WIDE-BAND AMPLIFIERS FOR THE BIRMINGHAM — MANCHESTER TELEVISION CABLE ROUTE

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The first television link to be put into service in the U.K. was a UHF radio-relay system which was designed, manufactured and installed by The General Electric Co. Ltd. to the order of the British Post Office. This link, which brings television from London to Birmingham, was described in *G.E.C. Telecommunications* Vol. 5, No. 1 1950.

An extension of regular television service is now going ahead for the Manchester area, and the vision signals will be carried between Birmingham and Holme Moss (near Manchester) by 0.375-inch coaxial cables. For this cable system, special amplifiers are installed at repeater stations spaced at up to six-mile intervals along the route. In general, the amplifiers are similar to those already manufactured by the G.E.C. for multi-circuit speech systems over coaxial cables, and the associated supervisory and power feeding arrangements are almost identical. The transmission of television signals, however, imposes a number of additional and more severe requirements on the amplifiers, which have been manufactured by the G.E.C. to the design of the Post Office Engineering Dept.

Four amplifiers are equipped at each repeater station—one worker and one standby for each direction of transmission. Including spares, a total of 127 amplifiers has been supplied for the route. Pilot control arrangements ensure that the removal or failure of a working amplifier causes immediate change-over to the associated standby amplifier without noticeable interruption to the television programme. All intermediate repeater stations are unattended, since supervisory circuits operating over the interstice pairs of the coaxial cables enable the terminal station at either end of the cables to control the route. All faults and alarm conditions, including power failures, are remotely indicated at the terminal stations, while regulation of the cables to allow for seasonal temperature variations can be carried out by the removal or insertion by remote control of temperature equalisers at one or more of the repeater stations. Where power supplies are unreliable or difficult to obtain, 50c/s power is fed along the central conductors of the actual coaxial cables.

The Amplifier.

The frequency range of each amplifier extends from 60kc/s to just over 4.34Mc/s, and is thus suitable for a 3Mc/s video signal that has been translated into the frequency range 1-4Mc/s, and a vestigial sideband below 1Mc/s.

The gain of the amplifier has been designed on the basis of a 6-mile spacing along a 0.375-inch coaxial cable, and is finally adjusted to be equal and opposite to the loss of six miles of this cable. An additional margin of +1·7db is allowed for possible variations. The actual values of these gains and losses are shown in Fig. 1 The amplifier gain is, in fact, fixed, and should any cable section be less than six miles, cable-simulating networks associated with each amplifier can be used to build up the section to an electrical equivalent of six miles (9.6kms). The cable-simulating networks are adjustable with a minimum incremental step of 0.2 mile (0.32km), thus giving a final adjustment to within ± 0.1mile (0.16km).

While the gain of the amplifier at 4Mc/s is approximately 50db, the gain at 1Mc/s is approximately half that value. The 1Mc/s signals at the inputs to the amplifiers are therefore maintained along the route approximately 25db higher in level than the upper frequencies. The signal-to-noise ratio at 1Mc/s is thus 25db better than at the higher frequencies, and a considerable advantage is obtained since noise at the low-frequency end of the television signal has a much more pronounced visual effect than a corresponding noise level at the high-frequency end.

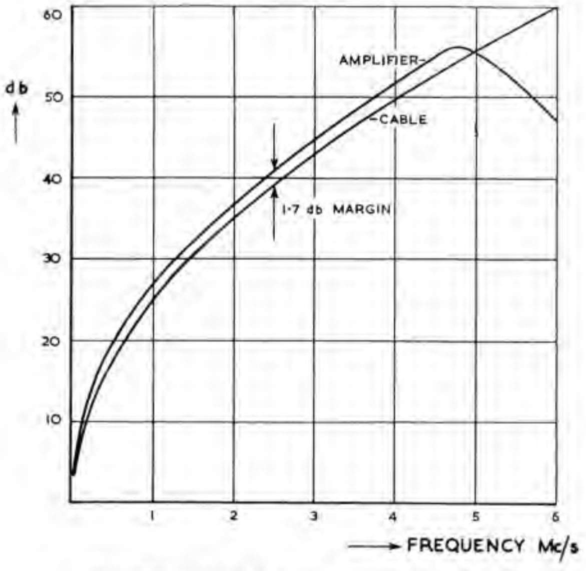

Fig. 1.—Amplifier gain/frequency and coaxial cable attenuation/frequency characteristics.

