frac{R_{r\,max} + R_{in}}{T_{V_o}^2} \qquad (6\text{-}43)$$

A loop voltage gain of 1.4 is usually adequate for a worst-case design and substituting this value into Equation (6-41) gives:

$$T_{V_o} = \frac{1.4}{G_V \cdot A_{V_C}} \qquad (6\text{-}43)$$

The permissible plate signal voltage V_o max is related to V_{max} as:

$$V_{o\ max} = V_{max}/T_{V_o} \qquad (6\text{-}44)$$

The oscillator plate load resistance R_L is related to R_T and R_{FB} as:

$$R_L = \frac{R_T \cdot R_{FB}}{R_{FB} - R_T} \qquad (6\text{-}45)$$

The terminating resistance level at the input side of the crystal unit is $T_{V_o}^2 \cdot R_o$, where R_o is equal to R_p and R_L in parallel.

6-27. Impedance Transforming Network

The impedance transforming network is required to give a 180-degree phase shift, and either the π network or a phase inverting inductive transformer is suitable, although of the two, the inductive transformer is perhaps to be preferred since it can also be used as a parallel feed path for the tube plate current. This is particularly advantageous if the available plate supply voltage is low.

The secondary load impedance of the transformer consists of R_r max and R_{in} in series and therefore has values of from not less than 60 K to more than 200 K. In view of the high level of the secondary load, the most suitable inductive transformer operating condition is that obtained when the secondary winding inductance is small compared to the secondary load resistance. The design equations for this type of operation are:

$$T_{V_o} = \frac{V_2}{V_1} = -k\sqrt{\frac{L_2}{L_2}} \angle 90^o - \tan^{-1}\frac{\omega L_2}{r_s} - \tan^{-1}\frac{r_s}{k^2\omega L_2} \qquad (6\text{-}46)$$

$$\frac{\omega L_2}{r_s} \le \frac{1}{3}, \text{ where } r_s = R_{r\,max} + R_g. \qquad (6\text{-}47)$$

The inductance of the primary winding is determined from consideration of the plate circuit loaded Q. The plate circuit Q should not be too high, otherwise temperature changes may cause large variations in the plate tuned circuit phase angle, in turn increasing the oscillator frequency tolerance. Because of this, a plate circuit loaded Q of less than 15 is considered desirable. This determines the minimum value that the primary inductance may have relative to the amplifier output resistance. The plate circuit loaded Q, assuming the coil Q is large, is:

$$Q_L = \frac{R_T \cdot R_p}{(R_T + R_p)} \cdot \frac{1}{\omega L_1} \tag{6-48}$$

For Q_L equal to or less than 15, this gives:

$$\omega L_1 \geq \frac{R_T \cdot R_p}{15\ (R_T + R_p)} \tag{6-49}$$

The effective parallel resistance R_{LP} of the transformer reflected into the plate circuit forms part of the calculated oscillator load R_L. The relationship is:

$$R_L = \frac{R_L' \cdot R_{LP}}{R_L' + R_{LP}} \tag{6-50}$$

where R_L' is the actual oscillator load reflected into the plate circuit. Depending on the external oscillator load relative to the calculated R_L and the Q of the transformer windings, the transformer loss resistance may necessitate a larger value of primary inductance than that given by Equation (6-48).

Plate circuit tuning may present a difficulty at the lowest frequencies because of the large value of tuning capacitance required. One possibility is to adjust the transformer to resonance at the design frequency before installation in the circuit. Another alternative is to wind the transformer on a tunable pot core.

6-28. DESIGN EXAMPLES

The design process consists of obtaining a suitable loop gain while satisfying the limiting condition on T_{V_0} and k. The design procedure closely follows that given previously for design in the 90 KC to 60 MC range. The following examples illustrate the approach.

6-29. 16 to 100 KC Series Oscillator

This example is presented for the two extreme frequencies of the range. The circuit value changes required for intermediate frequencies should be evident.

Crystal characteristics:

	16 KC	100 KC
$R_{r\ max}$	100 K	60 K
P_{CMAX}	100 UW	100 UW

For $k = 0.5\ (R_{in} = 0.5\ R_{r\ max})$, $A_{VC} = \frac{1}{3}$.

Then:

	16 KC	100 KC
V_{max} (RMS)	4.5	3.5
$R_g = R_{in} = k\ R_{r\ max}$	50 K	30 K
$R_{r\ max} + R_{in} = (1 + k)\ R_{r\ max}$	150 K	90 K
$R_{r\ max}$ in parallel with R_{in}	33 K	20 K

Using a 12AT7 triode and selecting an operating point at $E_p = 100$ VDC, $I_p = 4$ MA, $V_G = -0.9$ VDC, the tube characteristics are $R_p = 14$ K, $\mu = 62$ and $C_{pg} = 1.5$ PF. Then for $R_T = 14$ K, the voltage gain G_V is 31 and C_M is 48 PF. The feedback network impedance transforming network voltage ratio is:

$$T_{V_o} = \frac{1.4}{G_V \cdot A_{VC}} = 0.135$$

$$T_{V_o}^2 = 0.018$$

Then:

	16 KC	100 KC
$R_{FB} = \left(\frac{R_{r\ max} + R_{in}}{T_{V_o}^2}\right)$	8.2 MEGO	4.9 MEGO
R_L	$\approx R_T$	$\approx R_T$
V_o max	33 VRMS	26. VRMS
The oscillator external load R_L	14 K	14 K

	16 KC	100 KC
The crystal unit input terminating resistance, $\left(T_{V_o}^{2}\left[\frac{R_L \cdot R_p}{R_L + R_p}\right]\right)$	130 ohms	130 ohms
X_{C_M}	210 K	33 K
$\left(\frac{k}{1+k}\right)\frac{R_{r\ max}}{X_{C_M}}$	0.16	0.6

Neutralizing is therefore necessary at 100 KC. The required neutralizing capacitor is approximately 1.5/0.135 = 11 PF. The phase angle at 16 KC is acceptable, and no neutralizing is required.

