Equipment for Acoustic Measurements

(Part 2)

A Portable Tone Source Developed for Use in Room Acoustics †

By C. G. Mayo, M.A., B.Sc., M.I.E.E., * and D. G. Beadle, B.Sc.(Eng.), A.C.G.I., A.M.I.E.E. *

It is usual when making measurements in room acoustics to use an audio frequency tone warbled to average the reverberation time over a band of frequencies and it is desirable that the bandwidth should be a fixed percentage of the mean frequency. One method of achieving this result is to rock the stator of the variable capacitor of the oscillator circuit by a motor-driven cam, but this method adds considerable weight and bulk to the equipment as well as causing mechanical vibration and consequent microphony in the valves. Various electronic methods of warbling have been tried, but they usually take the form of a reactance valve across the tuned circuit, and unless the gain of the reactance valve is varied in step with the variable capacitance, the bandwidth will be a fixed number of cycles and independent of the mean frequency.

In the instrument to be described an electronic warble having a fixed percentage deviation from the mean frequency has been obtained, and a small synchronous motor and gear box are included to give slow glides. By the use of miniature components the outside dimensions of the tone source have been kept to 17in. × 10in. × 6in. with a total weight of just under 20lb.

The main details of the portable tone source are:

FREQUENCY RANGE	20-20,000c/s on a single dial with logarithmic divisions. Adjustment of ± 50c/s on an incremental dial.
ACCURACY	Resetting accuracy better than 1 per cent, scale length approximately 20in.
WARBLE TONE	A 10 per cent warble at 7c/s is obtainable at all settings of the dial with negligible amplitude modulation.
OUTPUT LEVEL	Either + 20db or 0db above 1 milliwatt into 600 ohms, selected by means of a key and a 25db uncalibrated variable control.
OUTPUT IMPEDANCE	600 ohms balanced.
HARMONICS	0.5 per cent at maximum output of + 20db. (Note: The full output of + 20db is not obtainable below 50c/s owing to limitation on size of output transformer.)
HUM AND NOISE	More than 55db below maximum output.
FREQUENCY CHARACTERISTIC	Flat within ± 0.25db from 20-20,000c/s.
FREQUENCY STABILITY	Total drift from cold approximately 10c/s.
SLOW GLIDE	A synchronous motor and gear box provided to cover the range 20-20,000c/s in 4, 8, 16 or 32 minutes.
EXTERNAL DRIVE	Provision is made for driving the variable capacitor by external means.
POWER CONSUMPTION	Approximately 50 watts at 200-250 volts, 50c/s.
DIMENSIONS	Outside dimensions of carrying case 17in. × 10in. × 6in.
WEIGHT	20lb.

† *Patent Application No. 22273/49.*

* *Research Department, BBC Engineering Division*

General Considerations

The requirement of a frequency range of 20-20,000c/s on a single dial made the choice of a beat frequency oscillator almost inevitable. The second requirement, a logarithmic scale, presented a difficult problem as commercial capacitors with a logarithmic law and sufficient maximum capacity are too large to be accommodated in the standardized miniature apparatus box of the B.B.C. Research Department. This difficulty was overcome by using a three-terminal capacitor in the form of a piston attenuator for the incremental capacitor of the variable oscillator. As is well known, this device has the property of giving a transfer capacitance, from the fixed to the moving electrode, which bears a logarithmic relationship to the distance between the electrodes, provided they do not approach one another too closely, i.e., C varies as e^{-kx}, where C is the capacitance, x the distance between the plates, and k a constant. This transfer capacitance is too small to be used directly, but by connecting it between the output and input terminals of an amplifier, the capacitance can be increased to a suitable value by Miller effect. Furthermore, a cyclic variation in the gain of the amplifier will produce a warble tone with, to a first order, a fixed percentage deviation of the set frequency.

A pot type ferrite core is used for the oscillator coils, as this gives the advantages of a high Q and almost complete magnetic screening—a point of considerable importance when the oscillators have to be close to one another. Two slight disadvantages of the material are its high dielectric constant and core losses, both of which increase with temperature. The temperature rise is kept small by thermally insulating the coil boxes from the rest of the apparatus, and the self capacitance of the coils is further reduced by insulating the core from the frame.

The apparatus is constructed on the unit principle which greatly facilitates manufacture and maintenance. The views of Fig. 1 show how this has been accomplished, and Fig. 2 is a circuit diagram.

