SIMPLE TONE CONTROL CIRCUIT

Bass and Treble, Cut and Lift

By E. J. JAMES, B.Sc.

THE tone control system described here has the merit of requiring only resistors and capacitors. As a result it is unusually easy to fit to an existing amplifier, particularly as the absence of an inductance reduces the likelihood of trouble from hum pick-up.

While the circuit does not give the large amounts of lift which can be obtained by more complicated designs or by the use of resonating circuits, it is sufficient for normal requirements. The bass lift is not intended to compensate for the falling record characteristic below 300 c/s. This should be dealt with separately, so allowing the tone control to give extra lift for records abnormally deficient in bass or for listening at low volume. If required, however, a fair measure of compensation can be obtained.

It is not always realized that large amounts of bass lift cannot be achieved in a simple single-stage non-resonating circuit without lifting the lower middle register as well. The maximum rate of lift is fixed and it is only by starting at a higher frequency that greater lifts can be obtained. The amount of top lift which can be satisfactorily used is limited by amplitude distortion. Since this distortion consists of the introduction of frequencies 2, 3, 4, etc., times the fundamental frequency, a rising frequency characteristic emphasizes any which is present in the signal prior to the tone-control stage. The higher order harmonics, which are the most disturbing to the ear, are the ones which receive the greatest amplification. This limit to the useful degree of top lift applies to all forms of top lift circuit, and is inherent.

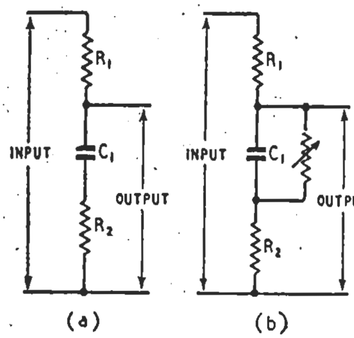


Fig. 1. The basic bass lift circuit is shown at (a). The lift is controllable by a variable resistor (b).

The basic bass-lift circuit is shown in Fig. 1(a). The capacitor C_1, has a reactance which increases as the frequency decreases, so that the output increases at lower frequencies. By shunting it with a variable resistor, Fig. 1(b), the degree of bass lift can be controlled. In the same way Fig. 2(a) shows the circuit for bass cut, and in Fig. 2(b) a variable resistor controls the amount of bass cut.

The two circuits of Figs. 1(b) and 2(b) can now be combined to give that of Fig. 3, where bass lift and cut are controlled by the potentiometer R_3.

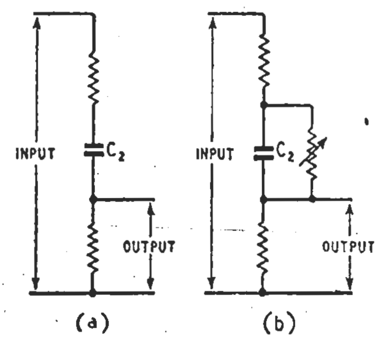


Fig. 2. Bass cut can be obtained with this circuit (a) and is controllable by a variable resistor (b).

Fig. 4(a) shows a circuit giving top lift. Here the reactance of the capacitor C_3 decreases as frequency increases, so that the output rises with frequency. In this case a variable resistor in series with C_3, as shown in Fig. 4(b) gives control of top lift.

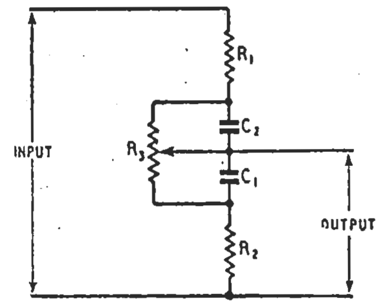


Fig. 3. This diagram shows the bass cut and lift circuits combined and controlled by the potentiometer R_3.

Similarly Figs. 5(a) and 5(b) show top cut and controlled top cut respectively. Once more the two circuits can be combined, Fig. 6, to give control of top lift and top cut by means of the potentiometer R_4.

