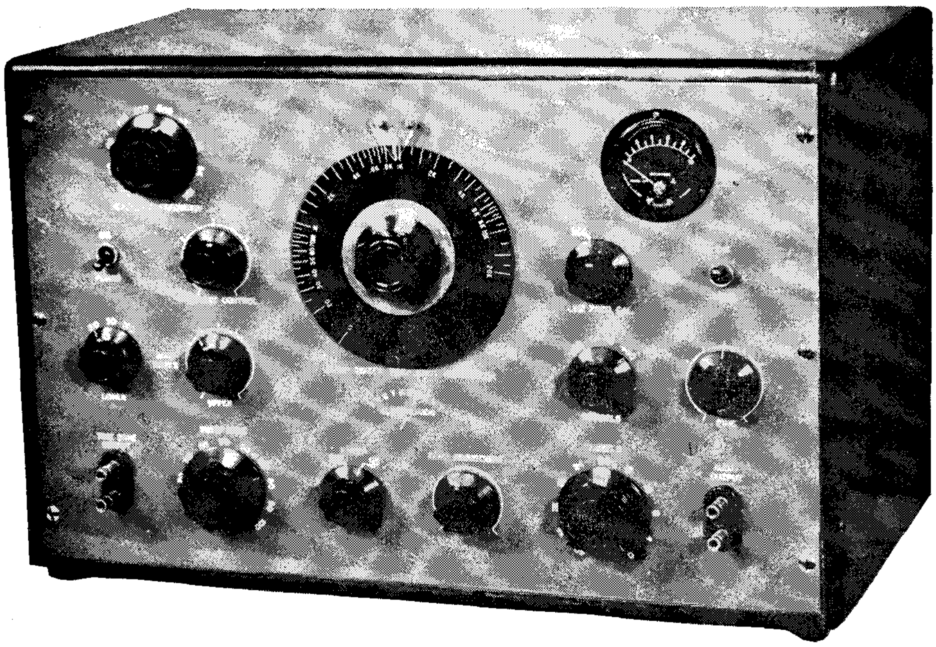

A New Electronic Audio Sweep-Frequency Generator

By H. TOOMIN*

Optimum presentation of frequency-response data on a 'scope screen requires a special form of a-f signal generator. Circuit details of such an instrument are outlined by the author.

An audio sweep frequency generator is an instrument designed primarily to make possible the presentation of audio frequency response curves on a cathode ray oscilloscope. Several approaches to this problem have been made in the past [1,2,3] with results excellent in the high-frequency register but which have left much to be desired in the presentation of the bass response. *Figure* 1 shows a typical trace for a flat system using a commercial sweep generator. It is apparent that even though the system measured is flat to below 40 cps, there is very little information presented for frequencies below 500 cps. The most obvious fault with the presentation of *Fig.* 1 is the spacing of the cycles. The spot moves at a uniform rate across the screen so that just as much time is spent in traveling from 40 to 50 cps as is spent between 4000 and 5000 cps. Consequently, comparatively few cycles appear in the initial portion of the oscillogram. The wavelength or the distance between cycle crests is approxi-

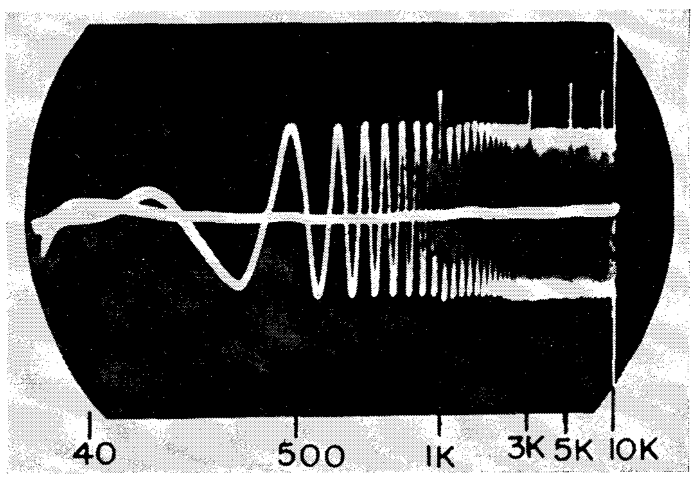

Fig. 1. Photo-electric-Scanner type audio sweep generator signal presentation.

