
An Ultra Stable Audio Oscillator

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The objective of the problem reported here was to obtain an oscillator for audio frequencies which was to be stable within one tenth of one cycle in about four hundred cycles. The oscillator was expected to be used as a frequency standard for the determination of musical scales. To obtain this objective a resistance tuned oscillator based on a circuit described by

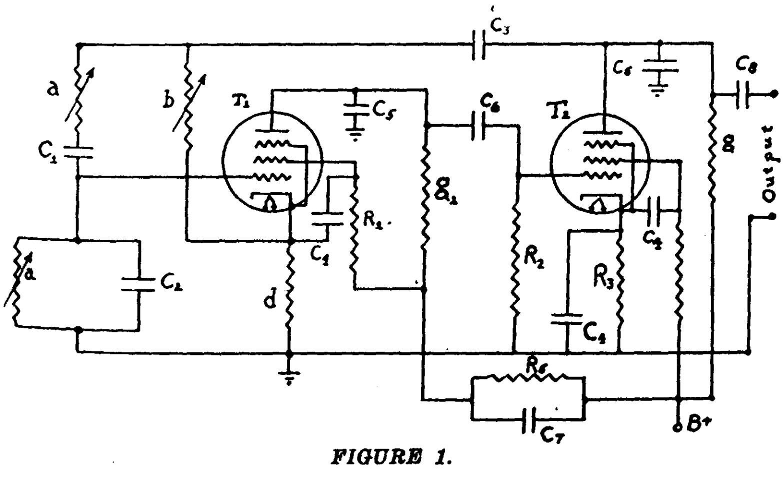

FIGURE 1.

Terman *et al* (1) was selected. The equivalent circuit analysis was carried through and the final two conditions obtained from the real and imaginary parts respectively are as follows (where the subscript 1 refers to the first stage and 2 to the second stage, f to the plate resistance, μ the amplification factor and the other symbols as given in Figure 1):

Real: $A(1-\psi^2c^2a^2)=a\psi^2c^2g_2B$

Imaginary: $3aA+g_2B-ag_2\mu_1C=o$

where
$$A=g_2[\mu_2g_1d(\mu_1+1)+f_2d(\mu_1+1)+f_2(f_1+g_1)] + (f_2+g_2)[bd(\mu_1+1)+(b+d)(f_1+g_1)]$$
$$B=f_2[bd(\mu_1+1)+(b+d)(f_1+g_1)]$$
$$C=(b+d)\mu_2g_1+f_2d$$

Using the following approximation, the circuit parameters shown in Table I were selected:

$$Af_2/(f_2+g_2)-B<<B$$

Then the frequency is given by:

$$\psi^2\cong\frac{1}{c^2a^2} \quad \text{or } f=\frac{1}{2\pi ac}$$

TABLE I

T_1T_2 6Ac7	a = 0 to 40,000 ohms
	b = 0 to 47,000 ohms
$C_1=1.07\times10^{4}$ μfd	d = 112 ohms
$C_2=1.07\times10^{4}$ μfd	g_1 = 5900 ohms
$C_3=10$ μfd	g_2 = 55 ohms
$C_4=5$ μfd	R_1 = 10,000 ohms
$C_5=0.001$ μfd	R_2 = 68,000 ohms
$C_6=0.01$ μfd	R_3 = 54 (140.8 —120) ohms
$C_7=20$ μfd	R_4 = 17,000 ohms
$C_8=1$ μfd	R_5 = 7,000 ohms

Using these parameters the approximation above is valid to nearly one per cent.

A separate analysis carried out by a somewhat different means yields the following equation

$$f=\frac{1}{2\pi ac}[1-3B/a\mu_1C+2B)]$$

which in terms of the transconductances t_1 and t_2, assuming $\mu_1>>1$, $f>>g_1$ and $d<<g$, reduces to

$$f=\frac{1}{2\pi ac}[1-3(1+t_1d)/at_1t_2g_1]^{1/2}$$

where the neglected term under the radical is less than 10^{-8}.

The results of satisfying the above conditions led to essentially the same parameters as previously chosen indicating that these are probably optimum conditions. Consideration of the imaginary part of the solution was found to be of no further importance.

It was observed that the feedback resistor and the grid leak resistor of the second stage were most critical to the stable operation of the oscillator. The latter effect was reduced when spurious high frequency oscillations were dissipated to ground through a small capacitor in the plate circuit. The frequency stability as a function of the feedback resistance was calculated to be $<10^{-4}$ cycles/ohm for $b=5000$ ohms.

Results

Data on frequency versus the tuning resistor are shown in Table II. It is interesting to note that the theoretical and the observed values agree quite well if the AC resistance for *a* is used and not the DC resistance.

TABLE II

AC Resistance *a* Measured Ohms	Resistance *a* Nominal Ohms	Frequency *f* Measured Cycles/Sec.	Frequency *f* Calculated Cycles/Sec.
32000	40000	465	466
26500	35000	496	562
25500	30000	595	585
21000	25000	725	710
17400	20000	920	860
14300	15000	1115	1040
9600	10000	1580	1560
4980	5000	2720	2890
2600	2500	4750	5680

Concerning the stability in general as a function of time one is able to say that the oscillator constructed for testing purposes was at least as stable as the Hewlet-Packard oscillator used for testing and upon comparison with radio signals from WWV the conclusion was drawn that it was probably more stable than the Hewlet-Packard oscillator although the latter comparison was qualitative because of interference.

The pickup of the more or less open bread board system did not allow accurate stability measurements. However if the oscillator is isolated from high frequency coupling with the power supply, tuned with well balanced non-inductive resistors and balanced capacitors, and well shielded from spurious 60 cycle pickup it should serve as a reliable audio frequency standard which is accurate to a few per cent without calibration and stable to 1/10 cycle in four hundred cycles.

LITERATURE CITED

1. Terman, F. E., R. R. Buss, W. R. Hewlett, and F. C. Cahill. 1949. Some applications of negative feedback with particular reference to laboratory equipment. Proc. I. R. E. 27: 649.