The input and output impedances of the amplifier are maintained above a return loss of 20db with respect to the cable impedances. This return loss is of extreme importance in the design of television transmission systems since reflection at the input and output would correspond to phase distortion of the television signals. Special circuits are used to minimise this effect, and the latest methods of *insertion loss* design have been employed to achieve this result. An outline of these methods is given in *Appendix A*.

The gain/frequency characteristic of the amplifier matches the loss/frequency characteristic of the line to within ± 0.1db. All the amplifiers along a route have sensibly the same characteristic so that when one or more working amplifiers are removed from circuit and replaced by standby amplifiers, the overall gain/frequency characteristic remains sensibly unchanged. To achieve this uniformity of performance, all amplifiers were tested and adjusted on identical test bays, which are sensitive to attenuation changes of 0.01db. One of the major problems in the manufacture and production of the amplifier was thus successfully solved.

The stability of the amplifier, achieved in design by the application of negative feedback, is such that for normal temperature and battery variations the changes in performance do not exceed approximately 0.01db. The production of harmonics in the amplifier is also of a very low order , under working conditions the harmonics of the 1Mc/s carrier are well below —80db with respect to the carrier level.

A block schematic of the amplifier is shown in Fig. 2. A constant-resistance equaliser section at the input of the amplifier gives a small amount of correction to the amplifier characteristic, mainly between 60kc/s and 300kc/s. This section is terminated by the input transformer which, together with an additional coil and capacitors, forms a two-section low-pass filter to comply with the impedance and insertion-loss requirements. A three-valve amplifier follows this filter, and has feedback circuits such that the gain/frequency characteristic of these three valve-stages follows the same slope as the coaxial-cable attenuation/

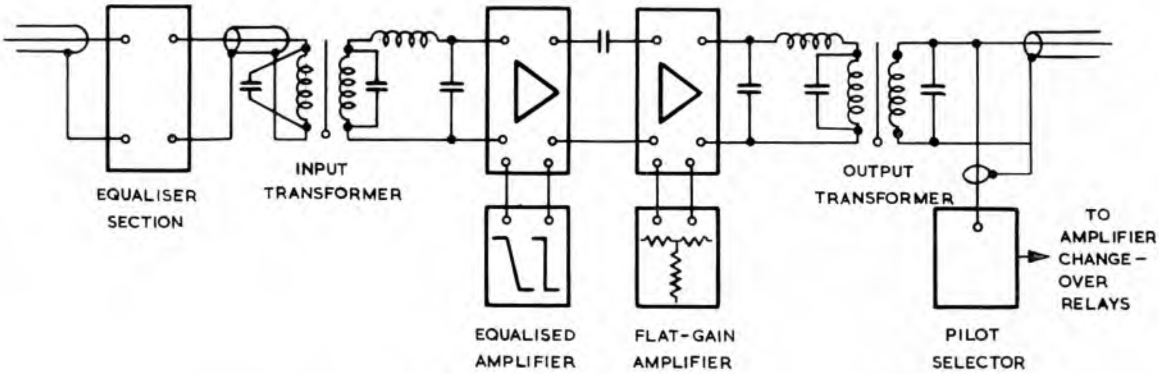

Fig. 2.—Block schematic of amplifier.

frequency characteristic. A small coupling capacitor connects this equalised amplifier to a *flat-gain* amplifier of three valve-stages, which is terminated by an output transformer Associated capacitors and a coil enable this transformer to be designed on the same principles as the input transformer A selector unit tapped across the output of the complete amplifier taps off some of a 308kc/s pilot for operating amplifier change-over relays.