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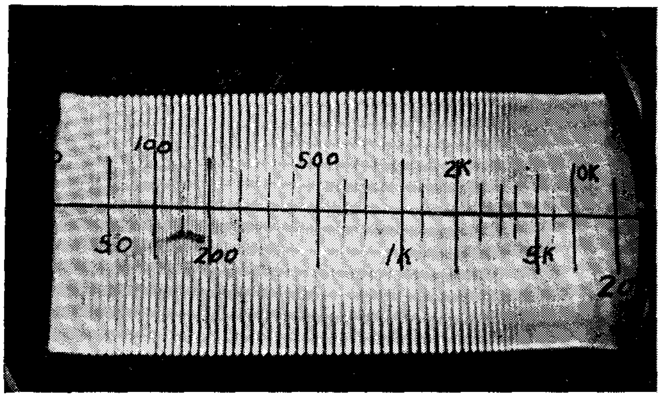
1 Electronic-Type Oscillographic Frequency Response Curve Apparatus of Wide Application, W. G. Gordon and A. H. Mutton, *J. Instn. Engrs. Australia*, Feb. 1937

2 Automatic Recording of Audio Frequency Characteristics, *Radio Engineering*, Feb. 1937

3 Audio Frequency Response Curve Tracer, J. B. Sherman, *Proc. I.R.E.*, June 1938



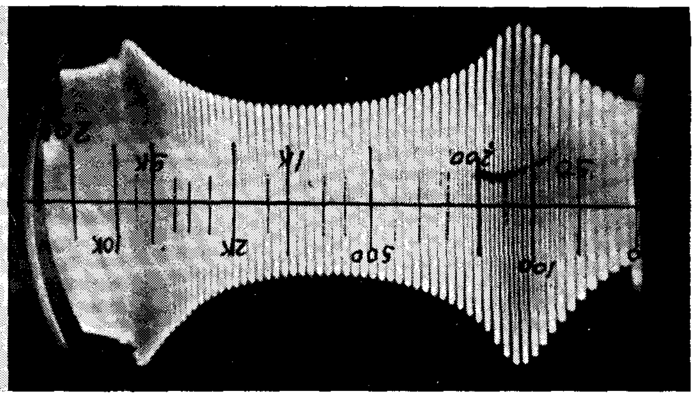
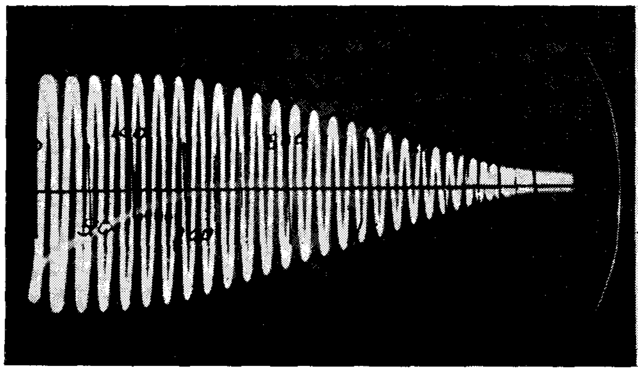


Fig. 2 (left). Output presentation of constant wavelength generator. Note evenly distributed cycle peaks. Level is constant within ½ db from 20 cps to 20 kc. Fig. 3 (right). Oscillogram of 20 to 20,000 cps frequency response of UTC Model 3AX Line Equalizer shown in log-log coordinates. The points of maximum equalization were set for 10 db at 100 cps and at 6000 kc.



