A BRIEF HISTORY OF WROTHAM.

At the end of World War Two, overcrowding in the Medium Wave Band was already getting serious and it was apparent that a move to a higher band was required. This also gave the opportunity for a greater frequency range to be broadcast as any new plan would not be confined to a 9kHz channel spacing. Experiments in the U.S.A. had indicated a possible improvement if F.M. was used instead of A.M. and a brief series of tests from A.P. at 45MHz appeared to confirm this. However, in view of the enormous implications if a wrong decision was made, it was decided to set up a full scale test of A.M. versus F.M. at the new frequency (Band II - 87.5 to 108.5MHz).

After some theoretical and practical site testing, it was decided to establish a high power experimental station at Wrotham in Kent and construction commenced in 1949. Two 20KW Transmitters were installed which were very similar to the Marconi Band I Sound Transmitters just installed at Sutton Coldfield.

Because the station was experimental no reserve transmitters were provided. Tests of AM v FM were run for several years with the same programme on each, generally Home Service and The Light Programme on alternate days with The Third Programme each evening. AM/FM receivers were provided to various staff members, 'The Trade', and others and eventually FM was chosen as the superior system. It was then decided to start covering the whole country with a three programme VHF/FM service starting with Wrotham in 1955. To enable a proper service it was necessary to:

1) Convert the AM transmitter to FM
2) Provide a 5KW switchable reserve transmitter for each to cover faults
3) Provide transmitters for The Third Service.

Since parallel operation had been proved by this time two 10 kW transmitters were installed and since these would provide the best reliability the priority programme (Home Service) was assigned to these. The station therefore opened with a public service on 2nd May 1955 with the following arrangement: see fig.1

NOTE:

1) Three types of transmitter were used (5,10,20KW)

2) In the event of a fault on FM1A or FM2A, R2 and R3 had a 45 second break whilst the reserve transmitter ran up from cold.

3) An aerial fault caused R2 and R3 to shut down until manually switched around diplexer (not shown in fig.1)
(4) Although two HV feeds were provided to the station both were joined just down the road and so almost always failed together!

Eventually a diesel generator was installed but it had to be manually started. In view of all this a full engineering staff was provided with an EIC, AEIC, 4 SMEs, 4 Engineers, 4 TAs plus a rigger, electrician, handyman, cook, office staff etc!

With the availability of stereophonic programme material in 1957, experimental broadcasts took place after regular closedown, using two of Wrotham's BII transmitters. The Third Programme transmitter broadcast the left hand channel on 91.3 Mc/s and the Home Service transmitters broadcast the right hand channel on 93.5 Mc/s. This developed into regular transmissions (still officially experimental every other Saturday morning with Third Programme transmitters (VHF and MF) broadcasting the left hand channel and television sound transmitters broadcasting the right hand channel.

These broadcasts went on for several years while much thought was given to a stereo coding system. Once the Zenith-GE system was chosen, experimental broadcasts were made from Wrotham's Third Programme transmitters from August 1962 until regular public service started in 1966.

From about 1962 staffing was reduced to a one man shift (i.e. four engineers) with EIC and AEIC covered form Crystal Palace. The station ran like this until the end of the 1970s with various facilities added over the years:

1966

(5) Start of stereo service on R3 using Telefunken encoders (first solid state gear on the station!)

1968

(6) Start of stereo on R2 and R4 (but line fed only)

1969

TV link to feed Dover installed (first in temporary caravan then in proper building). Later fed Heathfield also.

Stereo from Sutton Coldfield and Holme Moss both fed off RBL Wrotham (!)

1972

(7) PCM installed to provide much better quality
1974

Much discussion over Wrotham becoming a team base but decided NOT VIABLE (!!!)

1979

(8) Re-engineering began

November
Gordon Hitchcock surveyed site for new mast.

December
6th: Markers placed for new mast stays
22nd: Plans made available on station for public inspection

1980

January
TCPD, ACED, Council officials, Contractors preparing estimates. All on site regarding new mast.

February
Dick Manton planning feeder with Alan Dick.

March
Gordon Hitchcock on site with Eve construction.

June
Nobby Clarke Considering the future of TV links.

August
27th: Eve start work on mast base and stay blocks.