A suitable transformer primary reactance is 700 ohms. Assuming a primary winding Q of 100, R_{LP} = 70 K. This is 5 times R_L, increasing the oscillator load to 17.5 K.

	16 KC	100 KC
The primary winding inductance L_1 is	7 MH	1.1 MH
Assuming a coupling coefficient of 0.9, the secondary winding inductance L_2 is	158 UH	25 UH
and ωL_2	16 ohms	16 ohms
The tuning capacitance is approximately	0.143 UF	2300 PF

If desired, the winding inductances could be increased appreciably to ease the tuning problem.

6-30. 1 to 16 KC Series Oscillator

Crystal characteristics:

$R_{r\ max}$ and P_{CMAX} are assumed to be 200 K and 10 UW, respectively.

For $k = 0.5$, $A_{V_C} = \frac{1}{3}$.

Then:

$$V_{max}\ (RMS) = 2\ V$$

$$R_{in} = k\ R_{r\ max} = 100\ K$$

$$R_{r\ max} + R_{in} = 1 + k\ R_{r\ max} = 300\ K$$

$$R_{r\ max} \text{ in parallel with } R_{in} = 67\ K$$

Using a 12AX7 at an operating point of $E_p = 100$ VDC, $I_p = 0.5$ MA, $V_G = -1$ VDC, the tube characteristics are $\mu = 100$, $R_p = 85$ K, and $C_{pg} = 1.7$ PF.

For $R_T = 85$ K, $G_V = 50$ and $C_M = 87$ PF. The feedback impedance transforming network voltage ratio is:

$$T_{V_o} = 0.084$$

$$T_{V_o}^2 = 0.007$$

Then

$$R_{FB} = \left(\frac{R_{r\ max} + R_{in}}{T_{V_o}^2}\right) = 43 \text{ megohms}$$

$$R_L = R_T$$

$$V_{o\ max} = 24\ VRMS$$

The crystal unit input terminating resistance $\left(T_{V_o}^2 \left[\frac{R_L \cdot R_p}{R_L + R_p}\right]\right)$ is 300 ohms.

	16 KC	1 KC
X_{C_M}:	115 K	1.84 MEGO
$\left(\frac{k}{1+k}\right)\frac{R_{r\ max}}{X_{C_M}}$:	0.58	0.036

Neutralizing is therefore necessary at 16 KC. The required neutralizing capacitor is approximately 1.5/0.084 = 18 PF. No neutralizing is required at 1 KC.

A suitable transformer primary reactance is 4.3 K. Assuming a primary winding Q of 100, R_{LP} is 430 K. This is 5 times R_L, requiring an increase in the oscillator load to 110 K.

	1 KC	16 KC
The primary winding inductance L_1 is	690 MH	43 MH
Assuming a coupling coefficient of 1, the secondary winding inductance is	4.8 MH	0.3 MH
ωL_2	3 ohms	3 ohms
The tuning capacitance is approximately	0.037 UF	2300 PF

6-31. Untuned Low Frequency Oscillators

At the lower frequencies it may not be desirable to employ a tuned circuit in the oscillator because of the problem of tuning. One suitable alternative circuit which may be used below 16 KC employs the crystal unit as a four-terminal network. In this frequency range if requested from the manufacturer, the crystal unit can be supplied having four electrical connections which can then either be paired for operation as a conventional two-terminal crystal unit or can be used as a four-terminal network.

When used in this latter manner, the crystal operates similarly to a filter network giving maximum signal transmission with either a 0 or a 180 degree phase shift at the crystal unit resonance frequency. Using the crystal unit as a phase-inverting network in conjunction with a grounded-cathode amplifier then results in a very simple circuit. Due to the limited experience with this circuit, a worst-case design procedure has not been developed, and it will be necessary for the designer to draw conclusions in this respect.

The design method used consisted of experimentally determining the characteristics of a particular crystal unit as a phase-inverting network and then relating this to the amplifier characteristics. In this particular instance the design frequency was 1 KC, and it was found possible, using a stable audio signal generator, to measure the voltage ratio of the crystal unit input and output signals for various values of output load resistance with the test circuit of Figure 6-28. Including a resistor in the signal input line also enables the crystal unit input resistance to be estimated. The crystal unit test data are given in Table 6-8.

The tabulated data show:

(a) The input resistance at the crystal unit resonance frequency is approximately equal to the output load resistance R in series with R_r', the crystal unit input resistance when a signal is applied to the two input terminals with the two output terminals shorted.