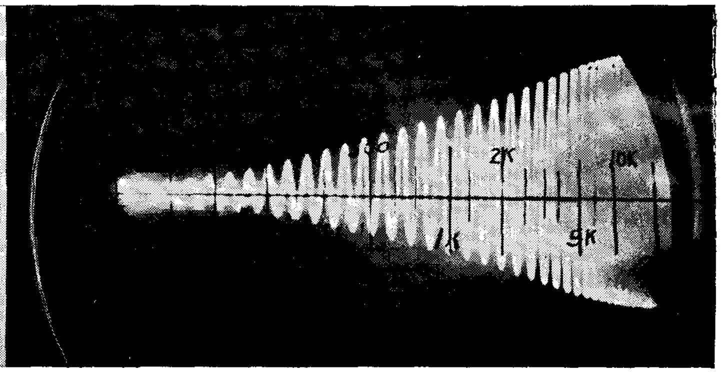


Fig 4 (left). Low-pass single-section RC network shown in log-log coordinates from 20 to 20,000 cps. $R\omega C = 1$ at 250 cps and at 6000 cps. Fig. 5 (right). High-pass single-section RC network shown in log-log coordinates from 20 to 20,000 cps. $R\omega C = 1$ at 8 kc. Note linear 6 db per octave rise.

mately inversely proportional to the log of frequency. It can be readily seen that a much better presentation would result if the wavelength were constant and independent of frequency. *Figure* 2 illustrates this point with an oscillogram taken with the new generator here to be described. The sweep band from 20 to 20,000 cps is shown. Note that the wavelength is approximately constant from 20 to 2000 cps. This feature makes possible the presentation of frequency response curves showing smooth contours in the bass as well as in other regions of the audio spectrum. *Figures* 3, 4, 5, and 6 illustrate various response curves obtained with this new generator.

It is highly desirable to have the frequency response curves plotted in Log vs Log coordinates so that they will closely resemble curves plotted in the conventional manner. That is, the vertical scale should be linear in *decibels* and the horizontal scale should be linear in log of frequency. Since an oscilloscope responds linearly to equal voltage increments and we wish it to respond linearly to equal decibel increments it is necessary to distort the signal applied to the vertical amplifier so that its peak value is always proportional to the logarithm of the output signal from the equipment being tested.

Generator Design Problems

The design of a suitable audio sweep-frequency generator consists of several problems. Since the constant-wavelength feature depends on maintaining the proper sweep velocity at each frequency on the scale, a suitable sweep-wave shape must be defined and then generated. The frequency must be made to change in synchronism with the sweep voltage and in the proper increments to maintain a logarithmic frequency-scale distribution. Methods for controlling low- and high-frequency band limits must be provided to prevent instability and frequency drift. Frequency markers are necessary for checking the frequency scale. A logarithmic distorting am-

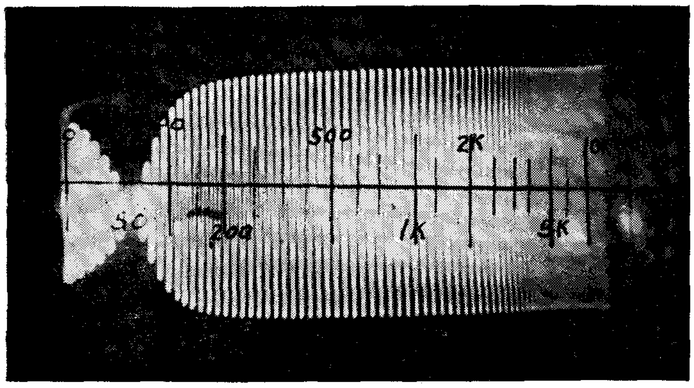


Fig. 6. 50-cps calibration null. Note smooth contours below 100 cps, and sharply defined null.

plifier must be designed for converting the vertical scale to decibels. Each of these problems will be discussed.

It has been seen that the constant-wavelength feature has worthwhile advantages. The following discussion will develop the expression for the sweep direction. A plot of this horizontal deflection as a function of time is shown in *Fig.* 8. On the right edge of this plot is shown a scale of frequencies from which the frequency at any instant can be determined. It will be observed that for 90 per cent of the sweep period the frequency is below 200 cps with the change from 200 to 20,000 cps occurring in the last 10 per cent of the time. It thus becomes evident that a major portion of the sweep time must be spent in the bass register to allow a large number of cycles to occur so that the curves drawn will be smooth in the bass region.