The Variable Oscillator

The variable oscillator (Fig. 3) consists of three parts, an oscillator V_1 and V_2, an anode follower V_3 and the warble valve V_4. V_1 and V_2 form an amplifier of fixed gain determined by the ratio (160:1) of the feedback transformer T_1. This, combined with the forward gain of 80db,

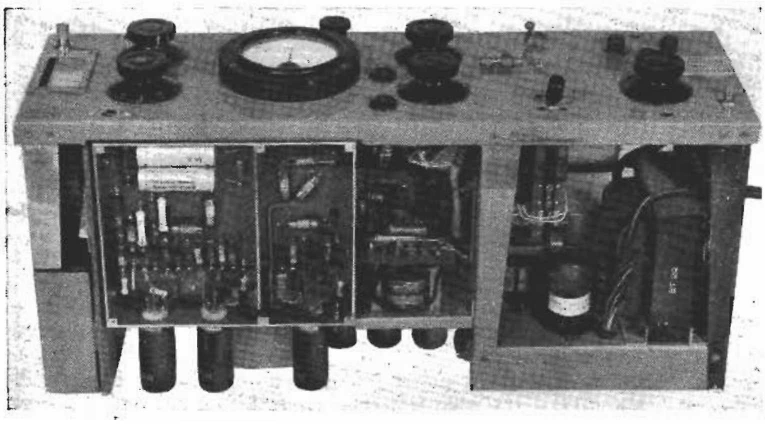


Fig. 1(a). The complete equipment showing the unit construction

gives 36db of negative feedback, which is considered adequate to prevent changes of gain with variations in mains voltage and valve characteristics. Regulated positive feedback is obtained from the anode of V_2 to the grid of V_1 through the resistances R_1, R_2 and the reversed parallel germanium crystals W_1 and W_2, one of which is biased from the cathode of V_2. The square waveform of the positive drive has a precise value determined by the delay volts on W_2 and has the effect of giving good regulation without changes of frequency.

The anode follower V_3 gives an amplification of 2 : 1 determined by the ratio of R_3 to R_4, and its low impedance output is used to feed the moving electrode of the three-terminal capacitor C, which is varied to alter the frequency of the oscillator.

It will be noted that the capacitor C is connected between the input and output of a three-stage amplifier and, consequently, due to Miller effect, appears to the coil as a capacitance $(1 + A)C$, where A is the amplification of the amplifier. Care has to be taken to prevent any phase errors occurring in the amplifier, as these will either increase or decrease the amplitude of oscillation. In practice a slight unavoidable phase displacement is corrected by a small capacitor across R_1.

In a beat frequency oscillator it can be shown that, to a first order, the beat frequency is $f_1\delta C_2/2C_2$, where f_1 = fixed oscillator frequency, δC_2 = the incremental capacitance, and C_2 = total tuning capacitance required to produce f_1. (See Appendix 1). Hence, in order to obtain a warble the deviation of which is a fixed percentage of the set beat frequency, it is only necessary to change δC_2 by a fixed percentage. This can be accomplished quite simply as δC_2 is the effective incremental capacitance of the tuning capacitor and depends directly upon the gain of the amplifier. Thus, variation of this gain will produce a frequency warble in which the deviation from the beat frequency is a fixed percentage of the set beat frequency.

In Fig. 3, V_4 is a transitron oscillator having a frequency of 7c/s determined by C_2, R_5 and C_3, R_6. It is used to modulate the variable oscillator signal which is applied to the control grid and the resultant modulated waveform is injected, with the correct amplitude and phase, into the grid circuit of V_3 so as to produce the necessary change of gain to give the 10 per cent deviation required. The warble has to deviate equally about the set beat frequency, and this is accomplished by adjusting R_7, with the transitron oscillator inoperative, until there is no change of frequency on closing the switch S.

One other point of interest is the method of obtaining the correct phase adjustment of the modulated waveform. As the input capacitance of the variable capacitor is across the anode load of V_3 it causes the grid voltage of V_1 to lag. This is compensated by feeding a leading voltage through C_1, R_8. It is essential that this adjustment should be correct, as maladjustment causes amplitude modulation.

Fig. 4 shows the variable capacitor with the outer casing (1) removed. It has been designed on kinematic* principles and consists of a fixed electrode (2), a moving electrode (3), and the lead screw (4). Rotation of the dial and lead screw moves the carriage (5) by means of a steel ball riding in the screw thread and held there by two spring loaded balls (6) on the opposite side. To prevent stressing the mechanism in the event of over-running the end of the travel, the ball can lift out of the thread and the two balls side by side prevent the wrong ball from re-locating in the thread. The carriage is prevented from rocking by the inverted V-shaped member (7) which houses four steel balls sliding on the guide rod (8). Connexion is made to the moving electrode by a phosphor bronze spring (9), which is soldered to the anchor points at both ends to ensure good electrical contact. The lead screw is carried on two "V" bearings and held there by two spring loaded balls (10) and (11). The ball (10) rests in a groove on the drive shaft to prevent endwise movement, whereas ball (11) rides on the shaft.