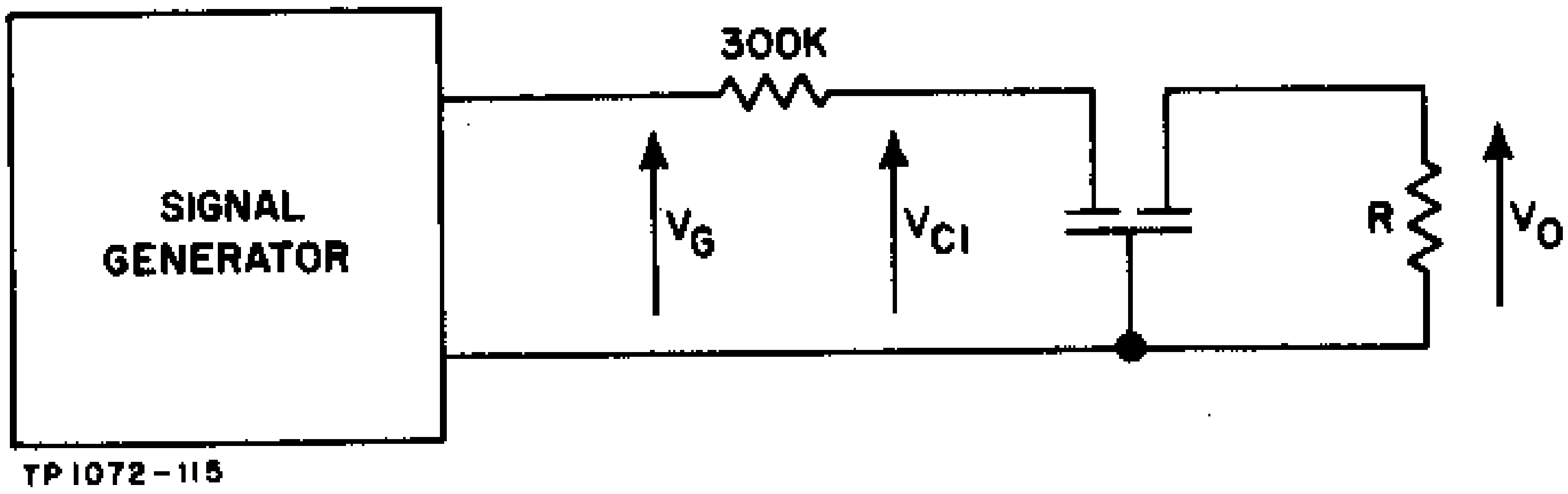

Figure 6-28. Crystal Unit Test Circuit

TABLE 6-8. CRYSTAL UNIT TEST DATA

R	$\frac{V_O}{V_{C_1}}$	$\frac{V_{C_1}}{V_G}$	Crystal Unit Input Resistance $R_{in} \approx R_r' + R$	$\frac{R}{R_r' + R}$
20 K	0.063	0.50	300 K	0.067
200 K	0.42	0.63	510 K	0.39
510 K	0.54	0.75	900 K	0.57
750 K	0.61	0.78	1.1 MEGO	0.68
1 MEGO	0.69	0.81	1.3 MEGO	0.77

(b) The voltage transmission ratio is approximately equal to $R/R + R_r'$.

(c) R_r' is approximately 5.5 times the resonance resistance of the crystal unit as a two-terminal network, which was 55 K in this instance.

It appears, therefore, on the basis of this test that, at the crystal unit resonance frequency, the crystal unit and load resistor act similarly to the network shown in Figure 6-29.

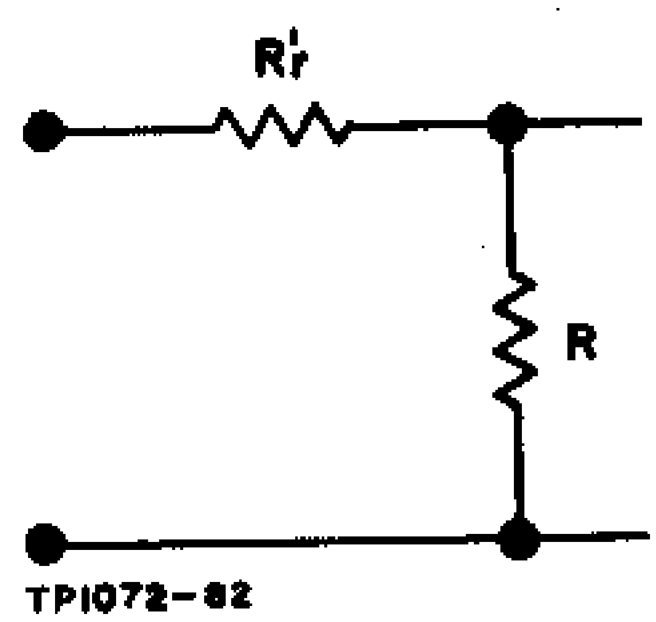

Figure 6-29. Equivalent Circuit of Crystal Unit and Output Load at f_r

The relationship between R_T and R_T' is not known, but if the relationship is linear, the maximum value of R_T' would be approximately 1 megohm. Because of this uncertainty a worst-case design was not attempted, and the following design was calculated for the particular crystal tested. The effect of the crystal output load was not known either, and the design calculation was made for a 200-K load, although the design was subsequently evaluated for loads of 200 K, 510 K, 750 K, and 1 megohm without, however, adjusting the loop gain. The difference in performance was found to be negligible.

Design Calculation (Using analogous notation to that previously employed) - Using a 12AT7 tube at I_p = 0.75 MA, E_p = 60 V, and V_G = -1.5 V, then μ = 35 and R_p = 35 K. For R_T = 17 K, the voltage gain is then 12. For R = 200 K, the voltage attenuation between the filter input and output terminals (A_{V_C}) is 0.42. Therefore, the permissible attenuation between the tube plate and the crystal input (T_{V_o}), allowing for a loop voltage gain of 1.4 is:

$$T_{V_o} = \frac{1.4}{G_V \cdot A_{V_C}} = 0.28$$

Using a resistive feedback network and assuming the loading due to the crystal to be negligible, the resistor ratio is then:

$$\frac{R_2}{R_1 + R_2} = T_{V_o} = 0.28 \text{ or } \frac{R_2}{R_1} = 0.39$$

where R_1 and R_2 are designated in Figure 6-31. For R_1 = 100 K, then R_2 = 36 K, satisfying the assumption that R_2 is much less than the crystal input resistance.

The amplifier total load resistance consists of the oscillator resistance, the plate feed resistance, and the feedback network resistance in parallel. The latter are 51 K and 130 K, respectively, and the external oscillator load resistance is therefore 33 K. The allowable crystal unit input voltage, assuming a permissible crystal unit dissipation of 10 UW, is 2.2 VRMS, and the allowable plate signal voltage is then 8 VRMS. The evaluation data for this design is presented in Table 6-9 and Figure 6-30.

