R. F. O'NEILL, B.Sc (Eng)

THE AERIAL AND FEEDER SYSTEM AT ALEXANDRA PALACE 1936

WITH THE INTRODUCTION of the Marconi–E.M.I high-definition television system the design of the aerials and feeders presented a number of problems not encountered in short-wave telegraph or telephone transmission.

The pictures transmitted with the Marconi–E.M.I System, of 405 lines, 50 frames per second, involved modulation frequencies of the order of 2·5 Mc/s, equivalent to a bandwidth of 5 Mc/s for the modulated signal. With a vision carrier frequency of 45 Mc/s, the double-sideband spectrum of 5 Mc/s represents a bandwidth of 11%, as compared with a bandwidth of approximately 0·02% for telephony transmission on the same carrier frequency.

In the interests of good picture reception, the waveforms generated in the camera during the process of scanning must be reproduced as sideband frequencies with a minimum amplitude or phase distortion, and to satisfy this requirement, the aerial and feeder, which constitute the transmitter load, should appear at the transmitter as a pure resistance. The importance of this was recognized at the outset, but its fuller implications only became clear in the course of experimental work.

Two further conditions had to be satisfied:

(a) The aerial impedance must be made to match accurately the characteristic impedance of the feeder over the sideband range. The necessity for satisfying this requirement arises from the fact that if the aerial impedance does not closely match that of the feeder, a form of picture distortion can occur due to waves arriving at the aerial being reflected back along the feeder to the transmitter and thence back again to the aerial. Since the length of feeder at Alexandra Palace was some 450 ft, the time taken for the double excursion was approximately one microsecond. During this time the scanning spot on the picture tube will have travelled a distance of about five line-widths in the horizontal direction, with the result that a vertical line in the picture will be followed by a second vertical line, thereby producing a relief effect in the picture.

(b) The feeder itself, when correctly terminated, must also appear as a constant pure resistance at the transmitter, and any inherent causes of irregularity must be removed or corrected. This condition will be considered more fully later in discussing the feeder system.

THE AERIAL SYSTEM

Separate aerials were used for the 45 Mc/s vision frequency and 41·5 Mc/s sound frequency.

The essential requirements which the aerials had to fulfil were that they should have maximum range, and should radiate with minimum distortion the picture waveforms from the transmitter. To ensure maximum range it was proposed:

(a) The aerials should be directional, concentrating as much energy as possible in the horizontal plane whilst radiating a uniformly circular field.

(b) Vertically polarized waves should be used, as earlier work had shown that they give a much greater field strength near ground level at and beyond the optical range than horizontally polarized waves.

(c) To minimize attenuation, the largest available size of feeder should be used.

A third requirement, in common with the rest of the station equipment, was that of reliability, since it had to perform a public service. This implied that the aerials should be of substantial construction and with reasonable access for servicing.

The aerial mast was a 100-ft octagonal self-supporting lattice steel tower, 7 ft between parallel faces. This tower rested on a lattice steel truncated pyramid having a base-width of 30 ft, and tapering to 7 ft 7 in. at a height of 100 ft. An ingenious system of connecting these sections obviated the necessity for guy-ropes on the upper section carrying the aerial. This composite mast was erected on one of the 80-ft corner towers of the Alexandra Palace building, giving an overall mast height of 300 ft. Since the building stands on a hill some 320 ft above sea-level, the effective aerial height was about 600 ft. Suitable ladders and platforms were incorporated in the towers to afford access to the aerials and feeders.

The aerials were designed by C. S. Franklin, well known in connection with the earlier Marconi–Franklin beam aerials, whilst the matching and feeder systems were designed by a joint team of Marconi and E.M.I engineers.

Separate aerials were provided for vision and sound, rather than a common aerial and diplexer, which would only have further complicated the problem.

The requirements of circular coverage were met by arranging, for vision and sound respectively, eight vertical aerials in the form of a ring around the mast, the vision aerial being uppermost. Each aerial unit comprised a reflector spaced approximately one quarter wavelength from one face of the mast, and an aerial a further quarter wavelength beyond the reflector. Adjacent pairs of aerial units were fed in parallel from a four-way distribution box, located within the mast, from which four trunks spaced 90° apart extended outwards to slightly beyond the mast bracing. At the end of each trunk were mounted two pyrex insulators in a vertical line for connection to the aerial units. The distribution box was divided into two compartments, in each of which was mounted centrally a frequentite insulator carrying a brass cap. These caps were connected by copper tubes to the pyrex insulators, and also connected together by a half-wavelength phase-reversing loop of copper tube feeder protruding from one side. The upper cap was connected, through the top of the upper box, to the concentric feeder from the transmitter.

