An RC Oscillator that Covers the
20 cps-20 kc Range in a Single Dial Sweep

OVER a period of time -hp- has designed resistance-capacity test oscillators for many fields of work from the sub-audio to the lower r-f ranges. The usefulness of this type of instrument has now been even further expanded in the form of a new RC oscillator that covers the entire 20 cps - 20 kc range *in a single dial sweep*. This new test oscillator thus simplifies and speeds testing of audio circuits and devices of many kinds. The response of amplifiers, transformers, speakers and circuits can all be checked over the entire audio range by a single dial twist.

Automatic response measurements can also be made with the new oscillator by equipping it with an external motor drive. Such an arrangement has proved valuable in both production and laboratory applications where performance information on audio devices is desired with maximum speed and minimum expense. In such applications the response of interest is plotted on the face of an oscilloscope or on an X - Y recorder. To facilitate using motor drives, the new oscillator is arranged so that an extension of the tuning dial shaft is available at the rear of the cabinet.

Automatic measurements are further facilitated by the fact that the dial calibration of the new oscillator is essentially logarithmic. This factor is especially convenient for making automatic response measurements in which the response of the device under test is recorded or viewed on an oscilloscope.

In addition to the above features the oscillator retains the basic advantages such as high waveform purity, constancy of output over a wide range, high stability, high calibration accuracy, and freedom from zero setting that have always been associated with -hp- oscillators.

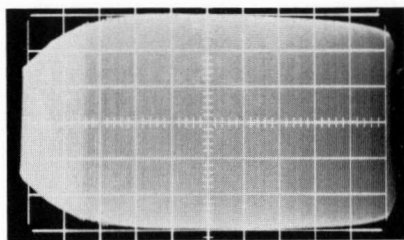Fig. 1 is typical of the response information that can be obtained in only a few minutes

Fig. 1. *Oscillogram of response of quality matching transformer at −30 dbm made by observing transformer output directly on oscilloscope while driving transformer and its amplifier from new -hp- single-band audio oscillator.*

Fig. 2. (right) *New -hp- Model 207A oscillator covers complete 20 cps-20 kc range in single band, has shaft extension at rear to enable it to be used with external motor drives for automatic audio response measurements on amplifiers, transformers, speakers, and other audio devices. No zero setting is required. Log dial facilitates response plots on scope or recorder.*
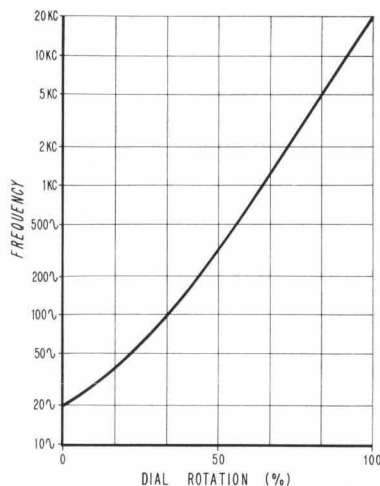
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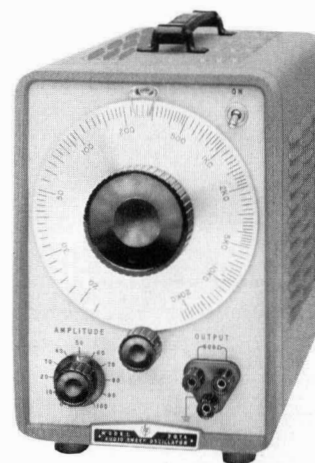
Fig. 3. *Plot of typical Model 207A tuning dial characteristic. Deviation at lowest frequencies from true log characteristic can be readily compensated as described in text.*

using the new oscillator with an oscilloscope. The response shown is that of a quality matching transformer at a low power level. In practice complete performance information of this nature has been often deferred because of the labor previously involved. Using the new oscillator it becomes a simple matter.