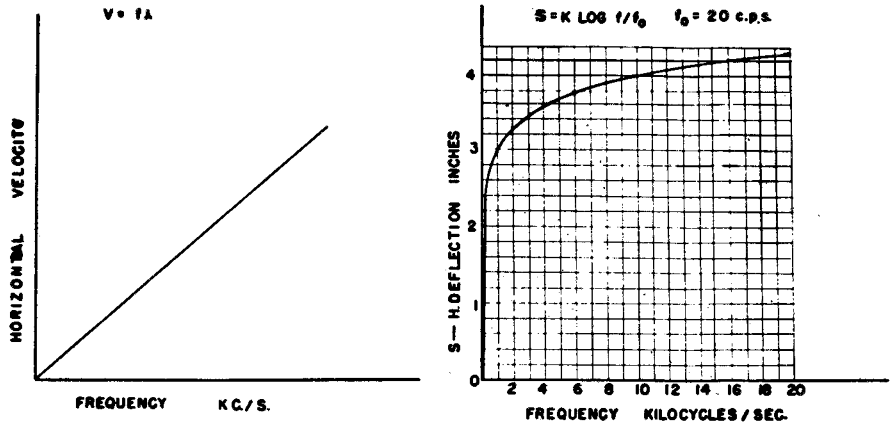


Fig. 7A (left) and 7B (right). Curves of Equations (1) and (2) showing conditions imposed on sweep velocity and frequency-scale division.

Sweep Circuit Details

Needless to say, the electronic circuit that fulfills these conditions did not evolve over night but required trials of many possible combinations before a completely satisfactory system was devised. *Figure* 9 shows the principles of the final circuit, some details being omitted for the sake of clarity. A linear sawtooth wave, generated by the 884 thyratron, is converted to the required wave shape and then drives a remote cutoff reactance tube to frequency modulate one oscillator of a B.F.O. The linear sawtooth wave, $e = at$, is distorted to a wave shape that makes possible this type of presentation. In the case of a wave drawn by a spot moving across an oscilloscope screen while the frequency of vertical motion increases as the spot progresses, a constant wavelength will be maintained only if the horizontal component of the spot velocity increases in proportion to the increase in frequency. This can be stated mathematically as follows:

$$f\lambda = v \qquad (1)$$

where f is the frequency at any point on the horizontal scale, λ is a constant wavelength, and v is the instantaneous horizontal spot velocity at the point. Equation (*1*) is illustrated in the plot of *Fig.* 7A.

The condition of logarithmic horizontal scale distribution can be stated as follows:

$$s = k \log_e f/f_o \qquad (2)$$

where f_o is the initial frequency at the left edge of the screen and s is the distance from f_o to f. k is a constant dependent on total scale length. Equation (*2*) is illustrated in the plot of *Fig.* 7B.

Equations (*1*) and (*2*) can be solved simultaneously to obtain the equation of s as a function of time, since v in equation (*1*) is equal to ds/dt. The resulting equation for a 5-inch scale, 20 to 20,000 cps bands limits is:

$$s = 0.724 \log_e 1 - \left(\frac{1}{.00999t}\right) \qquad (3)$$

where t is expressed in per cent of a sweep period. This expression defines the manner in which the spot must traverse the screen in the horizontal