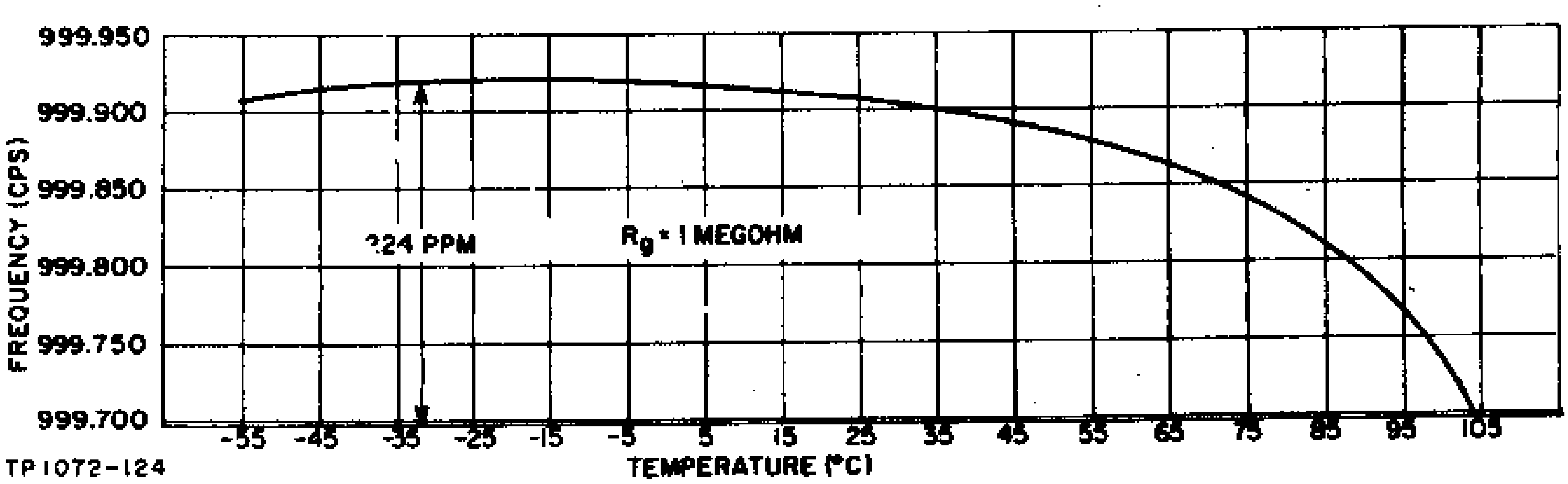

Figure 6-30. Frequency Vs. Temperature, 1-KC Tube Oscillator

TABLE 6-9. DESIGN EVALUATION DATA, 1-KC VACUUM TUBE OSCILLATOR (FOUR-TERMINAL CRYSTAL)

Crystal Unit: T-9J, f_r = 999.930 CPS, R_r = 55 K

	Value of R_g			
	200K	510K	750K	1 MEGO
Oscillator Frequency (CPS)	999.910	999.905	999.910	999.905
Nominal V_o	5.2	5.9	5.9	5.8
Influence of ±10% Change in B+ on Oscillator Frequency	<±10 PPM	<±10 PPM	<±10 PPM	<±10 PPM
Influence of ±10% Change in B+ on Output Voltage	ΔV_o = ±22%	ΔV_o = ±20%	ΔV_o = ±20%	ΔV_o = ±14%
Influence of ±10% Change in R_L on Oscillator Frequency	<±4 PPM	<±4 PPM	<±4 PPM	<±4 PPM
Influence of ±10% Change in R_L on Output Voltage	ΔV_o = ±6%	ΔV_o = ±5%	ΔV_o = ±5%	ΔV_o = ±4%
Influence of ±10% Change in E_f on Oscillator Frequency	<±3 PPM	<±3 PPM	<±3 PPM	<±3 PPM
Influence of ±10% Change in E_f on Output Voltage	ΔV_o = ±3%	ΔV_o = ±2%	ΔV_o = ±2%	ΔV_o = ±2%
Influence of -50°C to +80°C Change in T_A on Oscillator Frequency	±60 PPM	±50 PPM	±55 PPM	±50 PPM
Influence of -50°C to +80°C Change in T_A on Output Voltage	ΔV_o = ±6%	ΔV_o = ±2%	ΔV_o = ±2%	ΔV_o < ±2%