The same information can be rapidly converted to permanent form by using an X - Y recorder. In this case a simple wide-band rectifier will be required on the output of the device under test so that d-c will be available for the Y system of the recorder. A rectifier circuit constructed using a germanium diode is usually adequate for this purpose.

DIAL CALIBRATION

In common with LC oscillators, the frequency characteristic of an RC oscillator is such that, if its tuning capacitor has an exponential variation of capacity with angular position, its tuning dial calibration will be a logarithmic function of angular position. This characteristic makes the oscillator especially convenient when it is used with an oscilloscope or recorder, since a linear sweep voltage will then present the frequency scale in true logarithmic form.

Commercially available exponential curve capacitors, however, have a foreshortened characteristic at the high capacity end. This has the result in the new oscillator that the frequency calibrations below about 200 cps depart somewhat from a true logarithmic characteristic. This departure is relatively unimportant for most applications, but if desired it can be readily compensated by altering the sweep voltage in a simple manner so that in oscilloscope or recording applications no significant error is obtained in the display.

Fig. 3 shows how the dial calibration on the Model 207A compares with a true logarithmic calibration in a typical case. At frequencies above 200 cps, the calibration is accurately logarithmic within a few percent, while at lower frequencies a noticeable departure occurs. If the sweep voltage is obtained by ganging a potentiometer with the tuning shaft extension at the cabinet rear, however, a simple network can be used to introduce a suitable non-linearity in the sweep voltage. With respect to this altered sweep voltage, then, the overall dial calibration will be logarithmic within a few percent.

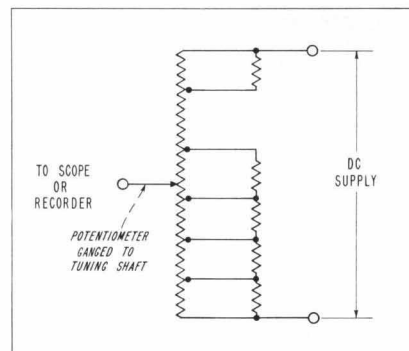To obtain the altered sweep voltage, the simple network indicated in Fig. 4 can be used. The poten-

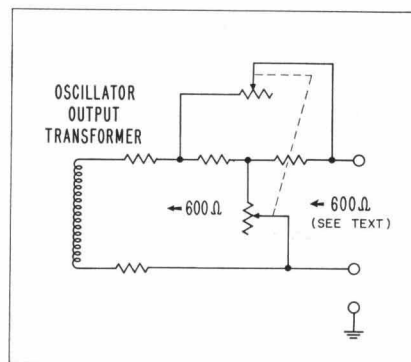Fig. 4. *Network used to provide special sweep voltage.*

Fig. 5. *Output circuit of -hp- Model 207A is arranged to permit balanced or single-ended operation.*

tiometer is ganged with the tuning shaft extension and operated from a small battery or other convenient d-c supply. The special multitap potentiometer is available from -hp-.

OUTPUT SIGNAL CHARACTERISTICS

For convenience in wide-range sweep testing, it is desirable that a test oscillator have a constant output voltage over its complete frequency range for a given setting of the output control. Care has been given to this requirement in the new oscillator with the result that it is rated as having an output which is constant within ± 1 db over its complete frequency range. Typically, in fact, the output is even more constant, being within about $\frac{1}{3}$ db as a rule over the complete 20 cps - 20 kc range.

Distortion in the generated signal is also low. Distortion is rated as less than 1% at all frequencies and is typically much lower at all but the lowest frequencies where it is still less than 1%.

OUTPUT CIRCUIT

Voltage-wise, the Model 207A provides a maximum of 20 volts open circuit or 10 volts into a 600-ohm load. Many audio devices can thus be tested directly from the output of the oscillator, although power devices such as speakers will require that the oscillator be followed by a power amplifier.

The output circuit in the oscillator is arranged so that it can be used to test balanced as well as single-ended devices. Output power is delivered from a balanced transformer which is provided with sufficient resistance to raise the source impedance of the system to 600 ohms (Fig. 5).