The input valve to each of the amplifiers within the complete amplifier is a special low-capacitance Osram triode CV408. The output valves are CV173, while the remaining valves are type Z77, (CV138).

To keep noise and other faults to a minimum, all valves used in the amplifier are soldered directly into circuit. Special valve-holders of polytetrafluorethylene make possible these soldered connexions and also minimise the effects of stray capacitances.

For ease of maintenance, the complete amplifier (Fig. 3) can be readily removed from its panel by turning four captive fasteners and withdrawing connecting plugs. Good amplifiers can thereby be easily substituted for faulty ones at unattended repeater stations, and repairs need not be carried out at these stations.

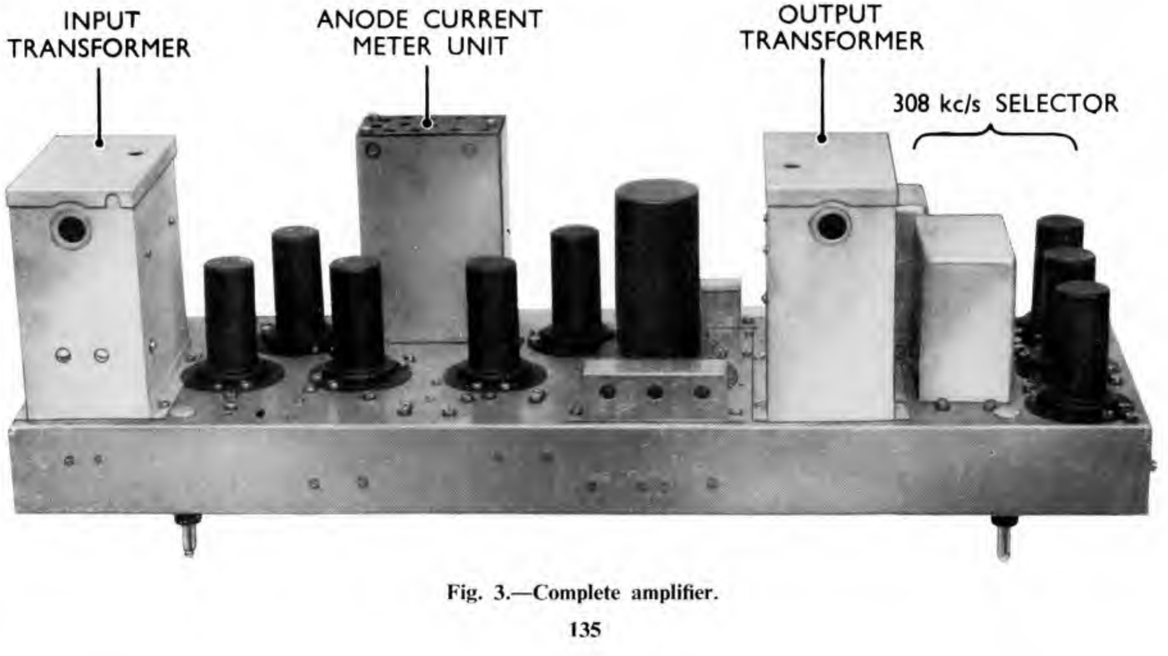

Fig. 3.—Complete amplifier.

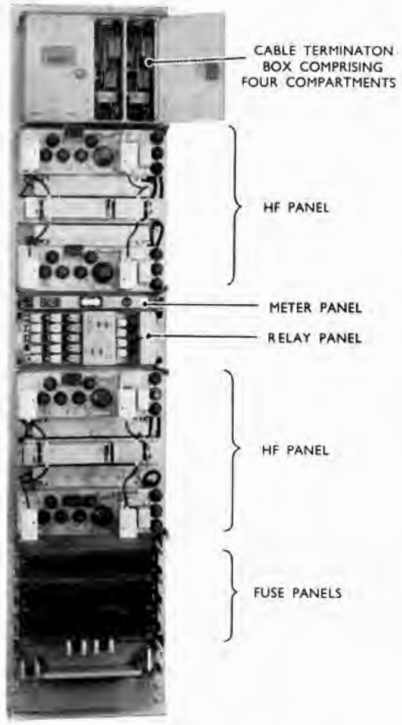

Fig. 4.—Repeater station bay—front view.