September
17th: Eve damage 11kV Feeder.
October

28th: TCPD meet Blandings on site regarding new mast.

December

New drives and drive change-over installed.
PYE transmitters testing into load.

1981

February

Contractors working on feeder duct.

March

17th: Alan Dick testing prototype combiners.
19th: Steelwork delivered for mast.
30th: Eve arrive on site.
30th/31st: Change-over to PYE transmitters postponed due to Reagan shooting.

April

6th/7th: Changed over to PYE transmitters. Problems with control circuits.

7th: Eve raises first mast section.
7th/8th: Control problems solved. PYE transmitters in satisfactory service.

27th: Contractors removing FM1A and FM2A.

May

6th: Old 5kW transmitters go to Hull University.
11th/12th: Alan Dick testing prototype combiners.
21st/22nd: Trial of new SCU chassis in TIE bay.

**June**
12th: Feeder delivered.

**July**
14th/15th and 15th/16th: Further trial of new SCU.
20th: Alan Dick on site for aerial erection.

**August**
14th: Feeder installation on mast started.
19th/20th: New SCUs installed in R3.
26th/27th: Alan Dick testing new aerials.
27th/28th: Aerial acceptance tests.

**October**
Combining gear delivered.
21st: Dover TV feed transferred to Bluebell Hill.

**November**
9th: Marconi transmitters on test.
10th/11th: Full overnight Marconi tests start.
25th/26th: Combiner acceptance.

**December**
11th: Marconi transmitters in service.

**1982**

**June**
7th/8th and 8th/9th: PCM receivers removed to main building.

**September**
Start to dismantle old mast.

**October**
Finish dismantling old mast. TM1M in use.

1987
October

New team base for Southeastern region.
Heathfield and Dover TMTs closed.
Establishment consisted of 1 TM (Graeme Keys), 1 ATM (John Ward), 3 STEs (Bob Harrison, Bob Long and Melvyn Pickworth), 4 Engineers (Peter Chamberlain, Phil Foster and two attachees Bruce Mann and Andy Shaw who filled the positions taken by Ciaran Fitzgerald and Keith Snook who were working elsewhere).
Other attachees at this time were Neil Bundle, Dave Davey, Martin Vanden Busken, Chris Hales and Jack Beaton.
Also work commenced, by Al Williams, to fit new drives and transmitter input equipment. This replaced the old TIE fitted behind the MV room.

1988
March

New drives accepted. Facilities existed for Radio One. Also at this time Graham Harrison and Craig Brownlie arrived to replace Bob Long and Ciaran Fitzgerald.

1989
December

18th: Radio 1 start.
How the BBC Plans to Develop the VHF Service

By HAROLD BISHOP, Director of Technical Services

The official opening of the VHF station at Wrotham, Kent, on Monday, is a matter of first-step in the realisation of the BBC's plans for developing this new method of sound broadcasting in this country. It has long been clear to us in the BBC that some programme which would not depend on the obvious omissions in reception that has been caused by interference from foreign stations on medium wave-lengths. Many expedients have been tried, and are still being tried overseas and in our own trained staffs, but the number of stations in Europe has already doubled since 1950, and as a result the medium-wave band is far too crowded to permit good reception of the three BBC programmes throughout the country. The men who found that in many areas the Home Service, especially in a large part of Wales and in South-East England, is spoiled by foreign interference and there are no wavelengths available for additional medium-wave stations. Moreover, because several stations must share one wavelength, some listeners receive a Home Service programme intended for some Region other than their own.

But if there were a delay of some years caused by the understandable reluctance of the Government to sanction substantial capital expenditure during a period of acute economic stringency, the VHF system has become a reality. It will give interference-free reception of the three sound programmes to very many listeners who have not had it before. Not only will it get rid of the bad aspect of foreign interference, but it will greatly reduce interference from electrical appliances, which is especially troublesome in large towns on the long wavelength used by the Light Programme.

From Monday, some thirteen million people in London and the south-east of England within fifty miles of Wrotham will be able to receive the Home, Light, and Third programmes on VHF. Many of them will find it worth while to buy a receiver incorporating the VHF band, or an adapter to go with an existing receiver. Apart from the virtual elimination of interference, an improved standard of quality is available on VHF because the receivers do not have to cut out the higher notes in order to reduce interference from other stations. Of course, the quality will depend on the receiver, and the cheapest cannot be expected to be as good as the more expensive in this respect. Listeners near the fringes of the service area would be well advised to use outdoor aerials, but many others will find that aerials built into the receivers will be satisfactory. VHF receivers and adaptors are now on sale in the shops.