The aerials and reflectors were full-wave cage dipoles consisting of three wires at the corners of an equilateral triangle. They were suspended between horizontal wooden arms hinged to the mast. The upper arm was supported from the mast by wire stays, whilst the lower arm was carried by the aerials themselves, thus serving to keep the aerials taut.

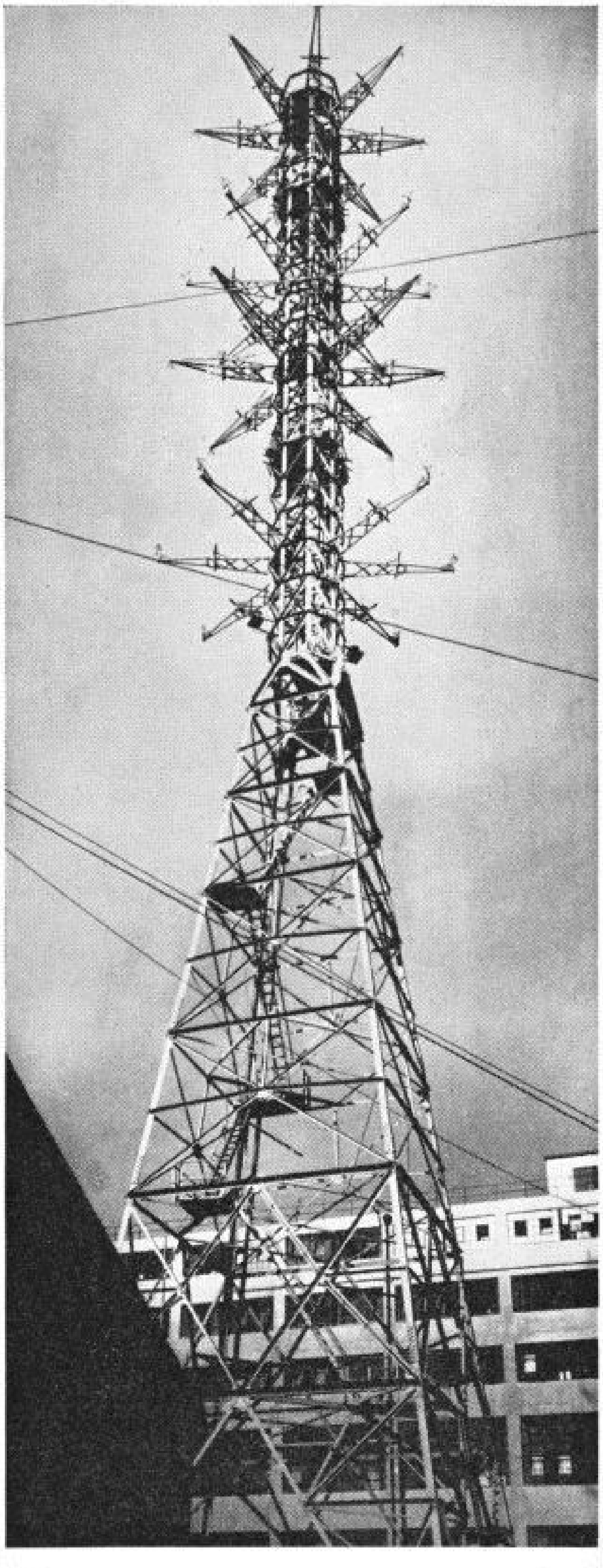

Fig. 1. The tower set up at Hayes on which tests and measurements were made on the aerials and feeders prior to erection at Alexandra Palace.

A great deal of experimental work was carried out to determine the optimum dimensions of the aerials and reflectors; and for this purpose a 55-ft replica of the upper mast was erected at the Marconi Company's Research Station at Chelmsford, together with the aerial supporting arms, distribution trunk, and half-wave loop to transform from the unbalanced power feeder to the balanced aerials. (Fig. 2.)