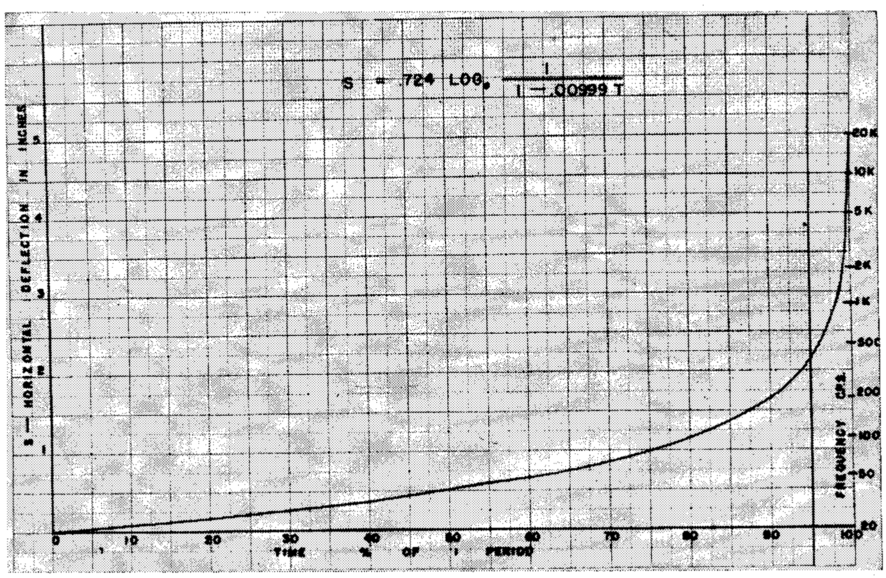


Fig. 8. Required sweep-wave shape plotted in inches horizontal deflection vs. per cent of a sweep period. Frequency scale on right shows required position of each frequency for logarithmic scale.

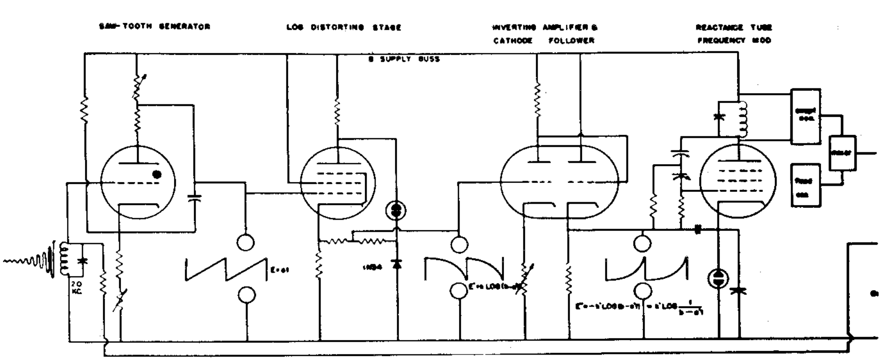


Fig. 9. Simplified circuit diagram of sweep generator, showing wave form at significant points in the circuit.

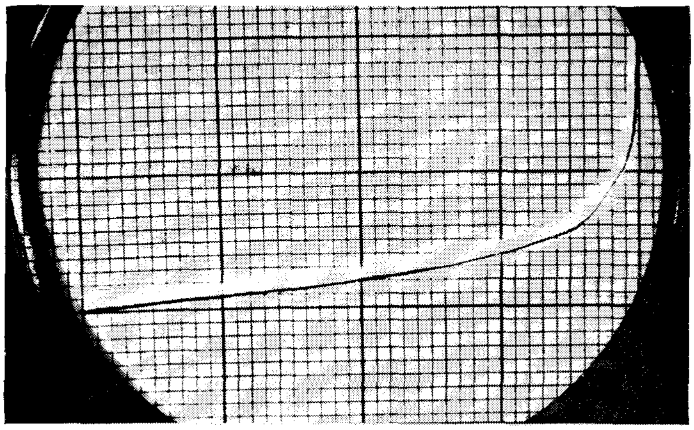


Fig. 10. Oscillogram comparing calculated sweep wave shape with experimentally obtained output from generator of Fig. 9.

log function by means of 1N34 germanium crystals which have the characteristic that the voltage across the contacts is proportional to the logarithm of the current through them[4]. In this case a constant current from the *B* supply passes through the contact rectifiers from which is subtracted the amplified saw tooth wave at the output of the second stage. The wave form at the input to the third stage can therefore be expressed as follows:

$$E' = c \log_e (I_B - I_{saw}) \qquad (4)$$

Where E' is the voltage across the contact rectifiers and c is a constant of proportionality.

The wave form at this point must be inverted to obtain the required sweep voltage since the inversion puts a minus sign before the expression of equation (*4*) and

$$-\log_e (I_B - I_{saw}) = \log_e 1/ (I_B - I_{saw})$$

The output of the amplifier stage, E'', is therefore of the required wave form since I_{saw} is proportional to time and I_B is constant. Thus:

$$E'' = c \log_e 1(b - a't)$$

where c', b, and a' are constants. See *Fig.* 9.