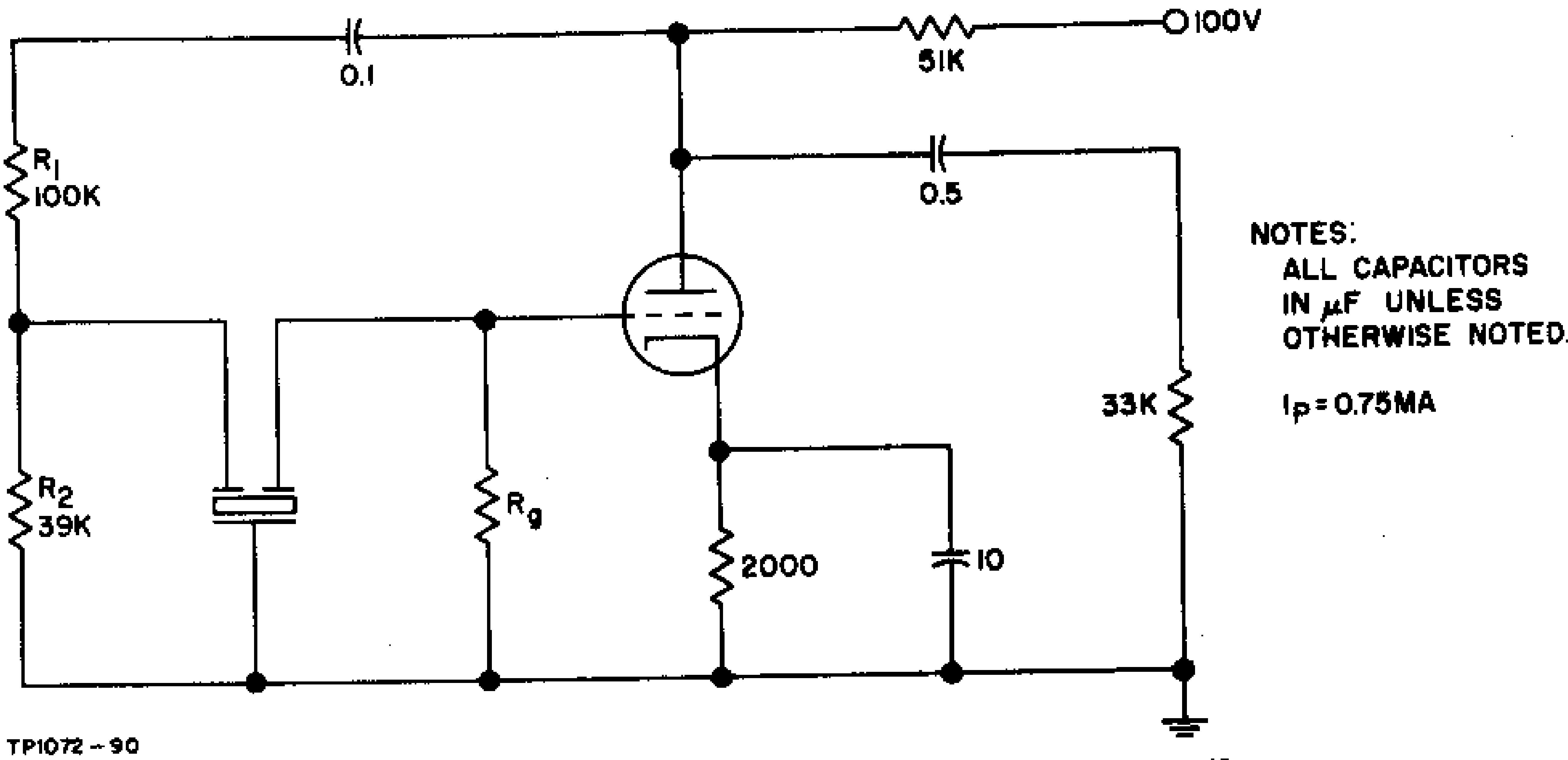

Figure 6-31. 1-KC Crystal Phase-Inverting Oscillator

6-32. Two-Stage Oscillator

The alternative to using the crystal unit as a phase-inverting filter is a two-stage amplifier configuration where the increased voltage gain allows an inefficient feedback network to be used. Tuning is not entirely eliminated, however, because of the possibility of uncontrolled oscillation at high frequencies; the crystal unit parallel capacitance completing the feedback path.

One method of doing this is to include a Wien bridge network tuned to the design frequency in the feedback network. But this is not entirely satisfactory because of the resulting circuit complexity. Another possibility (not tried) would be to arrange the time constants of the grid and plate circuits so that their net phase angle is zero at the design frequency but which introduces a substantial phase lag and gain reduction at higher frequencies. The techniques used in analog computer circuits may be helpful in this respect. The design procedure employed is similar to that described previously for use at higher frequencies.

The oscillator configuration for this design example is as shown in Figure 6-32, and the design calculation using analogous notation to that employed previously is as follows, using a 12AX7 triode operating at E_p = 100 VDC, I_p = 0.5 MA, V_G =-1 VDC, R_p = 85 K, μ = 100. For R_{T1}= 50 K and R_{T2} = 30 K, the total voltage gain from V_1 grid to V_2 plate is 970. For a loop voltage gain of 1.4 in a worst-case design, the voltage attenuation A from the plate of V_2 to the grid of V_1 is then $\frac{1}{690}$. This is satisfied by the feedback network