MEASURING APPARATUS

A 120-watt transmitter, field-strength measuring set and impedance meter were constructed. In the lack, at that time, of RF bridge-type equipment for measurement at 45 Mc/s, a shunted tuned-circuit was used for impedance measurements, in which the aerial resistance was compared with known resistors, and the reactance deduced from the change in value of a calibrated tuning condenser, required to maintain resonance with and without the parallel loading of the aerial system. Comparison between the aerial and resistor was effected by a simple change-over switch to which connection was made through mercury cups. All measurements were made at the input feeder-connection point of the distribution box.

The use of cage-type elements was decided upon in order to reduce the changes in resistive and reactive components of the aerials and reflectors over the frequency band since this arrangement, as compared with a single wire, has the effect of reducing the self-inductance and correspondingly increasing the self-capacity, thus leading to a reduction of characteristic impedance.

The reflectors were spaced one quarter wave-length behind the aerials, and though primarily intended to give a directional polar diagram, they also had a marked influence on the aerial impedance.

Successive measurements were made, initially on a single aerial-reflector unit, to achieve the minimum impedance variation over the band, and arising from these measurements it was decided to construct the aerials of length $0{\cdot}77\frac{\lambda}{2}$ on either side of centre, on a 15-in. triangle, and the reflectors of length $1{\cdot}08\frac{\lambda}{2}$ on a 9-in. triangle, and to feed them together from a pair of wires spaced 2 ft apart.

In the meantime, a full-scale version of the Alexandra Palace 200-ft mast had been built at the E.M.I Research Establishment at Hayes, Middlesex, upon which the aerial was erected for further work on matching it to the feeder to the accuracy required. (Fig. 1.)

Measurements taken at 43 Mc/s and 45 Mc/s and 47 Mc/s respectively showed resistance values of 23·3,

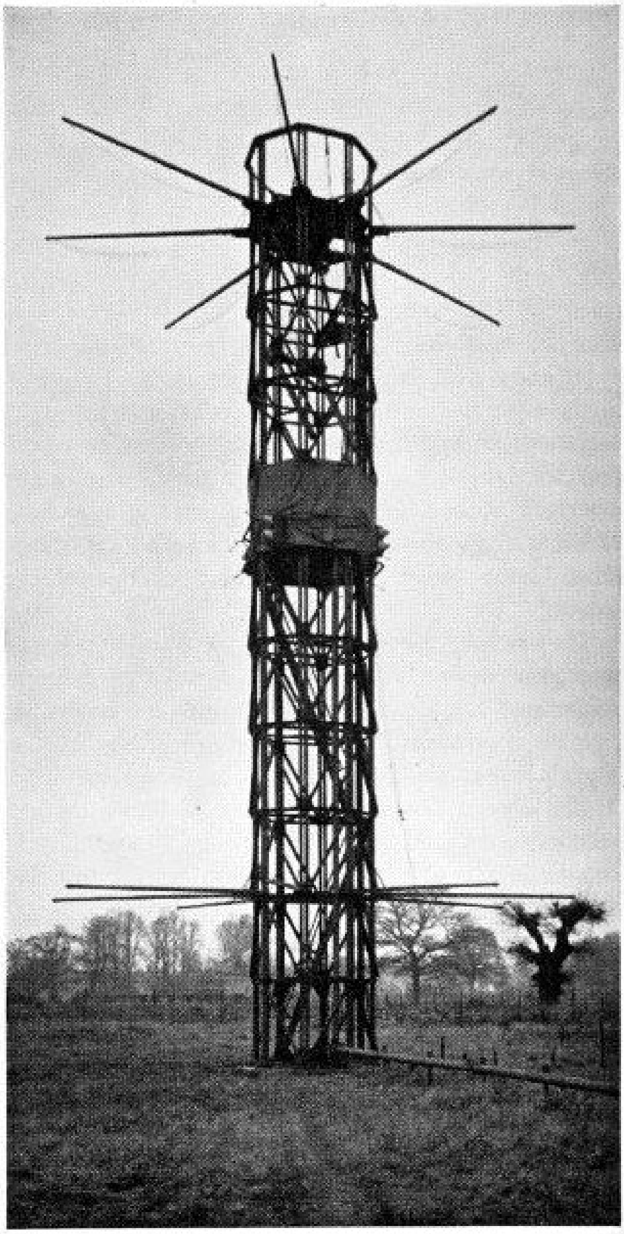

Fig. 2. The replica of the upper mast at Marconi's Research Station used to determine the optimum dimensions of the aerials and reflectors.