The treble and bass controls can now be combined into the circuit shown in Fig. 7, and will normally be used as part of the coupling between two valves. For signal current the resistance, $R_1 + R_2$, is in parallel with the anode load resistance of the previous valve. R_1 and R_2 should therefore be as high as possible so that the valve does not work into too low a load. The minimum load should be about twice the valve impedance. On the other hand they must not be too high or the valve output capacitance and stray capacitances will affect response at high frequencies.

A simple method of finding

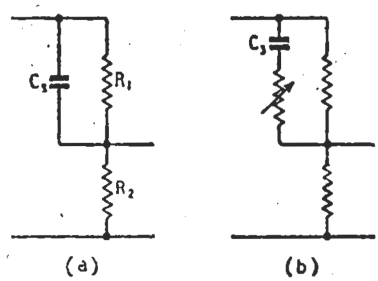


Fig. 4. Top lift is given by this basic arrangement (a) and can be varied by a series resistor (b).

COVER

ɜen erected by the G.E.C. on the sites
'row, Dunstable, Byfield and Rowley
ıingham television link. These masts,
ɜ used for the initial working of the
ɹcted towers have been built. This
. the mast at Harrow. The smaller
signal can be transmitted direct from
y during tests, thus avoiding routeing
ɜrminal station in London.

should remember to correct S meter readings for the displacement due to the local b.f.o., which does affect the a.v.c. characteristic of most receivers, however well designed they may be.

Instead of a modulation report, a c.w. operator might welcome a few words on his keying characteristic by a nearby reporting station.

In testing with a receiving station if the first S meter reading is taken as an arbitrary level, then immediate subsequent readings are of a definite value to a transmitter making test adjustments and assessing their effect on the radiated signal. H. HARDY, G4GB.
Ruislip, Middx.

Long-delay Relay Circuit

THIS circuit, described in your February issue, works well in practice, and I have used it for a year or more. The best results are obtained by using a high-slope triode having a short grid base, and I have recently found that an EC91 (miniature triode) used with C=2 mfd. and R=3.3 megohms will easily enable a 5-minute time delay to be attained.

A similar result can be obtained by connecting R_0 in the anode instead of the cathode circuit of the valve, and C from anode to grid, instead of grid to h.t. negative.

Whichever circuit arrangement be used, the time constant CR becomes effectively multiplied by the amplification factor. If any of your readers are seeking more information they might be interested in an article by the writer published in *The Engineer* of 29th October, 1948, in which these circuits are described and analyzed. J. H. LUCAS.
Mullard Electronic Research Laboratory.

"Simple Tone Control Circuit"

I SHOULD like to draw your attention to the fact that a tone-control circuit exactly similar to that described by E. J. James in your February issue, except for the slight differences in values of elements, was designed by our engineer

Michael Volkoff as early as July, 1939, when the first amplifier embodying this circuit was built. We have used this circuit ever since then, and there are now over one thousand amplifiers in Belgium with this tone control built in.
WILLY L'HOEST,
Rocke International, Ltd.
Brussels.