The First Ten Stations

What of the rest of the country? Wrotham is one of ten VHF stations all to be completed by the end of 1956. Three of these will, we hope, be in service and one partially in service by the end of this year. The first priority among these has been given to the one at Pontypool in North-East England, because it will enable VHF listeners to hear the North of England Home Service and items of local interest, instead of the combined Northern Ireland and North of England programme which they have received for many years from the transmitter at Stagshaw and Scarborough. This VHF station will serve some three million people. Next will come Divis in Northern Ireland, giving similar programme freedom there, and then Middlesbrough near Aberdeen, South-East England. With them these two stations will serve another one-and-a-half million people. Also before the end of 1953 we hope to bring VHF to Wales, which has suffered much from the interference. Both of these stations have wavelengths, especially during the past year. The station at Wenvoe will serve over two million people in South Wales; the transmitter for the Welsh Home Service will come first, and the other two early in 1956.

The other stations in the first stage will be North Hessary Tor (South Devon), Sutton Coldfield, Norwich, Blaen Ppwy (Cardiganshire), and Helmsley Moss. These first ten stations will together serve eight million people, or 17 per cent of the population of the United Kingdom. In addition, a temporary transmitter is being installed in Anglesey to improve reception of the Welsh Home Service in a populous part of North Wales, pending the completion of a permanent three-programme station there under the next stage of the plan; this temporary station will not affect progress on the main scheme and will be ready towards the end of this year.

In deciding where the first group of stations was to be built, the competing claims of all parts of the United Kingdom were carefully weighed. Further developments, to cover other areas, and the rate at which they can be introduced depend on the approval of the Postmaster-General! The BBC hopes to provide about nine more stations by the end of 1957 and others later, bringing the total VHF coverage to ninety-eight per cent of the population within the next four years.

There will still be a few areas, mostly mountainous districts with scattered communities, that may not be adequately served. They will not be forgotten, but it will not be easy to provide them all with a service of the VHF system—which is not so well suited to mountainous country. When all the present plans have been completed, we shall be able to decide what remains to be done and how best to do it.

Finally, I must make it clear that in providing this new service we are not taking anything away. The existing long- and medium-wave transmissions will continue for many years side by side with the VHF transmissions.
Wrotham Transmitting Station

B.B.C.’s Experimental A.M./F.M.

Broadcasting on 3 metres

INVESTIGATIONS into the possibilities of microwave broadcasting were instituted by the Engineering Department of the B.B.C. as far back as 1945, the frequency used being in the region of 90 Mc/s. The two rival systems, amplitude and frequency modulation, were employed from time to time.

These early tests were definitely encouraging, but the power employed was low and so it was decided to carry out a more comprehensive programme of test transmissions on high power, simultaneously on a.m. and f.m., so that direct comparisons could be made. This plan was implemented last year when a new station was completed on the summit of Wrotham Hill, which is almost 100 miles south-east of London and adjoining the London-Folkestone road. If a more precise location is desired, the national grid reference is 51/504504.

It is ideally situated for v.h.f. transmissions, as the hill rises to 730 feet above sea level and it is now surrounded by a 470-ft mast of similar design to that used at Sutton Coldfield, but without the television top section. The aerial in this case is the 110-ft tubular section at the top, which is 6 ft in diameter and has 32 vertical slots cut in its circumference. These are arranged in eight tiers of four, equally spaced on the surface.

Transmitting hall at Wrotham; the f.m. transmitter is in the foreground. It is a typical example of modern design with all units totally enclosed.

WIRELESS WORLD, APRIL 1951
Comparison between the giant BR128 v.h.f. air-cooled transmitting valve and a typical modern receiving valve.

the effect of converting the aperture into a folded slot, the counterpart of a folded dipole, but curiously enough, with a lower input impedance than unfolded. In the case of the Wrotham aerial the slot impedance is 150 ohms. The outputs of the f.m. and the a.m. transmitters are fed simultaneously into the one aerial system.