Fig. 10 shows an oscillogram in which E'' is plotted against time and is superimposed on a drawing of the calculated curve. The close agreement between the experimentally generated curve and the theoretical curve is readily apparent.

It will be observed that this waveshape requires great accuracy and stability of the trigger point since approximately half the screen is covered in the last 1 per cent of the sweep period and a very slight jitter in trigger time could easily cause the upper band limit to vary between 20 and 50 or more kc. *Stability of the upper band limit* is a problem that was solved by causing the trigger time to be determined by the output frequency. Note in *Fig.* 9 that the *LC* network, tuned to 20 kc, in the grid circuit of the 884 is excited in a constant-current fashion from the audio output of the generator. *The voltage across this circuit* therefore rises as the output frequency approaches 20 kc and triggers the sweep when it is large enough to over*come the bias on the grid of the gas* tube. Thus the trigger occurs at the same frequency for each sweep regardless of the total time taken by individual sweep periods. Since the a.c. *grid voltage on the 884 increases as the* output frequency approaches 20 kc, and ends the sweep when it is large enough to overcome the bias, controlling the bias offers a means of varying the upper band limit. A reduction in bias will lower the voltage required to trigger the sweep and will therefore lower the upper band limit. This control appears on the front panel as the upper band limit control. The upper limit may be set anywhere between 2000 and 20,000 cps.

Control of the lower band limit is achieved by setting the initial bias on the reactance tube grid, thus changing the initial frequency without disturbing the horizontal scale distribu*tion. A decrease in bias merely* cuts off the low end of the sweep range and thus raises the lower band limit. A study of the equations reveals that this *method of control does not change the* constant-wavelength feature except to

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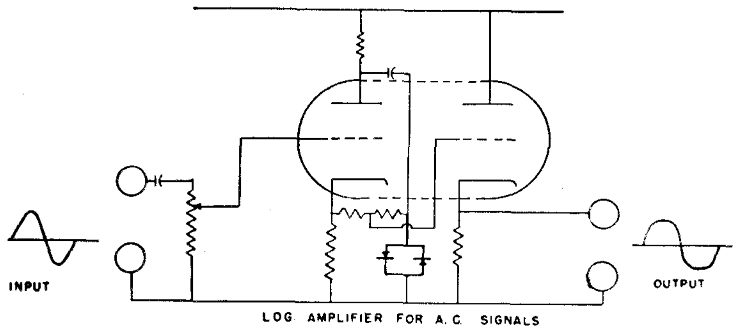

Fig. 11. Circuit of logarithmic distorting amplifier for obtaining vertical deflection linear in decibels.

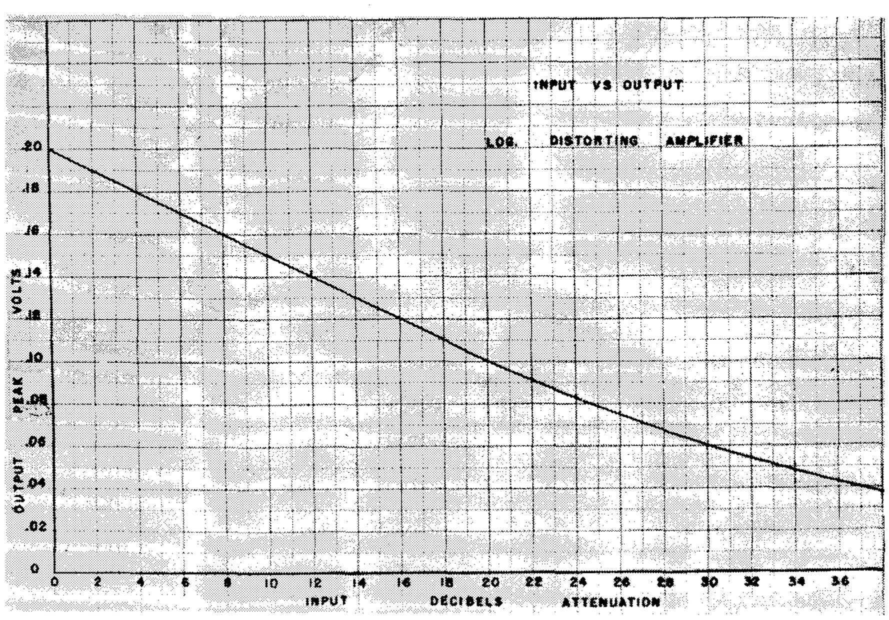

Fig. 12. Input voltage versus output decibels curve for amplifier of Fig. 11 showing linearity of vertical decibel scale.