The output level is controlled by an uncalibrated bridged-T attenuator which has a 40 db range (nominally 10 volts to 0.1 volt). Since the attenuator is unbalanced, the output circuit is unbalanced when the attenuator is used. The attenuator is constructed, however, so that when it is set for zero attenuation the series arm becomes a short circuit while the shunt arm becomes an open circuit. The attenuator is thus removed from the circuit and the output system then becomes balanced. This arrangement enables the oscillator to be used with an external balanced attenuator to test balanced systems without incurring the cost of a balanced attenuator for applications where it is not required.

DESIGN PRINCIPLES OF THE 1000:1 RANGE SINGLE-BAND RC OSCILLATOR

In the conventional -hp- resistance-capacity oscillator the frequency of oscillation is controlled by a circuit like that shown in basic form in Fig. 1. Although various ratios of R_1 to R_2 and C_1 to C_2 are used, they are all such that the frequency of oscillation is expressed by $f_0 = 1/2\pi R_1 C_1$. Since a 10:1 range tuning capacitor is typically used for C_1 and C_2, the oscillators typically cover a 10:1 frequency range in a single band.

When the frequency characteristic of one of the RC pairs of the frequency-determining circuit is plotted on a reactance chart, the plot will appear as shown in Fig. 2. At the frequency at which the resistance curve R intersects the reactance curve of the capacitor, the voltage e_g out of the network (Fig. 1) is in phase with the voltage e_f applied to the network and the overall circuit oscillates. As the capacitor is tuned through its 10:1 range, the reactance moves through a 10:1 range (indicated by shaded area in Fig. 2), and the frequency of oscillation consequently moves through a 10:1 range.

1000:1 RANGE NETWORK

If a wider than 10:1 frequency range is desired for the same 10:1 change in the tuning capacitor, the resistive element R of the RC pairs can each be replaced with a network which has a slope between 0 and −1, i.e., between that of a resistance and that of a capacitive reactance. When this is done, the limits of the range over which the circuit can be tuned will occur where the impedance curve of the new network intersects the reactance limit lines of the tuning capacitor, as shown in Fig. 3. In particular, if this new network has an impedance line whose slope is −⅔ as shown in Fig. 3, the
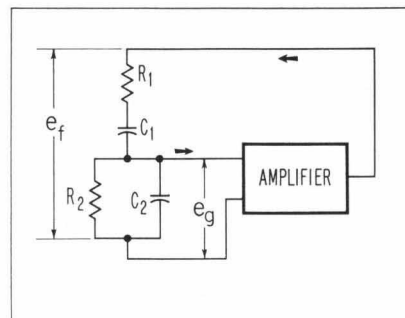

Fig. 1. *Basic arrangement of positive feedback loop used in -hp- RC oscillators.*