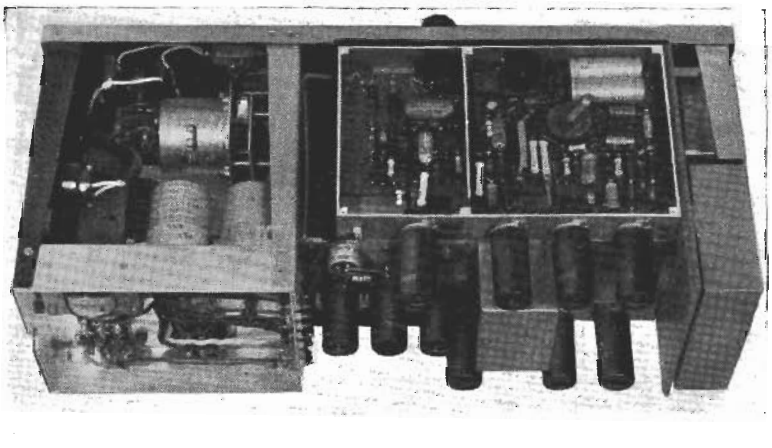
A plot, Fig. 5, of capacitance against angular displacement of the drive shaft shows that the logarithmic law is well maintained over most of the range, but that the inverse distance law causes the capacitance to rise faster as the electrodes approach one another. The departure from the true logarithmic law is used to compensate for the fact that the beat frequency is no longer inversely proportional to the incremental capacitance at high beat frequencies, the squared term in Equation 2 of Appendix 1 necessitating a more rapid rise of capacitance to maintain a logarithmic law at high frequencies.

The Fixed Oscillator

This is a conventional tuned grid oscillator with "reaction coil" feedback from the screen grid of V_1. There are several interesting features in the design which help to achieve the requirements of low harmonic content and constant output level. A simplified circuit diagram is shown in Fig. 6.

** The word "kinematic" is used to describe the technique of instrument design in which accurate movements or displacements are achieved by using the minimum necessary number of constraints to the moving parts rather than extremely accurate workmanship in manufacture.*