SENSITIVE ELECTRONIC RELAY

R.F. Oscillator Controlled by External Capacitance

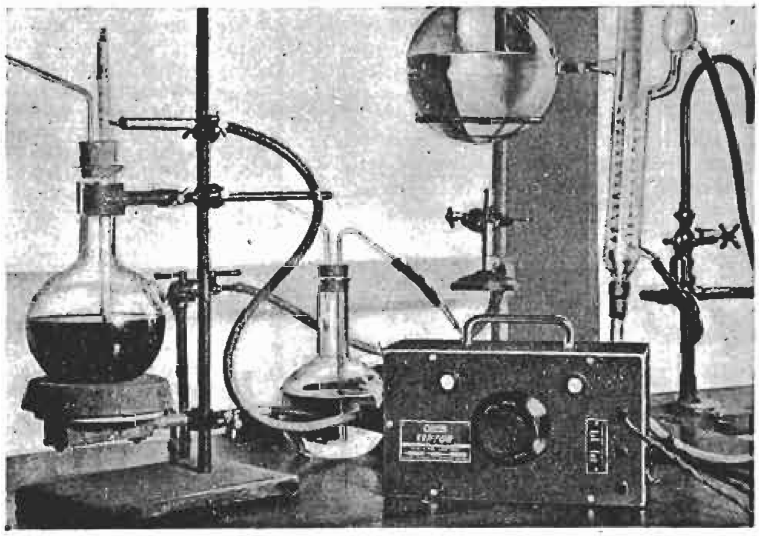
A RANGE of electronic units designed for industrial use and functioning on the principle that the proximity of a substance, whether solid, liquid or a gas, trips a relay has been introduced by Fielden (Electronics) Ltd., Holt Town Works, Manchester, 10.

The tripping of the relay can be utilized to perform a variety of functions, for example, counting the number of items passing a given point, giving warning when the level of a liquid has reached or fallen below a certain level, or, alternatively, to operate mechanism to stop or start the flow of liquid. Many other applications will suggest themselves.

In the case of objects, it is not necessary that they be conductors, and the devices will be actuated by any body of a reasonable size, be it jam-jars, biscuits, bricks, motor cars or people.

The apparatus is known as the "Tektor" and consists of a valve oscillator with a capacitance bridge in the feedback circuit and arranged so that a change of capacitance at the end of a cable joined to the bridge reverses the phase of the oscillator feedback voltage. Thus if the circuit is set up to be in an oscillating state, the proximity of a body, liquid or gas to the remote electrode will stop oscillation. Conversely, it can be made to start oscillation.

The behaviour of the oscillator is easily utilized for any number of functions, mechanical or electrical, by rectifying the radio frequency or even using the change in anode current between the oscillating and non-oscillating state.



Fielden Tektor proximity switch attached to a thermometer and arranged to give remote warning when a liquid reaches a pre-determined temperature.

At present the Tektor is available in four different forms, a proximity switch, a proximity counter, a double Tektor for recording movement in two directions such as high and low levels of liquid in a container, and a meter relay which is actuated by current or voltage readings on an indicating meter. This unit has an additional pointer on the meter which can be moved to any part of the scale and when the normal indicating pointer comes opposite the fixed pointer the electronic relay is actuated and can be made to sound an alarm.

The apparatus operates from the a.c. supply mains and consumes between 20 and 25 watts according to the functions required.

Negative-Feedback Tone Control

By P. J. BAXANDALL
B.Sc.(Eng.)

Independent Variation of Bass and Treble Without Switches

THE circuit to be described is the outcome of a prolonged investigation of tone-control circuits of the continuously-adjustable type, and provides independent control of bass and treble response by means of two potentiometers, without the need for switches to change over from "lift" to "cut." Unusual features are the wide range of control available, and the fact that a level response is obtained with both potentiometers at mid-setting. The treble-response curves are of almost constant shape, being shifted along the frequency axis when the control is operated, and there is practically no tendency for the curves to "flatten off" towards the upper limit of the audio range. The shape of the bass-response curves, though not constant, varies less than with most continuously-adjustable circuits.

The "Virtual-Earth" Concept.—The performance outlined above has been achieved by the use of a negative-feedback circuit instead of the more usual passive type of network[1,2] and it is desirable that the reader should become familiar with the "virtual-earth" concept[3] as applied to feedback amplifiers, before the operation of the tone-control circuit is considered in detail. The idea behind this concept is quite simple, and may be explained with reference to Fig. 1, in which all irrelevant details such as blocking capacitors, grid bias, etc., have been omitted, and in which V_{in} and V_{out} refer to a.c. components only. If the input resistor, R_{in}, is made equal to the feedback resistor, R_{fb}, then the circuit becomes the well-known "see-saw" or "anode-follower" phase-splitter,[4,5] and gives an output voltage which is 180 degrees out of phase with the input voltage and of slightly smaller magnitude. Now the a.c. voltage at the grid is equal to the output voltage divided by the valve gain, which may be 100 or more if the valve is a pentode, so that for many purposes the grid voltage is negligibly small in comparison with V_{in} and V_{out}. By thus neglecting the grid voltage, the following approximate relationships may be immediately deduced :—

$$I_{in} \doteq V_{in}/R_{in} \quad \ldots \quad (1)$$

$$I_{fb} \doteq V_{out}/R_{fb} \quad \ldots \quad (2)$$

where I_{in} and I_{fb} are as shown in Fig. 1.