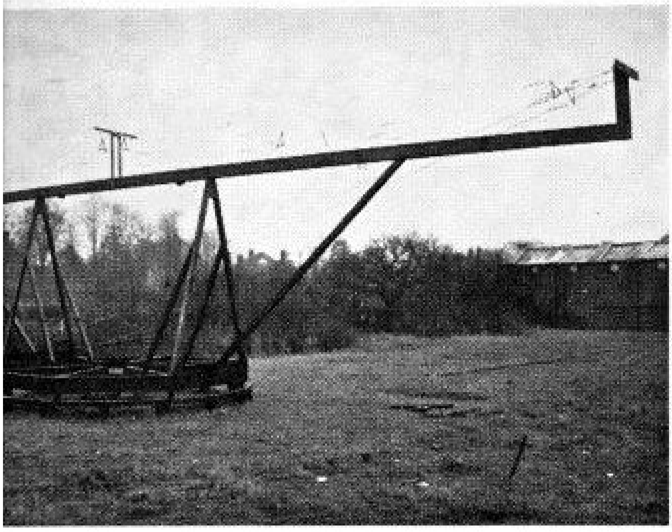

Fig. 3. The rig set up at Marconi's Research Station to determine field strength of various experimental aerials.

24·2 and 22·0 ohms, and positive reactance values of 9, 6·5 and 5·3 ohms. These values showed a reduction in the reactance obtained on the first experimental aerial and were achieved by a slight decrease in the reflector lengths, but approached more closely the preferred values which a study of the matching problem suggested would render the aerial impedance amenable to overall transformation to that of the feeder.

The first step was to transform the aerial impedance from approximately 20 ohms to a resistive value at midband of 75 ohms by means of a 42-ohm concentric line of a nominal quarter-wavelength but in fact slightly less to allow for the 6·5-ohm reactance value. The reactance values at the outer frequencies were then such as to compensate for the electrical variation in transformer length so as to give purely resistive values of 81, 75 and 81 ohms respectively.

The next step was to reduce this resistance variation of 6 ohms, by making use of a unique property of an eight-wave line, the input impedance of which is always equal to the characteristic impedance modulus of the line, irrespective of the nature of the load, but its phase angle depends upon the load impedance. If then a point is found on the feeder of such a distance beyond the end of the quarter-wave transformer such that its electrical lengths at 43 Mc/s and 47 Mc/s are respectively one-eighth less and one-eighth greater than at 45 Mc/s, the impedance at the point will be equal to that of the feeder. Such a point occurs at a distance of 61 ft past the transformer, equivalent to 22 eighth waves at 45 Mc/s. Measurements taken at this point gave impedance values of 75 ohms, purely resistive at midband, but with a small negative reactance at 43 Mc/s and an equal but positive reactance at 47 Mc/s.

The final step was to reduce this reactance by a parallel circuit, resonant at 45 Mc/s, across the feeder at this point. The form of tuned circuit was conveniently provided by inserting a transverse quarter-wavelength feeder, of which one end was shorted and the other end open, but both ends capable of adjustment. This correction did effect a reduction of the residual reactance.

The aerial matching procedure has been described with respect to the experimental aerial. However, the same sequence of matching was employed on the installation at Alexandra Palace, except that a 78-ohm feeder was used in place of the 75-ohm feeder used at Hayes. The final measurements showed a substantially constant resistive value over the frequency band, with no sign of distortion or echo effects from the transmitted picture.

THE FEEDER SYSTEM[1]

The importance has been stressed of accurately matching the aerial to the feeder to avoid reflections, but it has so far been assumed that the feeder is itself distortionless. This could be so only if the inner and outer conductors were truly concentric throughout their length and free from supporting spacers between them. However, these spacers must be provided, and that they could have a serious effect on the feeder impedance only came to be realized quantitatively during the course of the experimental work.