"FMQ" System of Modulation

The f.m. transmitter is of unusual design in that it embodies a quartz crystal oscillator and the crystal is actually frequency modulated by the audio signal. This system of modulation, developed by Marconi's Wireless Telegraph Company, is known as "FMQ." The frequency deviation at the crystal is not large, being of the order of a few parts in a thousand, but a comparatively low frequency crystal is employed and its output passed through four frequency multiplying stages before the actual radiated frequency of 91.4 Mc/s (2.98 metres) is reached. In the case of the Wrotham transmitter, which is made by Marconi's, the multiplication amounts to 24 times.

The frequency deviation, or modulation range, or depth, is multiplied by a similar amount and at this working frequency a deviation of 2.75 kc/s is obtainable. This is a measure of the depth of modulation and bears no direct relationship to the range of frequencies that can be handled.

Frequency multiplication takes place at a comparatively low power level, the output at the 24-th harmonic being of the order of a few watts only. Six stages of amplification at the working frequency are consequently employed, the first two are conventional push-pull amplifiers and the final four are single-ended earthed-grid stages with co-axial line tuning elements. The final, or output, stage consists of a pair of giant BR128 air-cooled valves operating in parallel and giving an r.f. output of 25 kW, an unusually high power for v.h.f. equipment of this kind.

The r.f. portion of the a.m. transmitter is identical to the f.m. set, the only difference being that the "FMQ" circuits are rendered inoperative. The quartz crystal is chosen to give a frequency, after 24 times multiplication of 93.8 Mc/s (3.28 metres) and the r.f. power output is, in this case 15 kW. These are quite carrier figures; while the aerial power does not change in the case of the f.m. transmission, it undergoes considerable variation in the case of a.m. An increase of anything up to 30 per cent is possible depending on the depth of modulation and the waveform. In this equipment the final r.f. amplifier, again a pair of BR128 valves, is modulated by a class "B" push-pull stage fitted with two ACT4 valves.

Some idea of the giant size of the special v.h.f. power amplifier valve BR128 can be obtained from one of the illustrations, which shows a typical receiving valve held alongside for comparison. These, and other valves in the transmitters, are cooled by air circulated under pressure.

Feeder System

Both transmitters are controlled and monitored in a single room adjacent to, and with windows looking into, the transmitting hall. In addition to switches and meters for controlling and monitoring the voltages and currents at each stage of the transmitters, there is also included special apparatus for measuring the frequency deviation (modulation depth) and for checking any shift in the mean carrier frequency. A concentric feeder system connects the output from each transmitter, via an harmonic filter, to a combined filter unit which prevents power from one transmitter being fed into the other, but diverts it into a common concentric feeder and thence to the aerial. The aerial system is common to both transmitters, as explained earlier.

Various methods have been evolved to enable one aerial to be used simultaneously for two or more transmitters. The diplexer as used at Sutton Coldfield is one and the Wrotham system, which consists of sections of concentric line, is another. The feeder is a large copper tube of some 6 to 7 in outside diameter and with a surge impedance of 97 ohms. Dry air is pumped into it and into the combined filter in order to exclude moisture, which, if allowed to accumulate, would change the characteristics of the feeder system to such an extent that it would upset the loading at the transmitters and very likely cause serious damage to the output valves unless a drastic reduction in power were made.

The slotted aerial system was designed by the Engineering Research Department of the B.B.C. The associated feeder system was developed by Marconi's and the mast designed and erected by British Insulated Callender's Construction Company.

Visits to the N.P.I.

THE National Physical Laboratory "Open Days" for industrial representatives, to be held this year in conjunction with the Festival of Britain, afforded scientific and technical workers in industry the opportunity of seeing the scientific research work and investigations undertaken. The Laboratory will be open on May 28th and 29th from 10 a.m. to 5.30 p.m. A number of tickets is being reserved for postal applications from accredited representatives of industrial organizations. They should be made to the Director, National Physical Laboratory, Teddington, Middlesex, by May 8th, stating the preferred day.