If grid current in the valve is also negligible, which is normally the case, the application of Kirchhoff's first law (or just common sense !) to the junction of R_{in} and R_{fb} gives $I_{in} + I_{fb} = 0$, so that, from (1) and (2) :—

$$V_{in}/R_{in} + V_{out}/R_{fb} \doteq 0$$

$$\text{i.e., } V_{out}/V_{in} \doteq -R_{fb}/R_{in} \quad \ldots \quad (3)$$

When the grid voltage is neglected in this way, the grid is often called a "virtual-earth" point, and the use of this concept, though not necessary for dealing with a simple circuit such as Fig. 1, is found to be very helpful when dealing with more elaborate arrangements, and frequently gives one a far clearer physical picture of what is going on than does a straightforward mathematical analysis. The great practical value of this method of approach appears to have been first fully appreciated by Professor F. C. Williams, who also introduced the name "virtual earth."

Treble-Lift Circuit.—The basic circuit used for obtaining treble lift is shown in Fig. 2, in which the potentiometer P is made of sufficiently low resistance to ensure that the voltage at its slider, when the latter is at the middle of the element, is not appreciably affected by the current supplied to C even at the top end of the audio range. Let k be the fraction of the total potentiometer resistance lying between the slider and earth; then the total input current, I_{in}, flowing towards the virtual earth, is $I_1 + I_2$, where I_1 is approximately V_{in}/R_{in} and I_2 is approximately $jkV_{in}\omega C$. The feedback current, I_{fb}, is approximately V_{out}/R_{fb} and the application of Kirchhoff's first law to the virtual-earth junction gives $I_1 + I_2 + I_{fb} = 0$ and hence the relationship :—

$$V_{in}/R_{in} + jkV_{in}\omega C + V_{out}/R_{fb} \doteq 0$$

which may be rearranged in the form :—

$$V_{out} \doteq -V_{in}(R_{fb}/R_{in} + jk\omega CR_{fb}) \quad \ldots \quad (4)$$

It will be seen later that in order to combine this treble-lift circuit in a satisfactory manner with the treble-cut circuit, R_{fb} should be made equal to R_{in}; then, using R in place of these symbols, equation (4) becomes :—

$$V_{out} \doteq -V_{in}(1 + jk\omega CR) \quad \ldots \quad \ldots \quad (4a)$$

The output voltage may thus be regarded as having two components, one of which is independent of frequency (for a constant value of V_{in}), whereas the other one, leading in phase by 90 degrees as indicated by the operator "j," has its magnitude proportional

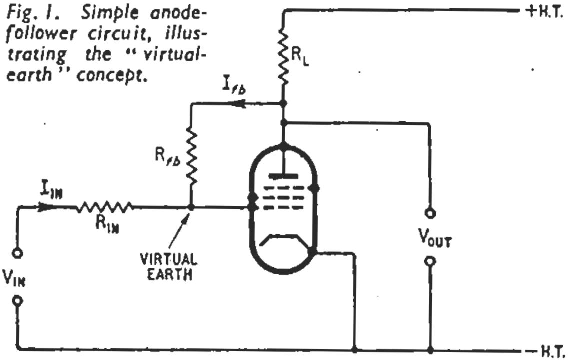


Fig. 1. Simple anode-follower circuit, illustrating the "virtual-earth" concept.