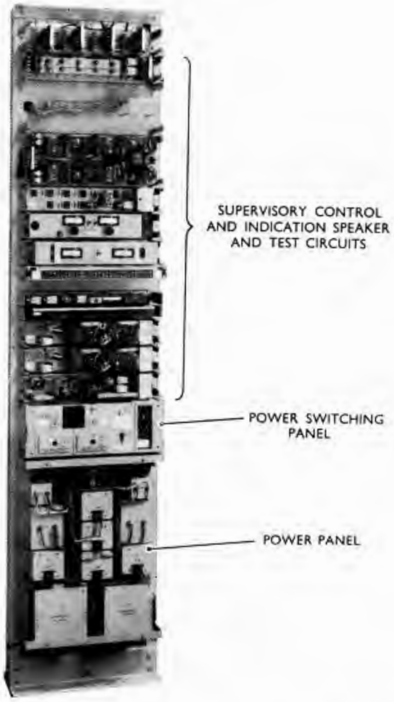

Fig. 5.—Repeater station bay—rear view.

Repeater Station.

All the equipment at a repeater station is mounted on a 7′ 6″ bay, (Figs. 4 and 5). A cable termination box at the top of the bay comprises four compartments, two for the *transmit* cable and two for the *receive* cable. Fitted on the front of the bay are two HF panels, one for each cable. A working and a standby amplifier are mounted on each HF panel, which also accommodates two sets of cable simulators, a temperature equaliser, input and output coaxial U-links, and change-over and control relays, (Fig. 6). The remainder of the equipment on the bay consists of supervisory control and indication circuits, speaker circuits, and a power supply panel.

An outline of the connexions of a repeater station is shown for one direction of transmission in Fig. 7 The cable termination box includes, in addition to the actual cable terminating equipment, two filters for separating 50c/s power from the television signals when a power supply is not obtained locally. From the cable termination box, the signals pass through the input coaxial U-link on the HF panel. This U-link is provided to facilitate initial lining-up, and is strapped out under normal working conditions. The temperature equaliser is connected to the U-link, and can be switched in or out of circuit by relay contacts. The signals next pass to one or other of the cable simulating networks and amplifiers depending on the position of the change-over contacts of relays that are operated by the 308kc/s selector Complementary relay contacts on the outputs of the amplifiers connect the appropriate amplifier to line and the other to a 75-ohm closing resistor A U-link and filters in the second cable termination box complete the circuit.

To guard against false operation of the change-over relays due to failure of the pilot rather than to failure of an amplifier, an additional set of relays is provided. On failure of the pilot, contacts SA open and the standby amplifier is switched into use

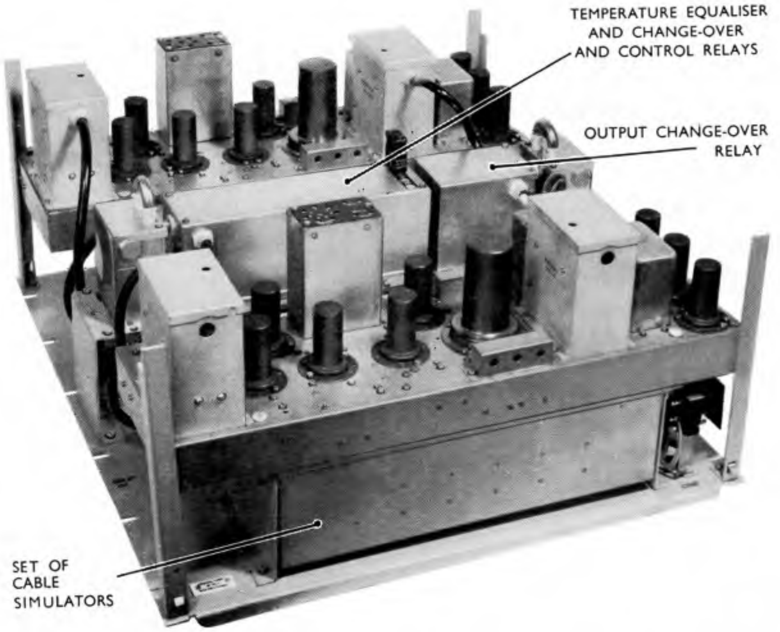

Fig. 6.—HF panel.