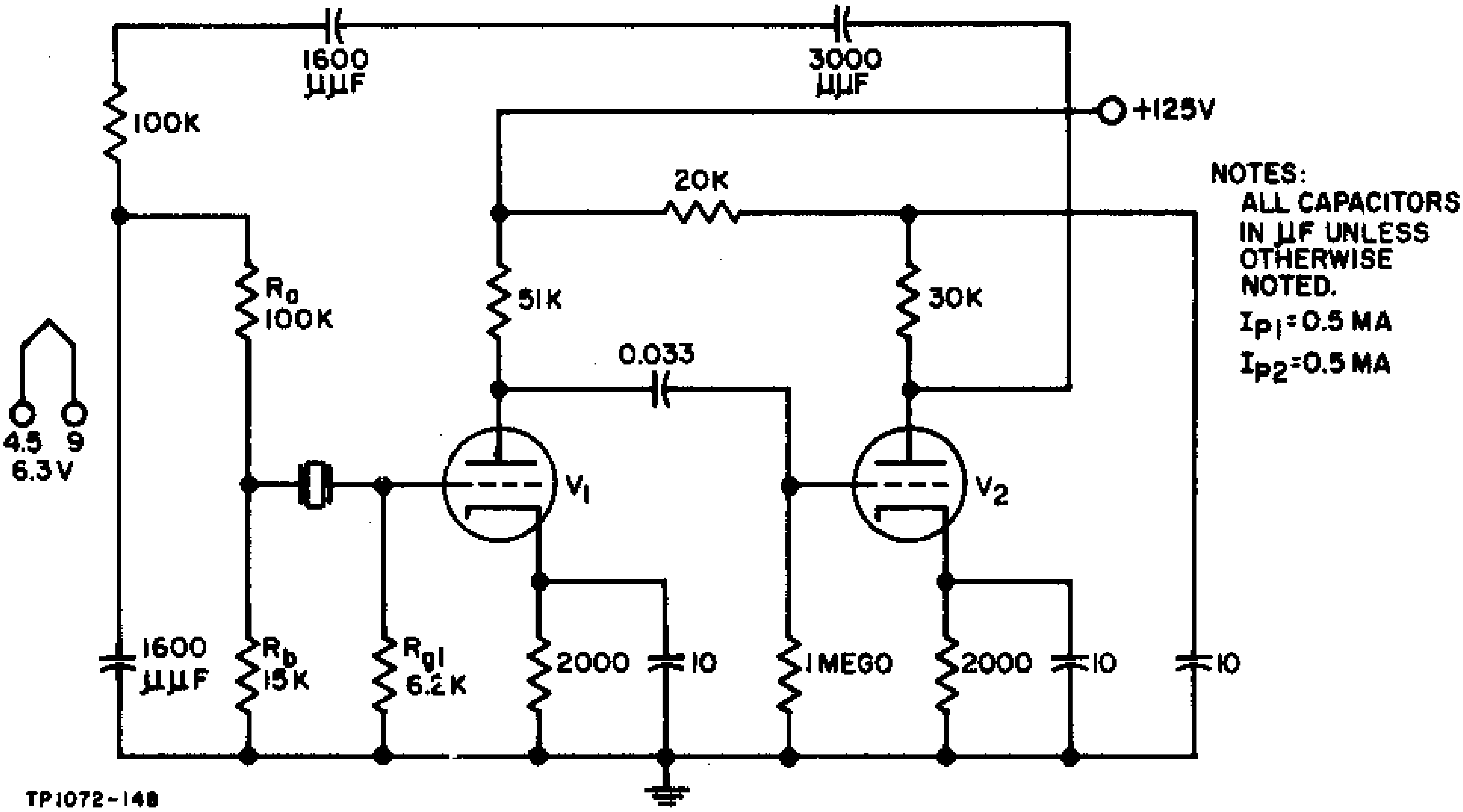

Figure 6-32. 1-KC Two-Stage Wien Bridge Oscillator

shown in Figure 6-32, where:

$$A = \frac{1}{3} \times \frac{R_b}{R_a + R_b} \times \frac{R_{g1}}{R_{g1} + 200\ K} = \frac{1}{690}$$

Referring to the Wien bridge analysis of Section 4, the requirement for zero phase shift in the Wien bridge network is:

$$C_1 R_1 C_2 R_2 = \frac{1}{(\omega')^2}$$

where the loading due to the crystal unit is included in R_2 and the amplifier output resistance forms a part of R_1. R_2 is therefore 113 K and R_1 is 122 K. For C_1 = 1150 PF and C_2 = 1600 PF, ω' = 6280 and f' = 1000 CPS. The nominal value of C_1 required was 1040 PF.

The permissible output voltage before crystal overdrive occurs is obtained by considering the case when R_r is equal to $R_{r\ min}$, which is assumed to be 1/9 $R_{r\ max}$; that is, 22 K. The crystal input voltage causing a crystal dissipation of 10 UW is 0.6 VRMS. The attenuation between the plate of V_2 and the crystal input terminal is approximately 0.043. Therefore, the allowable plate signal voltage when a very good crystal unit is in circuit is 14 VRMS.

The evaluation data are presented in Figure 6-33 and Table 6-10, followed by the data for a 3-KC oscillator of the same design in Figures 6-34 and 6-35 and Table 6-11.