[1] "Getting the Best from Records—Part III" by P. G. A. H. Voigt, *Wireless World*, April 1940.
[2] "Simple Tone Control Circuit" by E. J. James, *Wireless World*, Feb. 1949.
[3] Section 2.5 of "Waveforms," Book 19 of Radiation Laboratory Series, published by McGraw-Hill.
[4] "The See-saw Circuit" by M. G. Scroggie, *Wireless World*, July 1945.
[5] "The Anode-Follower," by B. H. Briggs, *R.S.G.B. Bulletin*, March 1947.

used for bass lift and cut, omitting irrelevant details as before. In order to give level response with the potentiometer at mid-setting, and to allow the circuit to be easily combined with the treble-control circuit, R_1 and C_1 are made equal to R_2 and C_2. At middle and high frequencies the potentiometer is almost "shorted out" by the low reactances of C_1 and C_2, so that the circuit becomes almost the same as Fig. 1 with $R_{in} = R_{fb}$ and a gain of approximately unity is obtained. As the frequency is lowered, the gain gradually rises or falls towards an asymptotic level determined by the potentiometer setting; and, as with the treble-control circuit, the response curves are approximately mirror images in the 0 db line for equal potentiometer displacements either side of the level-response setting.

The amount, in decibels, by which the gain of the Fig. 5 circuit departs from unity, is given approximately by:—

$$\text{Lift, in db} = 20 \log \frac{|Z_{fb}|}{|Z_{in}|} \quad .. \quad .. \quad (6)$$

where $|Z_{in}|$ and $|Z_{fb}|$ are the moduli of the impedances between input terminal and grid and between anode and grid respectively. (Note, if an impedance calculated by means of the "j" notation comes out to $R + jX$, the modulus, or magnitude, is $\sqrt{R^2 + X^2}$; see reference (6).) Equation (6) may be used to calculate the response curves, point by point, for various potentiometer settings—a straightforward though time-consuming process! The "cross-over" effect noticeable with some of the measured bass curves shown in Fig. 8 may seem surprising at first, but it is quite genuine and equation (6) gives just the same result.

Complete Tone Control.—Fig. 6 shows the final circuit evolved, which is, effectively, a combination of the treble and bass circuits described above. There is, however, one point about the relation between Fig. 6 and the previous circuits which may need some explanation. At middle and high frequencies, where C_1 and C_2 in Fig. 6 may be regarded as short-circuiting the potentiometer P_1, the relevant part of the circuit becomes as shown in Fig. 7(a). It will be seen that the three resistors R_1, R_2 and R_3 are connected in "star" between the three points A, B and C. Now it is well known that, as far as the external circuit is concerned, three resistors in "star" are exactly equivalent to three resistors, of suitably different values, connected in "delta"[7] so that Fig. 7(a) is equivalent to Fig. 7(b). In Fig. 7(b), the presence of R_c cannot appreciably affect the frequency response, because the resistance is between two points A and B both of which have a relatively low impedance to earth (point A, since the source of input voltage is assumed to be of low impedance; and point B, because it is the output terminal of an amplifier having voltage negative feedback). Hence, ignoring R_c for the above reason, Fig. 7 (b) is equivalent to a combination of the treble lift and cut circuits of Figs. 2 and 4, and therefore Fig. 7 (a) is also equivalent to this combination. The relation between star and delta networks is such that if R_1 is made equal to R_2 in Fig. 6, which is essential for giving "mirror image" lift and cut curves, then R_a and R_b in Fig. 7 (b) are each equal to $R_1 + 2R_3$. The important practical result of this reasoning is that the treble response will be 3 db up or down, at full-lift or full-cut settings respectively, at the frequency for which the reactance of C_3 in Fig. 6 is numerically equal to $R_1 + 2R_3$.