The feeder originally installed at Hayes was the standard Marconi Beam system type comprising two concentric high-conductivity copper tubes, the outer of 5 in. and inner of 1⅜ in. diameter giving a characteristic impedance of 78 ohms. The inner conductors were supported by heavy porcelain insulators spaced sufficiently apart to prevent sagging. Since these insulators behaved as capacities across the feeder they constituted a reactance in shunt with the feeder impedance, of about 700 ohms, and a succession of such shunt reactances gave rise to serious fluctuations in the feeder impedance.

The most serious condition arises in general when the insulators are spaced at intervals of one-half wavelength, for then their capacities become cumulative and their susceptance becomes progressively smaller. The least serious condition, on the other hand, occurs with a quarter-wave spacing since, by quarter-wave inversion, the net reactance of each pair of insulators will be zero and the end-effect of a series of insulators will be the reactance due to one only.

Another and obvious means of reducing this insulator effect is by the use of lower capacity insulators. This was in fact done, the large porcelain funnel type with a capacity of 5 pf being replaced by $\frac{3}{8}$-in. diameter steatite rods passing through the inner conductor and located by steatite sleeves. The capacity of one insulator was thus reduced to less than 0·5 pf. Each successive spacer was fitted at right-angles to the previous one.

Although the optimum spacing of insulators is a quarter-wavelength, this was not practicable at 45 Mc/s, since such a spacing, 5 ft $5\frac{1}{2}$ in., was considered to be too great, leading to possible sagging of the inner conductor. This in turn would also introduce impedance irregularities which could not be corrected. It can be shown that cancellation takes place also at eighth waves, in fact this spacing is approaching the value which Pupin deduced, though in a different context, of ten series loading coils per wavelength to produce the distortionless line.

To cater for corner bends in the feeders, angle boxes were fitted containing a large conical insulator for anchoring the inner conductor. The size of box leads to a shortage of capacity which is not wholly made up by the supporting insulator. The shortage of capacity was compensated for by a single plate condenser fitted in the angle box and adjusted during installation. (Fig. 5.)

In any length of feeder exceeding about 20 ft provision was made to take up changes in length of the tubes due to temperature variations. This consisted of cutting the feeders, and inserting a short sliding section sweated to one part and free to slide in the other. A gap was left between the two cut ends sufficient to take up the greatest expected variation. These expansion joints introduced an impedance change and were generally fitted adjacent to an angle box in the hope that both irregularities could be corrected by the angle box condenser. Otherwise an additional condenser was fitted to the joint.

As a precaution against the effects of moisture within the feeders, a heavy current drying-out transformer was fitted which could be clipped across the feeder at the transmitter end.

Measurements were made by the comparison method already mentioned and a similar type of impedance meter was made, capable of attachment