by the change-over contacts SB and SC. If the pilot does not appear at the output of the second amplifier, these additional relays release, leave the cable connected to the original amplifier, and lock the circuit until the pilot re-appears.

Simulating Networks.

Four cable-simulating networks are provided for each amplifier. The networks simulate 0.2, 0.4, 0.8 and 1.6 miles of cable respectively, and

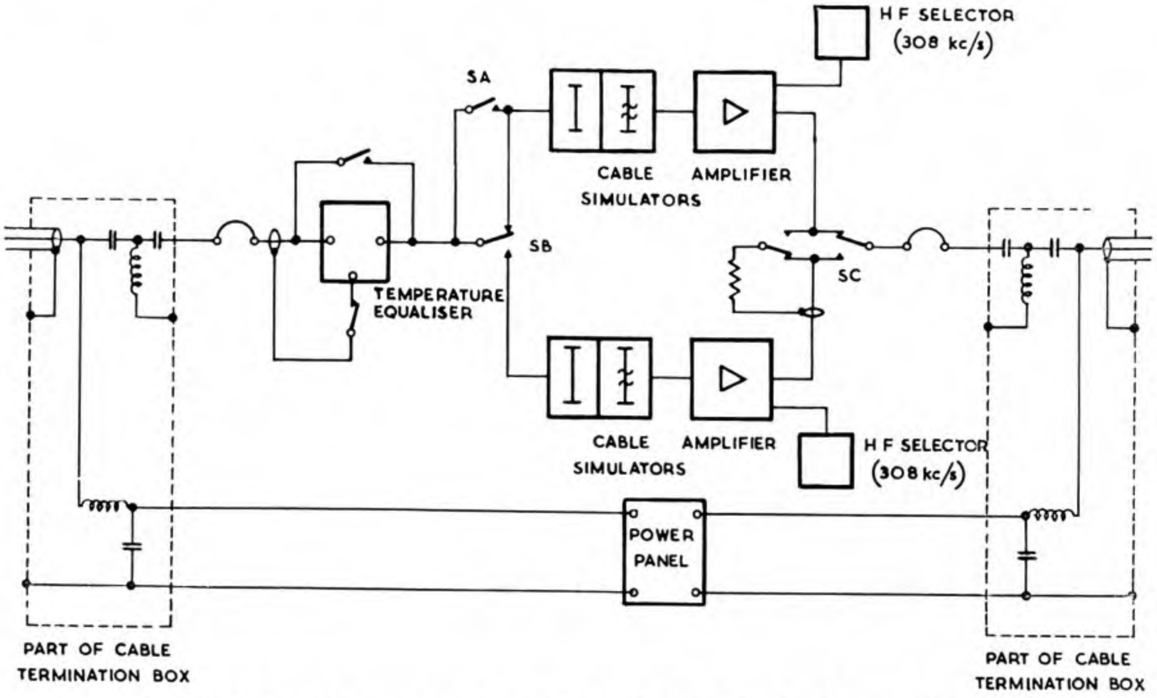

Fig. 7.—Outline of connexions at a repeater station—one direction of transmission only.

Fig. 8.—Cable-simulating network.

enable any length of cable between three and six miles to be built out to the required length of six miles to within ±0.1 mile. The mechanical construction of the networks, which are of constant resistance, is shown for a typical unit in Fig. 8.

Temperature Equalisers.