WIRELESS WORLD, APRIL 1951
Wrotham Aerial System

1—New Design of Slot-Radiator for V.H.F. Broadcasting

By C. GILLAM*

The Wrotham aerial is a high gain omni-directional v.h.f. radiator for horizontal polarisation. With its transmission line it is designed to handle simultaneously either three 25-kW f.m. transmissions or one 25-kW f.m. and one 18-kW a.m. transmission in the frequency band from 87.5 Mc/s to 95 Mc/s. The radiator consists of multiple co-phased slots fed by a branched transmission line. A "notch" type combining filter is installed for either two separate f.m. transmissions or one f.m. and one a.m. transmission.

The v.h.f. broadcasting aerial system at Wrotham comprises a high gain omni-directional radiator, a rigid tube co-axial transmission line and a combining filter for two simultaneous transmissions. The radiator consists of an assembly of co-phased slots on the surface of a vertical cylinder which forms the upper part of a stayout mast. This mast has a total height of about 469 ft above the ground level. The lower part, up to a height of about 357 ft is of lattice steel construction with a triangular cross section; near the top of this part there is a railed gallery. The upper part of the column is cylindrical with a diameter of 6 ft 6 in and right at the top there is a second railed gallery. The part of the cylinder forming the radiator proper is built up from eight cylindrical sections each 10 ft 6 in long, each section being made of four quarter-cylinder curved plates with angles welded on to all sides and ends. The plates and sections are bolted together through these angles and there are diametral cross struts at the section junctions. Each quarter-cylinder plate is pierced with a slot 8 ft long and 12 in wide; there are thus thirty-two slots in all, arranged in eight tiers of four slots equi-spaced around the cylinder, and with slots in successive tiers vertically above the lower ones. The television aerial support masts for the new high power stations, of which Sutton Coldfield was the first, are all provided with similar slotted columns for eventual use as radiators.

Inside the cylinder angle bars are fitted horizontally, forming a square cage about 4 ft 6 in on the side, the corners of which meet the cylinder mid-way between

* Marconi's Wireless Telegraph Company.

**Fig. 1. Current distribution around a radiating slot in an infinite conducting plate.**
**Fig. 2. Skeleton enclosure of horizontal loops behind a vertical slot produces uni-directional radiation and behaves as a reflector.**
**Fig. 3.** In a folded slot currents on the central bar cancel out.

Wireless World, June 1951
the slots. The bars are spaced about 1 ft apart vertically, and they form enclosures of segmental cross-section behind each slot. The distribution feeder system is accommodated inside the square cage, and sufficient space remains for climbing up through the radiator column.

How a Slot Radiates

Slot aerials are perhaps a little unfamiliar, and at first glance it is difficult to see what they have in common with other types of aerial. The simplest viewpoint is to regard the slot as a means of persuading current to flow in a desired manner in the conducting sheet in which the slot is cut, and then to consider radiation in terms of these currents. The usual slot is about half-a-wavelength long and rather narrow. It is fed by connecting a generator—or more usually the inner and outer conductors of a coaxial transmission line from a generator—across the slot lips at the centre of their length. Viewed from the feed points, the slot edges form short-circuited transmission lines a quarter-wavelength long. Such lines have a high input impedance, but a comparatively large current flows in the short-circuited ends. As will be seen from Fig. 1, rather large currents flow in the conducting sheet at the ends of the slot. There are, of course, also currents flowing in the sheet lengthwise of the slot, but as the figure shows, they flow in opposite directions on the two sides of the slot and in the upper and lower parts, so that they practically cancel each other out. The radio-frequency difference of potential across the slot lips sets up an electromagnetic field in the slot which radiates outward on both sides of the conducting sheet. This field is polarised in the plane at right angles to the slot length, that is, its electric force is in the plane. As mentioned earlier, the radiation can equally well be accounted for in terms of the currents flowing in the sheet at the ends of the slot, and it is then clear that the magnetic force is in planes lying parallel to the slot length. A slot radiator behaves in fact very much like a dipole aerial but with the planes of magnetic and electric force interchanged with respect to the length of the radiator.