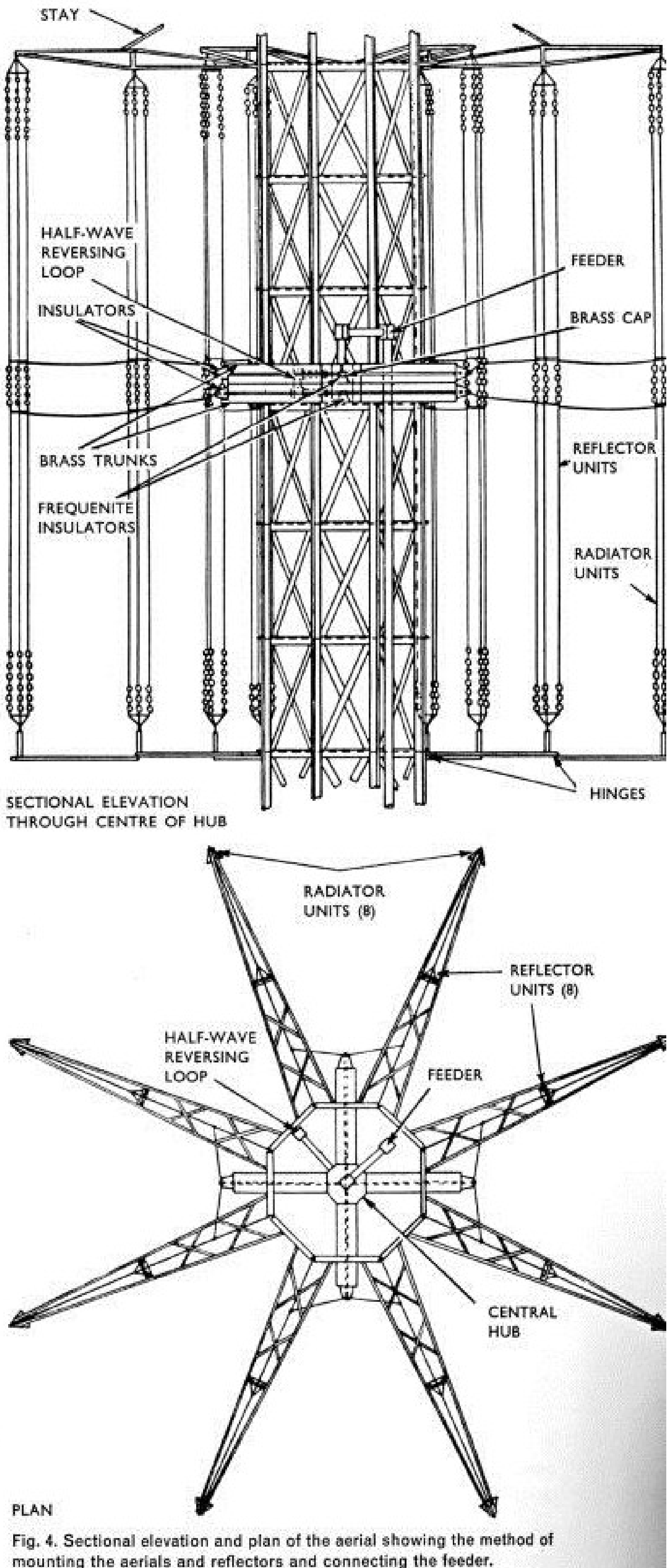

Fig. 4. Sectional elevation and plan of the aerial showing the method of mounting the aerials and reflectors and connecting the feeder.

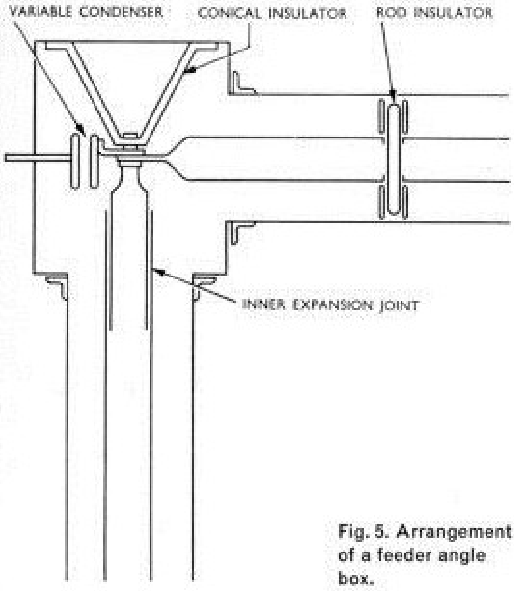

Fig. 5. Arrangement of a feeder angle box.

directly on to the outer tube, whilst the inner dipped into a mercury cup. Since aerial and feeder measurements were taking place concurrently, a terminating resistance was provided to connect across the end of the feeder. This termination was housed in a short length of feeder and a bank of resistors mounted between inner and outer tubes. To tune out the positive reactance of the resistors a small variable plate condenser was fitted. By a suitable combination of resistors and by adjustment of the variable capacity a matching accuracy of 0·2% could be achieved.

All measurements were taken from the transmitter end of the feeder. At each angle box, expansion joint, or other probable sources of irregularity, a fresh set of measurements was made and any necessary corrections made before erecting any further feeder length. Resistance measurements were made over the frequency band and the presence of a fault indicated by a periodic resistance fluctuation which could be corrected by adjustment of the appropriate condenser.

The feeder system was gradually extended in this way to meet the aerial correction cross already referred to, at which point the resistance varied by not more than 1 ohm.

When connected to the aerial feeder system the overall resistance variation was not greater than plus or minus 5 ohms.

The wide-band correction necessary on the vision feeder was not required on the sound feeder, since the bandwidth is of the order of only some 20 Kc/s, and measurements were made only at the sound frequency of 41·5 Mc/s.

REFERENCE

1 E. C. Cork and J. L. Pawsey: *I.E.E Wireless Proceedings*, Vol. 14, No. 41, June 1939.