The maximum variation of cable attenuation between summer and winter temperatures is approximately 5% of the total cable-attenuation. Networks simulating 0.3 miles of cable are provided and can be switched in or out of circuit as required either by movement of U-links at the appropriate stations or by remote control from a terminal station.

Pilot Frequencies.

Two pilot frequencies of 308kc/s and 4.340Mc/s are employed in the system. The 308kc/s pilot appears at the output of each working amplifier, where it is fed into a selector circuit for operating the amplifier change-over relays. Failure of this pilot due to failure of an amplifier causes change over to the standby amplifier (see *Repeater Station*). At the far end of the cable route, the 308kc/s pilot is used to give a continuous indication of the loss of the route at 308kc/s. Alternatively it can operate an automatic-gain amplifier to maintain a constant output level at this frequency The 4.340Mc/s pilot is used to maintain a continuous indication of the 4.340Mc/s level. When this level changes by more than 1.3db, one of the temperature equalisers at the repeater stations is switched in or out of circuit as required by remote control.

Supervisory Circuits.

The supervisory circuits associated with the television cable route enable the following functions to be carried out :—

(*a*) The control terminal station can substitute the standby for a working amplifier at any repeater station on the route. The supervisory system indicates at the control station which of the two amplifiers is in circuit at any time.

(*b*) The control terminal station can switch into or out of circuit any of the temperature equalisers at any repeater station, and again an indication of the equalisers in circuit is returned to the control station.

(*c*) An indication or alarm is sent to the control station if an amplifier change-over occurs automatically

(*d*) An indication is given at the control station if a power supply fails at a repeater station.

A speaker and ringer circuit is included in addition to the supervisory circuits. Other pairs in the cable provide cable fault location and also can be made to give a check on the temperature of the cable.

Appendix A.

To maintain a high value of return loss for the input and output impedances of the amplifier, both the input and output transformers have been designed as part of the two-section filter shown in Fig. 9. An inspection of this circuit shows that the self-capacitance of the windings of the transformer, represented by part of C1 and C2, have been separated from the valve capacitance which is part of C3. The leakage inductance of the transformer is represented by L1, while L2 is a separate coil added to the circuit. By using modern methods of *insertion loss* design, higher values of leakage inductance and self-capacitance in the transformers can be tolerated while maintaining the required value of singing point. A brief outline of the steps involved in the design is given below :—

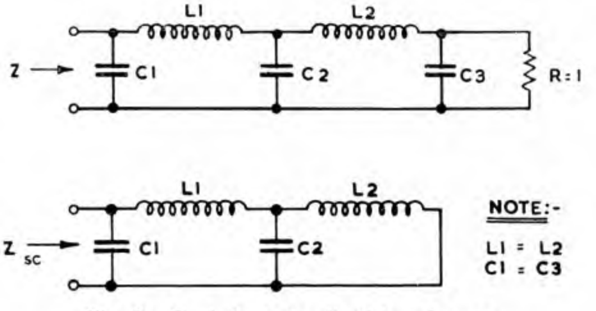

Fig. 9.—Equivalent circuit of transformer.

Let Z be the input impedance of the circuit that is to be matched to a pure resistor R. For this treatment, R can be made equal to unity

Then if $\propto$ is the singing point or return loss in nepers,

$$e^{\propto} = \left|\frac{1+Z}{1-Z}\right| \tag{1}$$

In the general case of a passive network of n meshes in which R is part of the $n^{th\cdot}$ mesh and of no other mesh,

$$Z = \frac{D^*}{B^*_{11}} = \frac{D' + B'_{nn}}{B'_{11} + B'_{11nn}} \tag{2}$$

where Z is the impedance seen by a generator in mesh 1,

D^* is the network determinant for R = 1,

B^*_{11} is the cofactor of its first row and column, etc.,

D' is the network determinant for R = O,

B'_{11} is the corresponding cofactor, etc.