The values of the main components in Fig. 6 were decided as follows. P_1 was fixed at 1 MΩ, this being considered the highest really desirable value for a carbon potentiometer. To give about 20 db asymptotic bass lift and cut, the nearest standard value for R_1 and R_2 was 100 kΩ. A suitable compromise for C_3 was 100 pF, on the grounds that, to obtain a result in accordance with calculation, the value should be large in relation to likely wiring strays, but that too large a value would result in an undesirably low impedance being thrown across the source of V_{in}. The value of P_2 then had to be chosen so that, with the slider half way between the centre-tap and one end the effective internal resistance of the potentiometer, regarding it as a generator feeding C_3 should be not more than, say, half the reactance of C_3 at 10 kc/s. Now the reactance of 100 pF at 10 kc/s is

[6] "'j,' What it is and How to Use it," by Cathode Ray, *Wireless World*, February 1948.

[7] "Electric Circuits and Wave Filters," by A. T. Starr, p. 80 published by Pitman.

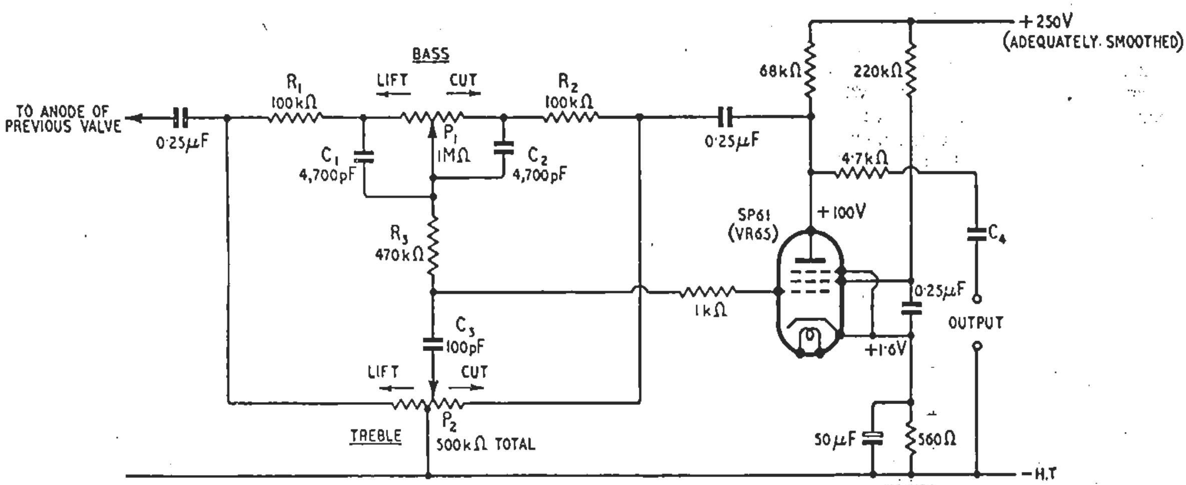


Fig. 6. The complete tone-control circuit. R_1, R_2, C_1, C_2, R_3 and C_3 should preferably be within 5 per cent of marked values. P_1 and P_2 is Dubilier Type 'C' control, 500kΩ, with fixed tapping at 50 per cent rotation. C_4 should normally be 0.05μF if following stage has 250-kΩ grid-leak.

Aerial Exchange

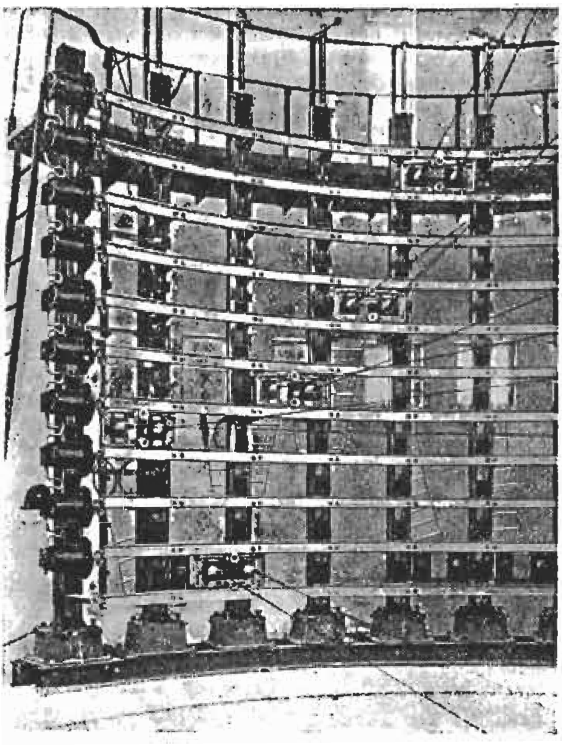
Switching on the Grand Scale for Ten Radio Transmitters and Twenty Aerials