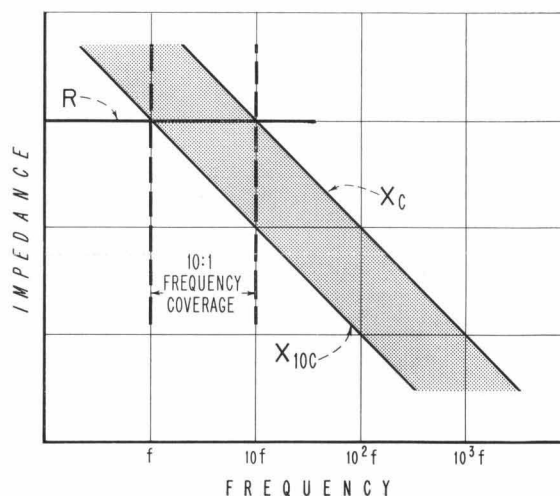

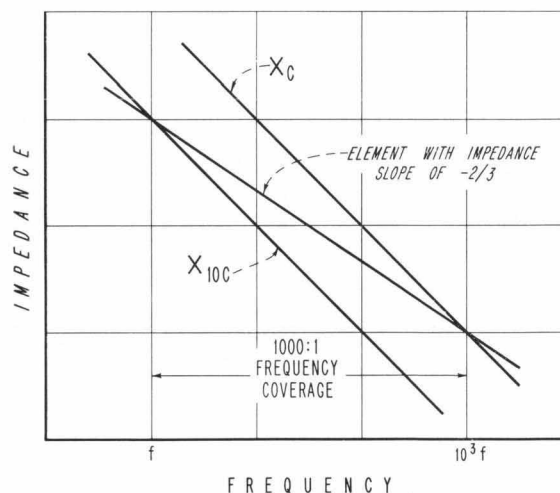Fig. 2. *Reactance plot of one of RC pairs in frequency-determining network.*

Fig. 3. *Reactance plot showing how a network with impedance slope of −⅔ will tune circuit over 1000:1 frequency range for a 10:1 change in tuning capacitor.*
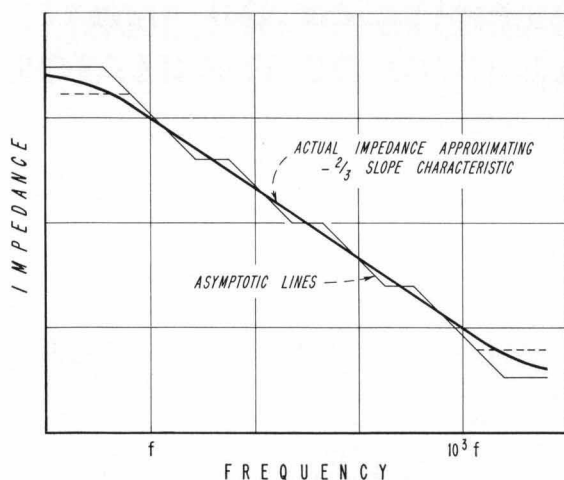
Fig. 4. *Plot of straight-line segment method used to approximate a* $-\frac{2}{3}$ *slope characteristic. Resultant of approximation is within a few percent of ideal over rated range.*
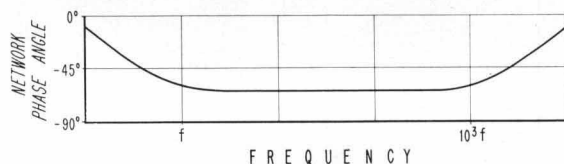

Fig. 6. *Phase characteristic of synthesized network. Deviation over rated range is less than a few degrees.*

Fig. 5. *Final configuration of synthesized networks connected in basic oscillator circuit. -hp- balanced type oscillator circuit is used.*

frequency coverage of the oscillator will be expanded to 1000:1.

Such is the technique used in the new oscillator to achieve a 1000:1 frequency coverage in a single band. The network that has a $-\frac{2}{3}$ slope frequency characteristic is synthesized from fixed resistances and capacitors. The poles and zeroes of the impedance of such a network all lie on the negative real axis and can be made to occur alternately. The asymptotic impedance lines corresponding to such an array form a broken line which changes from slope 0 to slope -1 at each frequency corresponding to a pole and from -1 to 0 at each frequency corresponding to a zero, as shown by the light broken line of Fig. 4. If the horizontal segments of this broken line extend for, say, one octave and the tilted segments for two, the "average" slope of the line will be $-\frac{2}{3}$. The actual impedance will be a very nearly straight line of this slope, as shown by the heavy line in Fig. 4, and is reasonable to achieve since it requires only five resistances and four capacitors. With this number of elements the synthesized characteristic approximates the ideal over the desired frequency range within a few percent. This error is even further reduced when two complex elements are used in the complete frequency-determining circuit as will be described later.

Fig. 5 shows how the complete circuit appears when the two networks are used.