Therefore

$$\frac{1+Z}{1-Z} = \frac{B'_{11} + B'_{11nn} + D' + B'_{nn}}{B'_{11} + B'_{11nn} - D' - B'_{nn}} \tag{3}$$

The elements of D', B'_{11}, etc. are of the form $pL_{ij} + p^{-1}S_{ij}$ where $p = \lambda + i\omega$ and corresponds to a complex frequency given by

$$\frac{\lambda + i\omega}{2\pi}$$

By making the substitutions

$$\left.\begin{aligned} p^nD' &= D \\ p^{n-1}B'_{11} &= B_{11} \\ p^{n-2}B'_{11nn} &= B_{11nn} \text{ etc.} \end{aligned}\right\} \tag{4}$$

where D, B_{11} and B_{11nn} are even polynomials in p with powers 2n to zero, 2(n—1) to zero and 2(n—2) to zero respectively,

$$\text{then } \frac{1+Z}{1-Z} = \frac{pB_{II} + p^2B_{IInn} + D + pB_{nn}}{pB_{II} + p^2B_{IInn} \quad D - pB_{nn}} \tag{5}$$

If the frequencies for which $\propto$ is infinity are made real, then B_{II} can be shown to equal B_{nn} , i.e. the circuit is electrically symmetrical.

Also, using the known identity

$$DB_{IInn} = B_{II}B_{nn} - B_{In}^2,$$

the expression for $e^{2\propto}$ can be reduced to

$$e^{2\propto} = 1 - \left\{ \frac{2pB_{In}}{p^2B_{IInn} - D} \right\}^2 \tag{6}$$

If the values of B_{In}, B_{IInn} and D are inserted for the circuit under consideration, this expression reduces to

$$e^{2\propto} = 1 + \left\{ \frac{A}{\omega(\omega^2-\omega_1^2)\ (\omega^2-\omega_2^2)} \right\}^2 \tag{7}$$

where A is a constant.

The problem now to be solved is the finding of values for ω_1 and ω_2 such that $\propto$ is equal to or greater than the chosen value for singing point. This value, say $\propto_{\text{min.}}$, represents the maximum deviation of the singing point from the ideal value of infinity

According to the Tchebycheff parameter theory, the maximum deviation of $\propto$ from infinity will be at minimum when all the maximum deviations are equal.

$$\text{If } e^{2\propto} = 1 + \left\{ \frac{A}{f(\omega)} \right\}^2 \tag{8}$$

$$\text{where } f(\omega) = \omega(\omega^2-\omega_1^2)\ (\omega^2-\omega_2^2) \tag{9}$$

$$\text{then also } f(\omega) = \pm \frac{A}{\sqrt{e^{2\propto} \quad 1}} \ . \tag{10}$$

If $\propto$ varies from infinity to $\propto_{\text{min.}}$, a sine function for $f(\omega)$ fulfills the equal deviation condition.

If $f_3 \left\{ = \frac{\omega_3}{2\pi} \right\}$ is made the maximum frequency of the band under consideration, then

$$f(\omega_3) \ll \pm \frac{A}{\sqrt{e^{2\propto\,\text{min.}} - 1}} \tag{11}$$

By making the following substitutions :—

$$\begin{aligned} \omega &= \omega_3 \sin U \\ \omega_1 &= \omega_3 \sin \frac{\pi}{5} \quad .. \\ \omega_2 &= \omega_3 \sin \frac{2\pi}{5} \end{aligned} \tag{12}$$

the equation becomes

$$f(\omega) = \frac{\omega_3^5}{16} \sin 5U \quad .. \qquad .. \tag{13}$$

which is of the required form.

$$e^{2\alpha} \text{ now equals } 1 + \frac{C}{\sin^2 5U}$$

from which

$$C = e^{2\alpha\,\text{min.}} - 1 \qquad (14)$$

$$\text{But } e^{2\alpha} = \frac{\sin^2 5U + C}{\sin^2 5U} = \frac{N(p^2)}{\sin^2 5U} = \left\{\frac{1 + Z}{1 \quad Z}\right\}\left\{\overline{\frac{1 + Z}{1 - Z}}\right\} \quad .. \quad (15)$$

where $N(p^2)$ is of the form $(p^2 - p_a^2)(p^2 - p_b^2)(p^2 - p_c^2)(p^2 \quad p_d^2)(p^2 - p_e^2)$