[4]Audio Frequency Response Curve Tracer, J. H. Jupe, *Telephony*, Aug. 16, 1947

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increase the wavelength uniformly throughout the band and therefore presents the response curves in greater detail. This, then, is a useful control since it makes increasingly detailed studies of the fine structure of response curves possible as the lower band-limit control appears on the front panel in the form of a switch for selecting specific lower limits such as 20, 50, or 100 cps. A fourth position is provided on this switch with a screwdriver adjustment in the back for the selection of any desired lower band limit.

The almost mandatory use of a heterodyne type of oscillator gives rise to yet another source of frequency instability which does not readily yield to the conventional solution of temperature compensation. The reactance tube will not sweep a high-capacitance tank circuit adequately and still maintain the logarithmic frequency-scale distribution so that a high *LC* ratio in the tank of the swept oscillator is necessary. This, of course, leads to poor frequency stability of this oscillator. Some method of lower band limit stabilization is therefore mandatory. Fortunately this problem yields readily to a form of automatic frequency control. The audio output is coupled to a single-stage low-pass *RC* filter. The time average of the voltage across the capacitor portion of this circuit depends on the time average of the output frequency. Since the major portion of the sweep time is spent below 200 cps, this average is very sensitive to small changes in the lower band limit. An average-reading rectifier across the capacitor develops a d.c. control voltage proportional to the average frequency which is applied to a control reactance tube across the swept oscillator tank. The polarity of this voltage is chosen to oppose changes in the lower band limit. A sweep oscillator of good stability is thus assured. After the first ten minutes of operation only a small and negligible frequency drift is discernible on the cathode-ray screen.

Curve Calibration

In order to make convenient use of the frequency response curves presented on the screen some means must be provided to calibrate the horizontal scale accurately in terms of frequency. One means for accomplishing this end is to use a number of parallel-T networks of the *RC* type with their points of zero transmission distributed throughout the frequency band. The frequencies 20, 50, 100, 500, 1000, 2000, 5000, 10,000 were chosen for calibration points since they are about equally separated on the log scale. A selected network is inserted in the signal path of the amplifier, and the output of the generator drops to zero at the null frequency, thereby accurately defining the position of that frequency on the screen. Selection of each null network in turn allows calibration of the screen at the selected frequencies. A switch on the front panel provides for selecting these null points. Feedback in the amplifier sharpens the nulls so that at one octave above or below the null the output is within one decibel of the final value[5]. *Figure* 7 shows the pattern produced by the 50-cps null point in a sweep from 20 to 20,000 cps.

The last problem to be discussed concerns the method of obtaining a vertical scale which is linear in decibels rather than in voltage. The desirability of a logarithmic vertical coordinate need not be justified here beyond mention that accepted practice utilizes Log-Log coordinates. *Figure* 11 illustrates the circuit of an amplifier that distorts the signal applied to it according to a logarithmic law introduced by the back-to-back connected 1N34 Germanium diodes. The output voltage across these diodes is instantaneously proportional to the logarithm of the input voltage to the amplifier stage.

In use, the output terminals of the log amplifier are connected to the vertical input of the oscilloscope and the input terminals are connected to the output of the equipment under test. *Figure* 12 shows the linearity of this amplifier when the peak output voltage is plotted against decibels input. It can be seen that the linearity is good over a range of about 26 db or an input voltage ratio of about 20 to 1. This is sufficient for most response curves. In *Fig.* 5, which shows the 6db/octave rise of a high-pass *RC* combination, the linearity of both the log frequency scale and the vertical decibel scale can be checked.

The unit constructed according to the principles herein outlined has given stable, trouble free service and the inherent flexibility of the all electronic design has proved itself many times to be highly desirable.

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[5] Negative Feedback Applied to Oscillators, *Electronics*, May 1940