PHASE CONSIDERATIONS

An essential requirement for the synthesized network is that its impedance phase angle be constant with frequency, since variations in phase would shift the frequency of oscillation an amount different from that dictated by a change in the setting of the tuning capacitor. How well this requirement is met is basically a function of the number of elements used to synthesize the complex network. The five resistor-four capacitor network, since its impedance slope is almost constant, gives a phase characteristic which is also almost constant, having a theoretical variation of less than 2° (Fig. 6) at all but the extreme ends of the rated frequency range. At the low and high frequency ends where the phase shift introduced by the network is not corrected by other RC steps, the first and final asymptotic segments have been expanded to cover a 7:1 rather than 4:1 range to minimize the undesirable shift that would otherwise occur at the ends of the range. This displacement does not significantly alter the impedance of the element within the desired 1000:1 range, as can be seen in Fig. 4. To maintain the effective phase angle even more constant, the locations of the poles and zeroes in one element are staggered from those in the other. One element thus compensates to a degree for the phase (and impedance) variations in the other.

GENERAL

The overall oscillator circuit uses the -hp- balanced oscillator configuration[1] in which the oscillator tubes are operated in push-pull. This arrangement
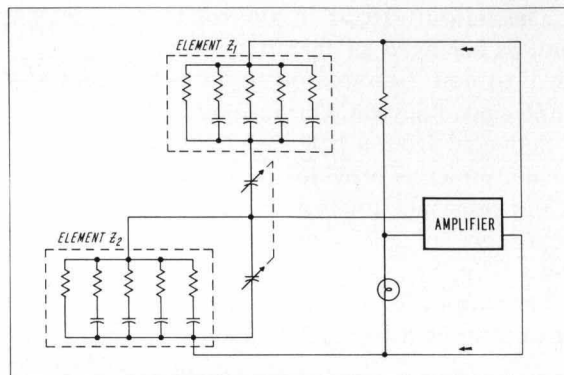
requires that the frequency-determining network produce a voltage division of 1:2.

In an RC oscillator the impedance of the series arm (Fig. 1) at the oscillation frequency is $R_1 + 1/j\omega C_1$, or $R_1(1-j) = \sqrt{2}\,R_1\underline{/-45°}$. Similarly, the impedance of the parallel arm is $R_2/(1+j\omega C_2 R_2)$, or $R_2/(1+j) = (R_2/\sqrt{2})\underline{/-45°}$. To attain a division ratio of 1:2 thus requires that $R_2/\sqrt{2} = \sqrt{2}\,R_1$, or $R_2 = 2R_1$ and $C_1 = 2C_2$.

In the wide range oscillator the impedance of the network and capacitor in the series arm (and similarly the admittances in the parallel arm) add at 30° rather than 90°. If the capacitor reactance and network impedance in the upper arm were equal at the oscillation frequency, the upper arm would have an impedance $Z_1 = N_1[(\cos 60° - j\sin 60°) + 1/j\omega C] = N_1[.5 - j(1+\sqrt{3}/2)] = 1.93\,N_1\,\underline{/-69.5°}$.

If the capacitor reactance and network impedance were equal in the parallel arm its impedance would then be $Z_2 = (N_2/1.93)\underline{/-69.5°}$.

This would demand an impedance ratio $N_2 = (1.93)^2\,N_1 = 3.73\,N_1$ and $C_1 = 3.73\,C_2$. Since this capacity ratio is inconvenient, a more practical solution is to change the capacity ratio to the nearest integral ratio (4:1). This ratio would require a five-section tuning capacitor, however, so the capacity ratio has been made the largest that can be achieved (3:1) with the more conventional four-section capacitor. The changed capacity ratio then necessitates that the ratio of the impedances of the two complex networks be changed to $N_2/N_1 = 4.78$. Oscillation now takes place at $\sqrt{\omega_1\omega_2}$ where

$\omega_1 =$ frequency at which $|N_1| = |X_{C_1}|$
$\omega_2 =$ frequency at which $|N_2| = |X_{C_2}|$

—*Nicholas Kovalevski and B. M. Oliver*

[1]B. M. Oliver, *The -hp- Balanced R-C Oscillator Circuit,* Hewlett-Packard Journal, Vol. 7, No. 6. February, 1956.