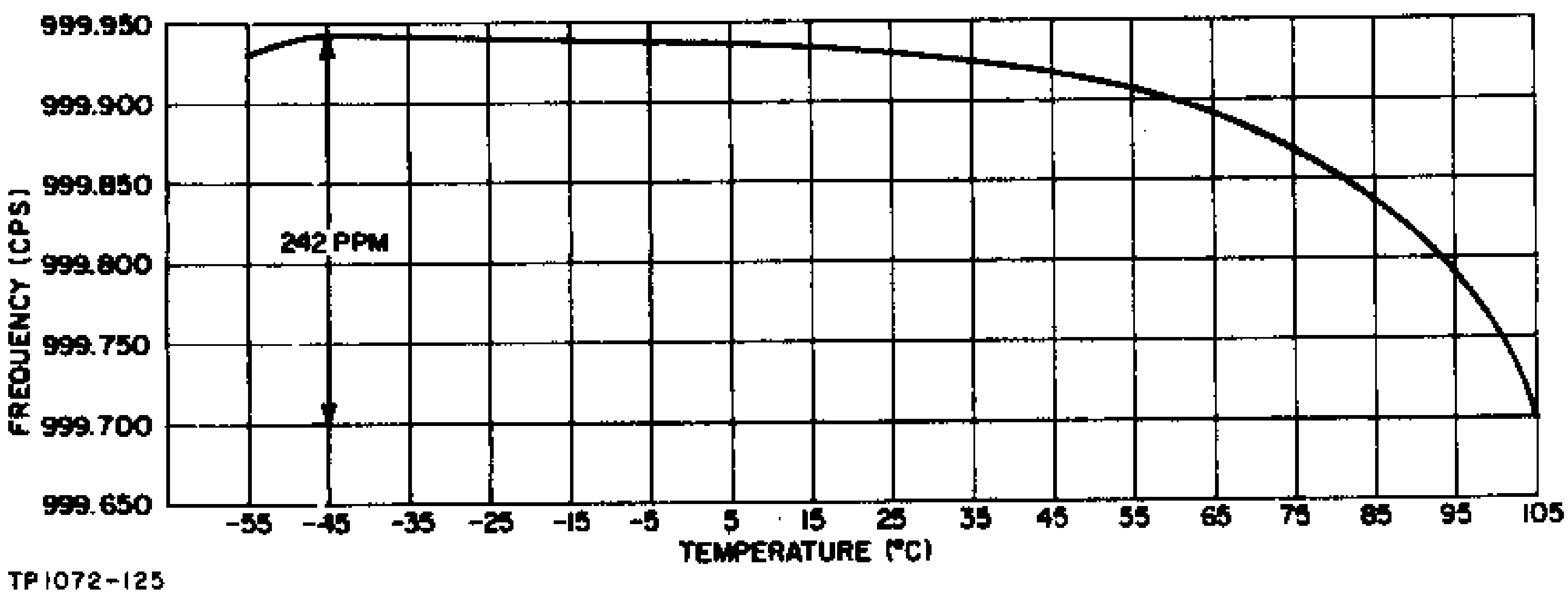

Figure 6-33. Frequency Vs. Temperature for the 1-KC Two-Stage Tube Oscillator (Wien Bridge)

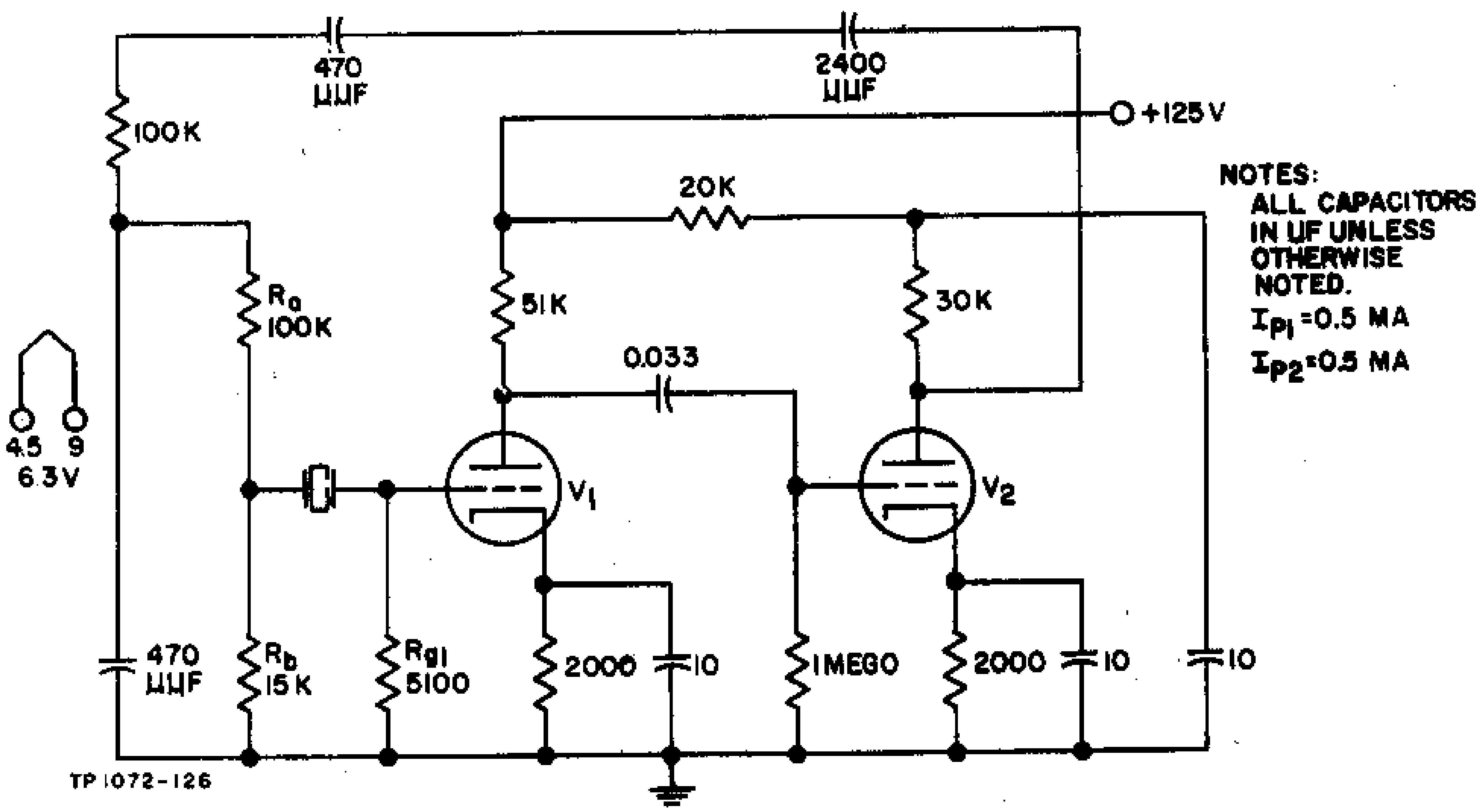

Figure 6-34. 3-KC Wien Bridge Oscillator

TABLE 6-10. DESIGN EVALUATION DATA, 1-KC TWO-STAGE TUBE OSCILLATOR

Crystal Unit: T-9J, f_r = 999.93 CPS, R_r = 55 K

EFFECT OF	CHANGE	TEST CONDITIONS
±10% Change in B+ on Oscillator Frequency	$\leq$ ±3 PPM	E_f = 6.3V, R_L = 30K, $T_A \approx$ 25°C
±10% Change in B+ on Output Voltage	ΔV_o = ±12%	E_f = 6.3V, R_L = 30K, $T_A \approx$ 25°C
±10% Change in R_L on Oscillator Frequency	$\leq$ ±3 PPM	E_f = 6.3V, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in R_L on Output Voltage	ΔV_o = ±7%	E_f = 6.3V, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in E_f on Oscillator Frequency	$\leq$ ±3 PPM	R_L = 30K, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in E_f on Output Voltage	ΔV_o = ±2%	R_L = 30K, E_{bb} = 125V, $T_A \approx$ 25°C
-50°C to +80°C Change in T_A on Oscillator Frequency	±47 PPM	R_L = 30K, E_{bb} = 125V, E_f = 6.3V
-50°C to +80°C Change in T_A on Output Voltage	ΔV_o = ±1%	R_L = 30K, E_{bb} = 125V, E_f = 6.3V