The roots of the equation $\sin^2 5U + C = 0$ are given by

$$U = \pm \frac{i}{5} \sinh^{-1} \sqrt{C} \qquad (16)$$

$$\text{From } \frac{i}{5} \sinh^{-1} \sqrt{C} = U_o \qquad (17)$$

$$\text{are derived the solutions } U = \pm iU_o$$

$$U = \pm iU_o \pm \frac{\pi}{5} \qquad (18)$$

$$\text{and } U = \pm iU_o \pm \frac{2\pi}{5}$$

and since $p = i\omega_3 \sin U$, the following values of p_a —— p_e result :—

$$\begin{aligned}
p_a &= -\omega_3 \sinh U_o \\
p_b &= -\omega_3 \sinh \left(U_o + \frac{i\pi}{5}\right) \\
p_c &= -\omega_3 \sinh \left(U_o - \frac{i\pi}{5}\right) \qquad (19) \\
p_d &= -\omega_3 \sinh \left(U_o + \frac{i2\pi}{5}\right) \\
p_e &= -\omega_3 \sinh \left(U_o - \frac{i2\pi}{5}\right)
\end{aligned}$$

By examining the relations between the two equations (6) and (15), i.e.

$$\frac{1 + Z}{1 - Z} = \frac{2pB_{\mathrm{II}} + p^2 B_{\mathrm{IInn}} + D}{p^2 B_{\mathrm{IInn}} - D}$$

$$= \frac{p\,(p - p_a)(p - p_b)(p - p_c)(p - p_d)(p - p_e)}{p^2\,(p^2 - p_1^2)\,(p^2 - p_2^2)}$$

the deduction can be made that

$$Z_{sc} = \frac{D}{pB_{\mathrm{II}}} = \frac{p(Ap^2 + B)}{C' p^4 + D' p^2 + E}$$

where Z_{sc} is the impedance of the network with the far end short-circuited, and

$$A = \omega_3^2 2S^2 \left(1 + 2\cos\frac{\pi}{5}\right)$$

$$B = \omega_3^4 S^2 \left(4S^2\cos\frac{\pi}{5} + 3\cos\frac{\pi}{5} + \frac{1}{2}\right)$$

$$C' = \omega_3\, 4S\cos\frac{\pi}{5}$$

$$D' = \omega_3^3 S\left(4S^2\cos\frac{\pi}{5} + 2S^2 + 3\cos\frac{\pi}{5} + \frac{1}{2}\right)$$

$$E = \omega_3^5 S\left(\frac{5}{16} + \frac{5S^2}{4} + S^4\right)$$

where $S = \sinh U_o$

Inspection of Fig. 9 shows that when $\omega \to 0$, $Z_{sc} \to 2L_1$. But when $\omega \to 0$, $Z_{sc} i\omega \to \frac{B}{E}$, so that

$$L_1 = \frac{S\left(32S^2\cos\frac{\pi}{5} + 24\cos\frac{\pi}{5} + 4\right)}{\omega_3(16S^4 + 20S^2 + 5)}$$

Similarly, when $\omega \to \infty$

$$Z_{sc} \to \quad \frac{iA}{\omega C'} = \frac{-i}{\omega C_1}$$

so that

$$C_1 = \frac{2\cos\frac{\pi}{5}}{\omega_3 S\left(1 + 2\cos\frac{\pi}{5}\right)}$$

By removing C_1 from Z_{sc}, C_2 is found to equal the following expression :—

$$C_2 = \frac{1}{\omega_3 S}\left\{2 - \frac{8\cos\frac{\pi}{5} + 3}{S^2\left(2 + 8\cos\frac{\pi}{5}\right) + 7\cos\frac{\pi}{5} + 2}\right\}$$

All the components of the network are thus determined.