Fig. 1(b). Another view of the complete unit



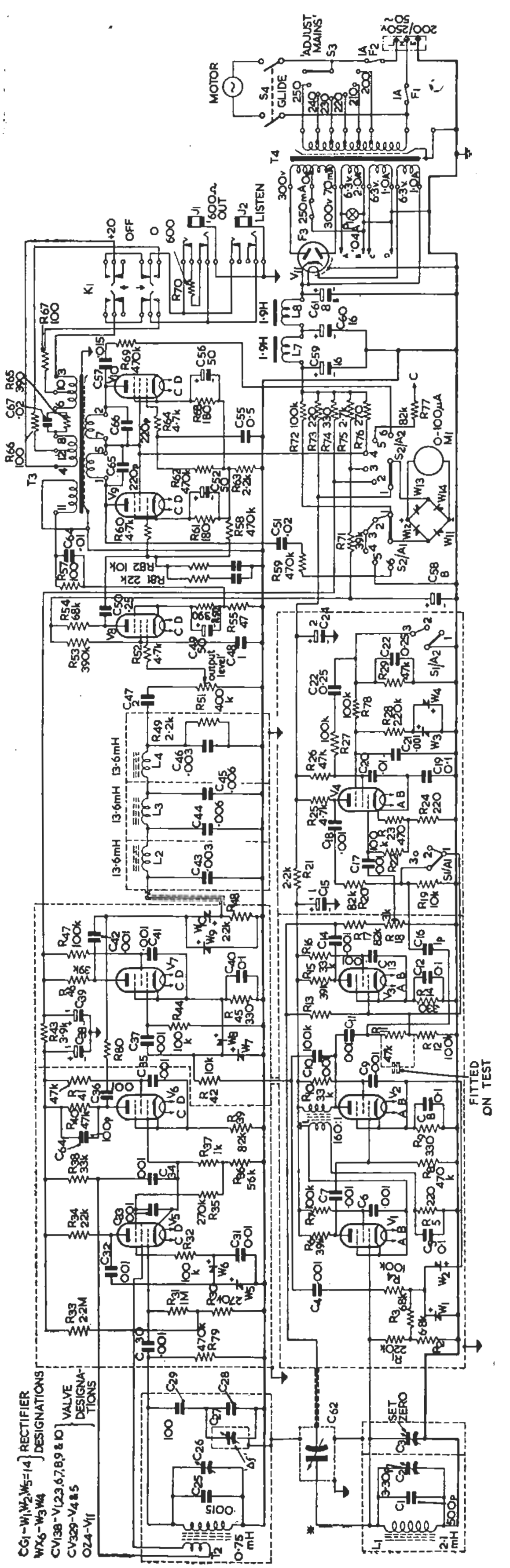


Fig. 2. Circuit diagram of the complete unit

A frequency of 150kc/s was chosen for the fixed oscillator as a compromise between frequency stability and departure from a logarithmic scale for the beat frequency.

Regulation is obtained by suitable division of the screen and anode currents of V_1. The suppressor grid is biased negatively and obtains a countering positive bias, proportional to the oscillator voltage, from the voltage doubling circuit W_1W_2 fed from the anode and delayed by the voltage across the cathode resistor R_1. Thus, if the oscillator voltage rises, the suppressor grid is made more positive and the screen grid current reduced, thereby reducing the amplitude of oscillation and vice versa. Heavy cathode feedback is employed and in order to provide correct working conditions the grid is returned to a point some 30 volts positive to ground. This arrangement, although dependent upon the H.T. supply for stability, gives adequate regulation, but should at any time better regulation be required, it can be obtained easily by stabilizing the grid voltage with a neon lamp. A regulation curve showing output volts against coil loss is shown in Fig. 7. It will be noted that an additional 2 micromhos of damping had to be added to arrive at a suitable working point as it was inconvenient to reduce the positive drive from the reaction coil or the screen grid current.

A low-pass filter R_2 C_1 is used to reduce harmonics and couple the output from the cathode of V_1 to the grid of V_2 which acts as a buffer stage to feed the mixer. Considerable cathode feedback is again used for stability and freedom from harmonics.

The $\pm$ 50c/s increment is obtained by a small trimmer across the main tuning capacitor of the fixed oscillator. As the increment calls for a change of capacitance of only $\pm$ 1pF a larger capacitor was chosen and suitably padded out as shown in Fig. 6 where C_2 represents the trimmer, and C_3 and C_4 the padding capacitors.

The trimmers, like the variable capacitor, are designed on kinematic principles, and in order to obtain a smooth bearing, use has been made of polytetrafluoroethylene for the bearing surface. An assembly view is shown in Fig. 8.

The Mixer

This circuit, shown in Fig. 6, is of particular interest as it produces a beat frequency output which is substantially free from harmonics. Two methods are commonly employed for obtaining the audio signal in a beat frequency oscillator. One is to multiply the two high frequency signals by passing them through a square law device which, unless it is exactly square law, will produce harmonics of the beat frequency. The output voltage in this type of mixer is proportional to the product of the fixed and variable oscillator voltages.

The second method is to add the two signals and obtain the beat frequency by linear rectification. This is equivalent to a single sideband modulated carrier and will give distortion unless one of the signals is small compared with the other. In this condition the output voltage is proportional of the smaller signal.

The method employed here makes use of the fact that the amount of beat frequency harmonic obtained when two high frequency signals are added and linearly rectified depends only upon the purity of one of the wave-forms and the maximum rate of change of voltage (or current) of the other. It follows that, if a pure sine wave is added to a rectangular wave of slightly different frequency, the resulting beat frequency from linear rectification will have no harmonics and, if the sine wave contains harmonics, the beat frequency will have no even harmonics and greatly reduced odd harmonics. A mathematical treatment of the theory has been established and it is hoped to publish the results at an early date[1].

The output of some 25 volts from the variable oscillator is squared by R_3 and the biased rectifiers W_3 W_4 on the grid of V_3 (Fig. 6). After amplification the square waveform is added to the pure waveform (10 volts) of the fixed oscillator and linearly rectified by the rectifiers W_5, W_6. The audio frequency output is obtained from the low-pass filter which forms the rectifier load and is used to suppress the primary oscillator components and other rectification products.

The Audio Frequency Amplifier

This is a two-stage amplifier with push-pull output and negative feedback from a tertiary winding on the output transformer to the cathode of the first stage. It is of similar design to that described in a previous article.[2]

The maximum output is + 20db above 1 milliwatt into a 600 ohm load, but owing to limitation on the size of the output transformer the maximum output is not obtainable below 50c/s.