PRACTICAL effect has recently been given at one of the Admiralty's high-power transmitting stations to a requirement calling for elaborate planning and precision engineering. This requirement was to provide a reasonably simple scheme for connecting any one of 10 radio transmitters to any one of 20 different aerial systems. Some are rhombics, others dipoles, but all have one common feature which is that 600-ohm balanced open-wire transmission lines are used.

The main problems were to provide a way of switching which would not disturb the characteristic impedance of any of the lines and to handle 25 kW of r.f. power. Changeover is not carried out with power on the lines.

The switching system is partially motorized and consists of a large semi-circular structure of 14 ft radius and some 16 ft high. This is fitted with 11 horizontal rails and between each pair is a movable carriage. Each carriage is driven by a small electric motor through flexible shafting and they can be traversed from end to end of the structure. There are 10 such carriages and their driving motors can be seen stacked on the left of the illustration.

Part of the aerial exchange switching frame. Horizontal traversing motors are stacked on the left and a few of the hand winders for the vertically moving carriages are seen round the top gallery. Aerial feeders are just visible in the background.



Similar carriages, but travelling vertically between the upright pillars, are mounted at the back of the structure. There are 20 of these and they are moved up or down by hand-operated lead-screws, the controls for which are arranged round a gallery at the top of the framework.

Each carriage, vertical and horizontal, is fitted with two large insulators having on their inner faces domed-shaped contact studs. The spacing is exactly 10-in which is the same as that of the transmission lines.

From a vertical column located at the exact centre of the system is taken a two-wire transmission line to each of the horizontally moving carriages. These lines are under spring tension and remain taut at all positions of the carriages. From this column the feeders pass into the transmitting hall and thence to the various transmitters.

Similarly, to each vertically moving carriage is brought, through a separate window in the outer wall of the building, a 600-ohm transmission line from one of the aerials; there are 20 in all and some of the lines can be seen in the illustration draped from the frame to the windows.

The method of switching is now fairly obvious, the carriage carrying a transmitter feeder is moved horizontally to the required aerial bay and that aerial's feeder carriage is moved up or down to bring the two sets of contacts into alignment. The rear set of insulators is on a sprung plate which ensures a firm and good electrical connection.

Initial planning of the system was carried out by the Admiralty Signal and Radar Establishment and the installation was engineered by P. & L. Miller, Ltd., of Heneage Street, London, E.1.

"Negative-feedback Tone Control"

OWING to an omission from the inscription to Fig. 6 of the above article in the October issue, some ambiguity has arisen regarding the law of the potentiometers P_1 and P_2, though from the curves of Fig. 8 it is implicit that they are linear. The relevant part of the inscription to Fig. 6 should read "P_1 and P_2 must both have linear elements. P_2 is Dubilier Type 'C' control, 500 kΩ, with fixed tapping at 50 per cent rotation."

The dotted curves of Fig. 8 with P_2 centre tap disconnected were measured with an input attenuator forming a return path for the grid. When the filter is fed via a capacitor (as in Fig. 6), and the modified response is required, the grid may be "tied down" to earth by a high-resistance leak, but the preferred method is to use two 330-kΩ resistors, one from the left-hand and the other from the right-hand end of P_2 to earth, the central tap being disconnected. The lower value of resistors avoids possible trouble from leaky coupling capacitors, and/or slight grid current, without appreciably affecting feedback and non-linearity distortion.