Just as arrays of dipoles can be used to increase the directive and gain of an aerial, so also can slots be stacked in horizontal and vertical rows for the same purpose. Another useful feature is that the slot can be turned into a uni-directional radiator by enclosing it on one side with a cavity. That this can be done is readily appreciated by considering a horizontal loop with a total length of half-a-wavelength connected from one side of the slot to the other, as shown in Fig. 2. Such a loop will have a high input impedance, i.e., it will accept very little current and so disturb only to a very small extent the conditions existing at the slot lips. Additional similar loops can be added above and below the first one, and if desired they may be put in contact with each other so that a continuous screen is formed. All radiation into the cavity so formed will then be reflected back and will reinforce the outward radiation. In fact, for this purpose the screen need not be continuous, and it is sufficient for the loops to be not more than about one-tenth of a wavelength apart. The exact cross-sectional shape of the enclosure—or skeleton enclosure—at the back of the slot is not critical; the length of path from one side of the slot mouth to the other is, however, an important factor. The impedances of similar means. In other words, the input admittance of a slot is affected by folding in the same way as is the input impedance of an ordinary dipole. Fig. 3 shows a folded slot, and it will be seen that the generator e.m.f. is in effect applied across only one-half of the slot width.

Returning now to the enclosed slot, the cavity behind the slot becomes filled with an electromagnetic field. This consideration leads to the converse of the previous procedure, in which a field is excited inside the cavity by any suitable means, and it then propagates out through the slot as radiation. In doing so it sets up a similar distribution of currents on the conducting sheet as would have occurred if the slot lips had been directly excited. Naturally, the field set up in the cavity must have the same character; that is, the same frequency and plane of polarisation whichever way it is produced.

Wide-Band "Folded" Slots

The Wrotham slots are fed in such a way that they behave as "folded" slots, with the result that the feed-point impedance is approximately 140 ohms, but in order to reduce the variation of feed-point impedance with frequency a system of reactance compensation is introduced. Each slot is fed by a coaxial feed line which terminates near the horizontal centre line of the slot in one corner of the square cage. At this point the outer conductor is earthed to the bars, while the inner conductor passes into the slot enclosure, and continues as a horizontal open conductor running just behind the cylindrical surface to a point near the horizontal and vertical centre of the slot opening. There it is joined to a vertical

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A comparatively high gain in all directions is obtained with the Wrotham v.h.f. aerial by arranging the 32 slot radiators in eight tiers with four in each tier spaced equally round the circumference of the cylindrical top section.
conductor which passes upward or downward on the centre line of the slot to one end of the opening where it connects with the cylinder wall. As seen from the end of the horizontal conductor, the vertical conductor forms with the cylinder wall a half-wavelength transmission line short-circuited at its termination. At its resonant frequency, the input impedance of this line is zero, so that the end of the horizontal conductor is joined to the wall of the cylinder by a connection of zero impedance. At frequencies off resonance, this line adds a positive or negative reactance in series with the slot feed impedance. Current flows from the inner conductor of the feed line along the horizontal conductor, and returns by way of the vertical conductor to the cylinder wall and the outer conductor of the feed line. The current on the horizontal conductor sets up a radio-frequency field in the slot enclosure, which is able to emerge from the slot opening as radiation, in so far as it is horizontally polarized and the slot is resonant at the appropriate frequency.

The energy lost by radiation is supplied from the transmission line by the feed line, and there is a corresponding real term in the feed line termination impedance. Over the rather wide frequency band in which radiation is required, the feed-point impedance would vary considerably, were it not for the behaviour of the vertical conductor as a reactance compensator. Both the length and the diameter of this conductor are chosen and adjusted critically for optimum results in this respect. The horizontally polarized field is unable to pass through the horizontal bars of the slot enclosure into the space beneath, but there is some vertically polarized field due to the vertical conductor, and a continuous steel strip 6 in wide is fitted to the horizontal bars behind each line of slots to prevent this entering the cage. This vertically polarized field cannot emerge from the slot opening as radiation. Because of the enclosure of the slots they have comparatively little mutual influence on each other.