The Power Supply Unit

The supply unit gives 70mA at 300 volts for the anode and screen supplies and 6.3V, 4A for heaters. A cold cathode rectifier (OZ4) is used for economy in heater power and to keep the temperature rise as small as possible. The valves are divided into groups for metering, and an output meter is provided for setting the output level. Table I gives the list of valves used and their feeds.

The Slow Glide

A small synchronous clock motor and a four-speed gearbox (Fig. 9) are provided, so that the frequency sweep of 20-20,000c/s can be covered in approximately 4, 8, 16 or 32 minutes.

A universal joint, through which the drive is transmitted by three spring-loaded balls resting in grooves, is interposed so that overdriving will not damage either the variable capacitor or the gearbox. A shaft is also available for driving the variable capacitor from an external source.

Performance

FREQUENCY CHARACTERISTIC: — This is within ±0.25db from 20-20,000c/s. A slight drop at the extreme ends of the band is attributable to the audio frequency amplifier.

HARMONICS AND NOISE LEVEL:—These were found to be low as shown in Table 2. The fact that they do not vary appreciably with output indicates that the audio frequency stage is satisfactory and that the mixer behaves as predicted.

In a paper[3] to be published elsewhere it will be shown that the distortion due to pulling at a frequency f when the locking frequency of the oscillators is f_0 is given by

$$\text{Distortion} = \frac{f_0}{2f} \times 100 \text{ per cent.}$$

Hence it can be seen that distortion from this cause is quite small.

The hum and noise level at 57db below maximum output is considered satisfactory.

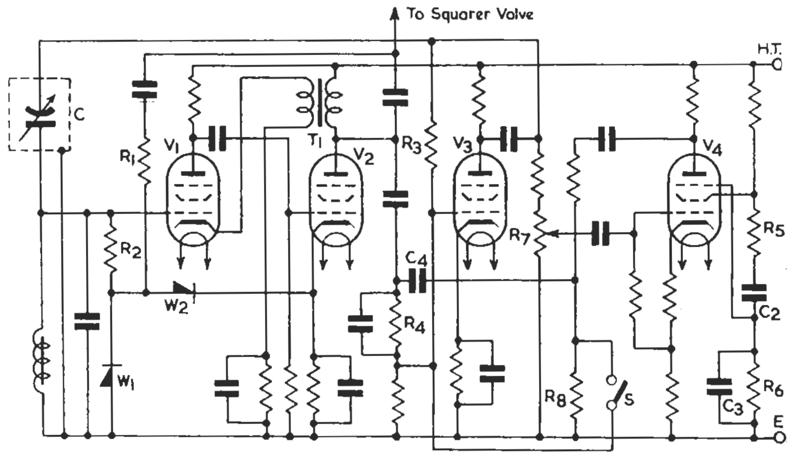


Fig. 3. The variable oscillator (simplified)

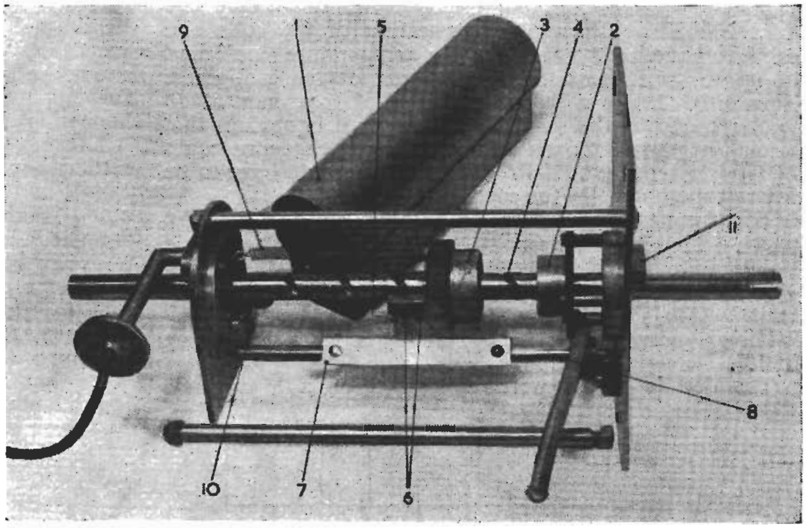
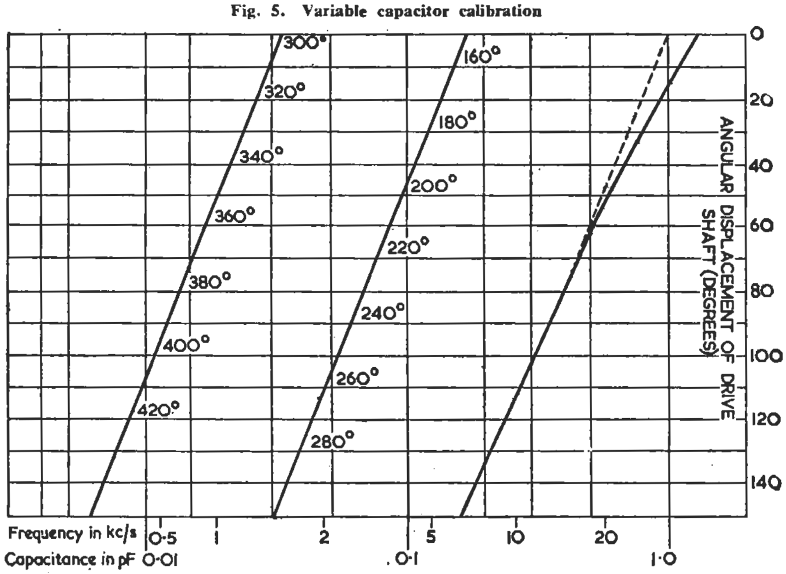