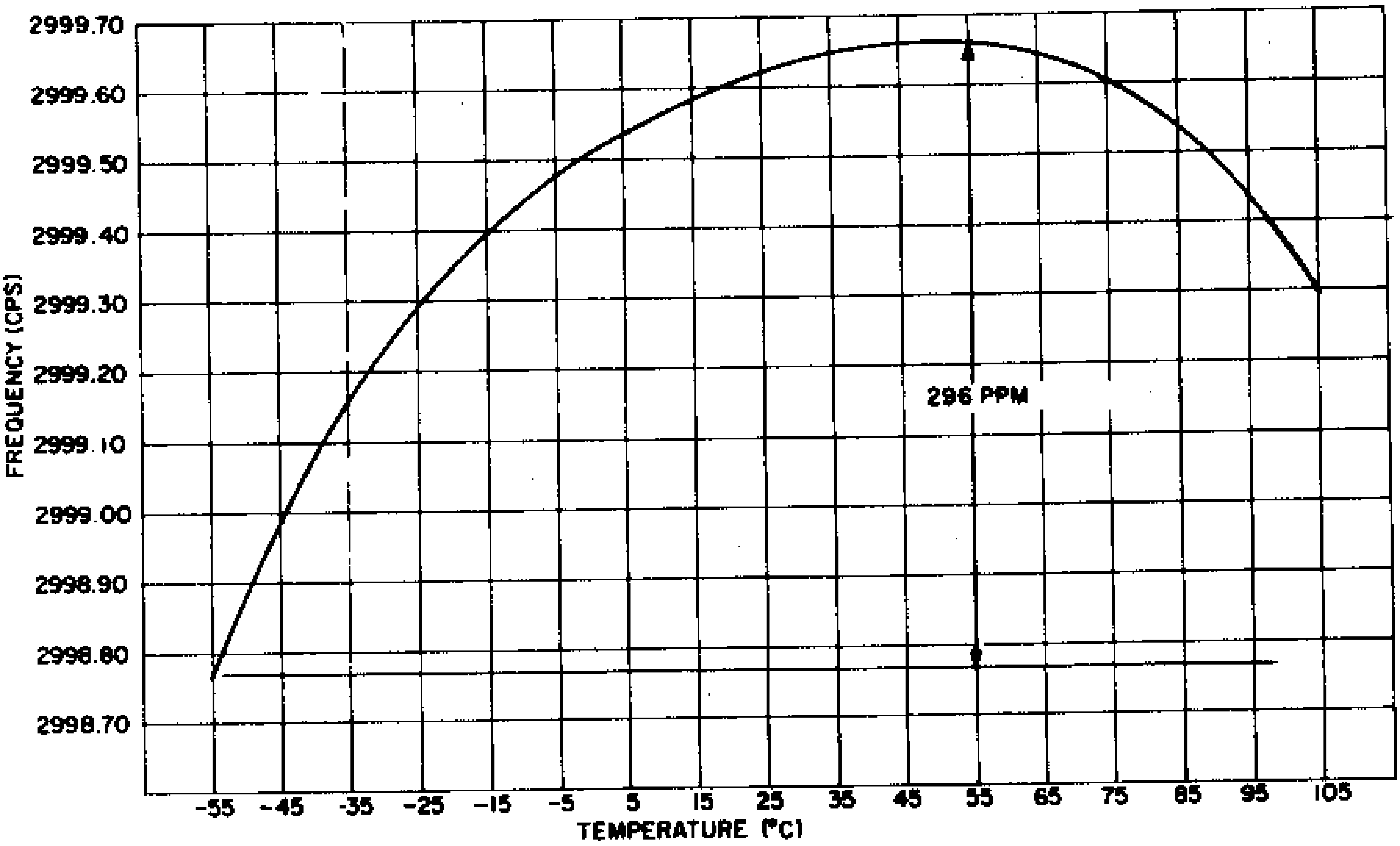

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Figure 6-35. Frequency Vs. Temperature, 3-KC Tube Oscillator (Wien Bridge)

TABLE 6-11. DESIGN EVALUATION DATA, 3-KC TWO-STAGE TUBE OSCILLATOR

Crystal Unit: T-9A [illegible] = 2999.6 CPS, R_r = 50 KC

EFFECT OF	CHANGE	TEST CONDITIONS
±10% Change in B+ on Oscillator Frequency	≤ ±3 PPM	E_f = 6.3V, R_L = 30K, $T_A \approx$ 25°C
±10% Change in B+ on Output Voltage	ΔV_o = ±13%	E_f = 6.3V, R_L = 30K, $T_A \approx$ 25°C
±10% Change in R_L on Oscillator Frequency	≤ ±3 PPM	E_f = 6.3V, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in R_L on Output Voltage	ΔV_o = ±7%	E_f = 6.3V, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in E_f on Oscillator Frequency	≤ ±3 PPM	R_L = 30K, E_{bb} = 125V, $T_A \approx$ 25°C
±10% Change in E_f on Output Voltage	ΔV_o < ±2%	R_L = 30K, E_{bb} = 125V, $T_A \approx$ 25°C
-55°C to +80°C Change in T_A on Oscillator Frequency	±150 PPM	R_L = 30K, E_{bb} = 125V, E_f = 6.3V
-55°C to +80°C Change in T_A on Output Voltage	ΔV_o < ±2%	R_L = 30K, E_{bb} = 125V, E_f = 6.3V