Fig. 4. The variable capacitor

Fig. 5. Variable capacitor calibration



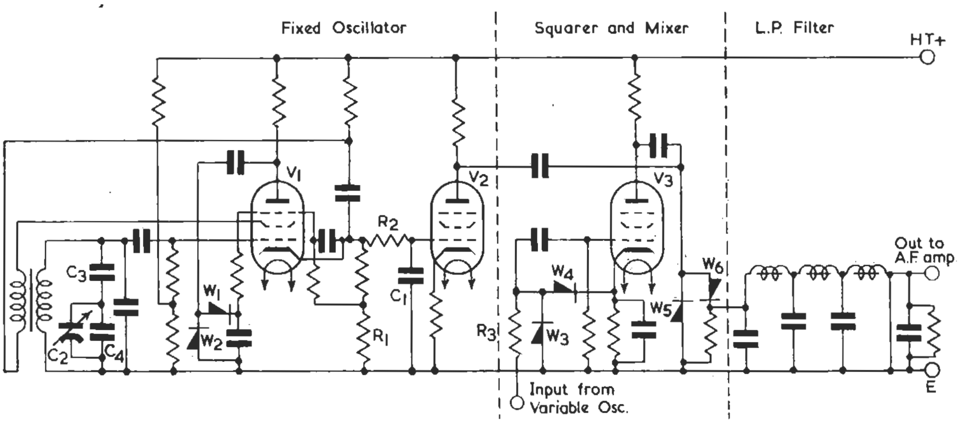


Fig. 6. The fixed oscillator squarer and L.P. filter (simplified)

DRIFT:—Typical drift curves are shown in Fig. 10, from which it will be seen that, although the oscillators drift a total of some 60c/s from cold, they keep in step so that the beat frequency drift is small enough to be considered satisfactory for a portable oscillator of this size. The drift is mainly attributable to heating of the coils and capacitors both of which have a temperature coefficient of up to + 50 parts per million per degree centigrade. Thus a 10°C. rise will give a change of frequency of up to 75c/s. From the shape of the curves it is obvious that a small negative temperature compensating capacitor could be used to reduce the drift, but its value would have to be found experimentally for each tone source.

The frequency scale was calibrated on opal perspex which is illuminated internally by a dial lamp. The decade points were obtained by calibration on a cathode ray oscilloscope against 10,000, 1,000 and 100c/s tone derived from a 1Mc/s crystal oscillator whose absolute frequency is known and whose frequency stability is better than 1 part in 10^7.

The decade points were subdivided on a logarithmic basis. It was found after calibrating six tone sources that the mean calibration curve showed an error of just over ± 2 per cent, which was attributable to errors in the screw thread and diameter of the electrodes and outer casing of the variable capacitor. As these capacitors were produced by normal workshop practice without special regard to precision, this result was considered satisfactory. It should be noted that a high degree of accuracy is required for the division of the scale to prevent the marks from appearing uneven.

SETTING ACCURACY:—As the scale is logarithmic the setting accuracy is constant throughout the frequency range, and is of the order of 1 per cent. No backlash could be detected in the variable capacitor, as the same frequency was obtained when approached from either above or below.

The " zero set " adjustment is made by setting the main dial to 50c/s, reducing the incremental dial by 50c/s, adjusting for zero beat on the " set zero " control and returning the incremental dial to its original setting. This somewhat elaborate arrangement is necessary, as with a logarithmic scale there is no zero. If some arbitrary zero had been chosen at 0.2c/s, say, a scale length equivalent

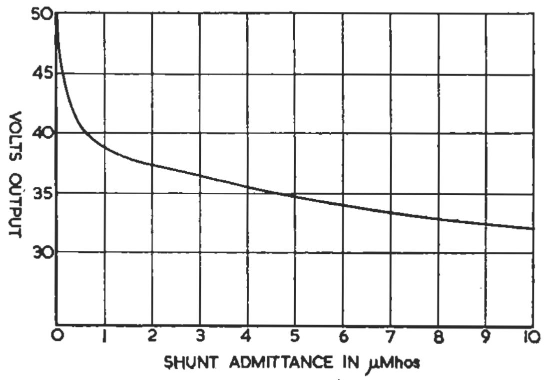
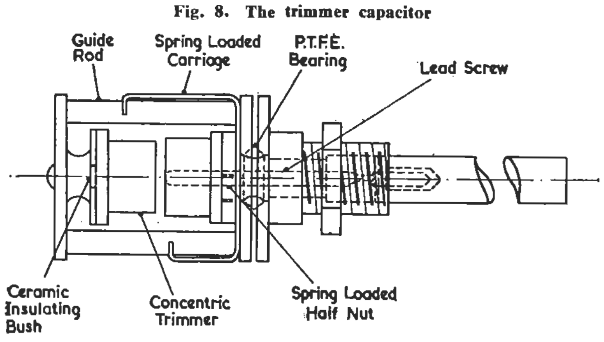


Fig. 7. Regulation of fixed oscillator

Fig. 8. The trimmer capacitor



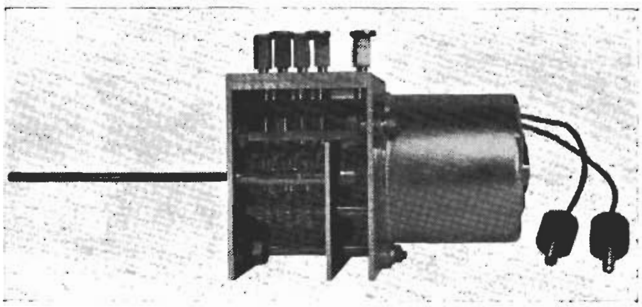
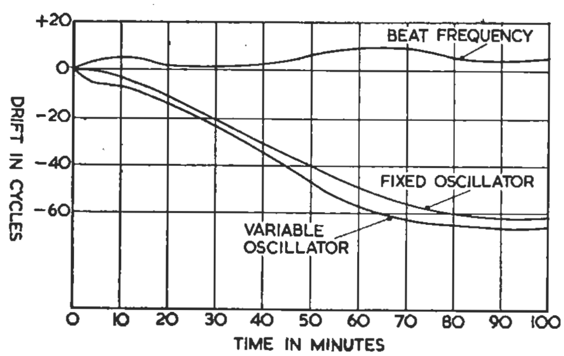


Fig. 9. The gearbox and motor

Fig. 10. Typical drift curves



to twice that of 20-200c/s would have been lost. An alternative method of injecting 50c/s from the mains could be used, but it would require an additional control on the front panel.

Acknowledgments

The authors wish to thank their colleagues of the B.B.C. Engineering Research Department for help in the development of this tone source and they are also indebted to the Chief Engineer of the B.B.C. for permission to publish this article.

APPENDIX

Relationship of Beat Frequency and Incremental Capacitance

Let $f_1 = K_1/C^{\frac{1}{2}}$ and $f_2 = \dfrac{K_2}{(C_2 + \delta C_2)^{\frac{1}{2}}}$

where f_1 = fixed oscillator frequency

f_2 = variable oscillator frequency

C & C_2 = values of main tuning capacitor

δC_2 = values of incremental tuning capacitor

and K_1 and K_2 are constants.

Then the beat frequency F is given by

$$F = f_1 - f_2 = K_1/C^{\frac{1}{2}} - \frac{K_2}{(C_2 + \delta C_2)^{\frac{1}{2}}}$$

$$= f_1 \left[1 - \frac{1}{(1 + \delta C_2/C_2)^{\frac{1}{2}}} \right] \quad \ldots\ldots\ldots (1)$$

since $f_1 = K_1/C^{\frac{1}{2}} = K_2/C_2^{\frac{1}{2}}$, i.e., $\lim\limits_{\delta C_2 \to 0} f_2 = f_1$

$$F = f_1 \left[1 - \left(1 - 1/2\, \delta C_2/C_2 + \frac{1/2 \,.\, 3/2}{1 \,.\, 2}\left(\frac{\delta C_2}{C_2}\right)^2 - \frac{1/2 \,.\, 3/2 \,.\, 5/2}{1 \,.\, 2 \,.\, 3}\left(\frac{\delta C_2}{C_2}\right)^3 + \ldots \right)\right]$$

$$= f_1 \left(\frac{\delta C_2}{2C_2} - 3/8\left(\frac{\delta C_2}{C_2}\right)^2 + 5/16\left(\frac{\delta C_2}{C_2}\right)^3 - \ldots \right) \quad \ldots\ldots (2)$$

$$\simeq f_1 \frac{\delta C_2}{2C_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Thus so long as $(\delta C_2/C_2)^2$ is small compared with $\delta C_2/C_2$, the beat frequency is proportional to δC_2. Above this point the scale will open out. Hence a logarithmic capacitance law for the variable capacitor results in a substantially logarithmic frequency scale.

TABLE I

Valve No.	Type	I_amA	I_{g2}mA
V_1	CV138	4.0	1.25
V_2	CV138	6.0	1.7
V_3	CV138	3.8	1.0
V_4	CV329	3.2	3.2
V_5	CV329	3.3	2.6
V_6	CV138	3.3	1.0
V_7	CV138	4.8	1.4
V_8	CV138	1.6	0.5
V_9	CV138	10.0	2.5
V_{10}	CV138	10.0	2.5
V_{11}	OZ4	—	—

(H.T. = 300 volts AC input = 52VA)

TABLE II

FREQUENCY c/s	OUTPUT LEVEL	HARMONICS PERCENTAGE		
		2nd	3rd	
60	+20	.44	.5	Higher harmonics negligible
	0	.35	.35	
1000	+20	.22	.35	
	0	.16	.32	
5000	+20	.23	.33	
	0	.20	.30	

(Hum and noise 57db below maximum output)

REFERENCES

[1] Mayo, C. G. Mathematical Theory of Mixing in a Beat Frequency Tone Source. *To be published in Wireless Engineer.*

[2] Shorter, D. E. L. and Beadle D. G. " A Portable Microphone to Line Amplifier." *Elect Engg. xxiii,* 126, (1951).

[3] Mayo, C. G. Mathematical Theory of Distortion due to Pulling in a Beat Frequency Tone Source. *To be published in Wireless Engineer.*

The Electronic Telescribe*

THE Electronic Telescribe is the name given to a unit which was used to demonstrate the application of photo-electric cells and cathode-ray tubes by Messrs. Mullard, Ltd., at the National Radio Exhibition.

It consists of two units linked together by a single cable. When the glass plate of the first unit is written upon, a small cathode-ray tube and photocell transfers the pencil marks into electric currents. These are conveyed to the second unit (a very slightly modified commercial television receiver) where they are changed back into a visible reproduction of the original writing.

This simple equipment is fully capable of reproducing photographs, drawings and printed matter laid face down upon the glass plate and in this way it offers an excellent and greatly simplified medium for picture transmissions. While the model shown is limited to 200-line definition, Mullard engineers state that, with only a few minor modifications, this could be extended to a full 1,000-line system. Under these conditions, picture reproductions of near-photographic quality could be readily obtained.

Although not originally intended as a commercial instrument, the principle of the Telescribe could, certainly be adapted to a number of important practical applications. Its most important application is undoubtedly the superimposition of maps on radar display screens. This has obvious value in all radar display systems.

The Electronic Telescribe utilizes, in a special manner, the principle known as the flying-spot scanning technique. The time bases of two cathode-ray tubes—one a " transmitting " and the other a " receiving " tube—are synchronized. In the transmitting unit, a raster is produced on the screen of a special Mullard projection tube. By means of an optical system, the light from this raster is projected on to the glass writing plate at the top of the unit. In this way the glass plate is continuously scanned by a pencil of light.

In the absence of any picture or writing, the light beam passes through the glass plate. If a mark is made on the plate, however, some of the light is reflected and dispersed, and is picked up by a photocell. Electric currents, corresponding to the light variations, are in this way produced. These currents are amplified and are then used to modulate the beam on the " receiving " cathode-ray tube, which, being synchronized with the " transmitting " tube, will trace " bright " or " dark " in sympathy. In this way a visible reproduction of the original work is immediately produced.

Communication from Mullard Ltd.