Co-Phase Feeding

All the slots of the radiator are fed in identical phase. This statement, unambiguous as concerning co-planar slots, requires further elucidation when applied to slots in a cylindrical surface. It means that if observers were situated at equal distances from the cylinder axis in directions radially from each of the four slots, and if they fixed their attentions on the electric vector of the radiation emerging from the slot opening facing them, then at a given instant all observers would see the vector pointing in the same direction relative to themselves. This situation is made clear by Fig. 4. The electric vectors thus all point round the cylinder alternately in one direction and then in the other. At sufficient distance from the axis of the cylinder, the field strength is practically constant in any radial direction; that is, the horizontal radiation pattern is almost circular. If it were required to radiate a higher frequency band with a similar horizontal radiation pattern it would be necessary either to increase the number of slots around the circumference of the cylinder, or to decrease the cylinder diameter. Similarly for lower frequency bands and for the same cylinder diameter, three or two slots around the circumference would suffice, and in the limit at a sufficiently low frequency, the pattern would be nearly circular with only a single slot on one side and the radiator becomes the American-designed "Pylon."

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**Fig. 4.** In the Wrotham aerial system all slots are fed in identical phase and the arrows shown here indicate the instantaneous direction of the electric vector for all radiators.

**Fig. 5.** Wrotham distribution feeder system with cylinder opened out into a flat plane. Radial feeders are all of equal length with point impedances shown as plain figures and characteristic impedances in "boxes."

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As compared to the radiation in the maximum direction from a single half-wave dipole, the assembly of four slots forming one tier of the Wrenham aerial has a gain of about unity. The stack of eight tiers then has an effective power gain of eight, or about 9 db.

The distribution feeder system is required to divide the transmitter power equally among the thirty-two slots, and to deliver it to the feed-points in equi-phase. This is accomplished by successive bifurcation of the feeder, with impedance matching at each junction, and with all paths from the first bifurcation to the slot feed-points of exactly equal lengths. There are more ways than one in which the slot feeds might have been progressively combined. At one extreme there could have been a single junction point with thirty-two feeders of equal length; at the other, from mechanical difficulties, an impedance transformer working from the very low resistance value of about 4.4 ohms would have been formidable. In the practical design, the slot feeds could have been combined first in pairs, then in fours, then in eights, and finally in sixteens, and there would still have been plenty of choice as to whether to start with vertical pairs, side-by-side pairs, or opposite pairs, and so on. The method finally adopted had little beyond a certain convenience to recommend it. It is shown diagrammatically in Fig. 5, which represents the cylinder as if it were slit down one side and opened out into a flat sheet. The individual feed-point impedances are about 140 ohms each. The slots are first combined in vertical pairs by 2-in diameter lines of 140 ohm impedance, running vertically near the corners of the square cage. At their centres these lines tee into 2-in diameter 70-ohm lines running radially from a central four-way junction box. The impedance at the input to this junction is then 70/4 = 17.5 ohms, and it feeds a group of eight slots. There are four similar junction boxes at levels corresponding to 1, 2, 3, and 1 of the radiator height.

Impedance Matching Transformers

Double quarter-wave transformer sections are joined directly to the junction boxes, and run alternately upward and downward along the axis of the cylinder; these transform the impedance to 51.5 ohms, and the lines are continued at an impedance of 51.5 ohms until they meet at tees. At the opposite direction, these lines and transformers have an outer diameter of 3½ in. At the tees, the impedance drops to 25.75 ohms, and it is restored to 51.5 ohms again by further double quarter-wave transformers. Here again, the lower transformer points upward and the upper one downward, and they are continued by 51.5-ohm lines until they meet at the final tee at the vertical centre of the radiator. This intermediate feeder and its transformers have an outer diameter of 5 in. At the final tee the main transmission line is connected through a further double quarter-wave transformer. On Fig. 5 point impedances are indicated by plain figures, and the characteristic impedances of the various parts of the feeder system, including the transformer sections, are indicated by a figure in a rectangle. All parts of the distribution feeder system are in rigid copper co-axial lines, with ceramic insulators throughout. It should be noted that the references above to the “outer” diameters of the feeders, transformers, etc., refer to the inside diameter of the outer conductors.

Since at every branch point the branch impedances are identical, the power divides uniformly between the

The main transmission line and part of the distribution system to the 32 slots in the aerial cylinder are shown in this cut-away view.
branches and eventually every slot receives an equal proportion of the total power. The complete aerial system was required to deal with up to three simultaneous fm transmissions on different frequencies in the band, each with a power of 25 kW. Thus the total power input to the radiator could be 75 kW and the power per slot 75/32 kW = 2.34 kW. These are the figures which control the conductor sizes from the view point of this aspect; the current is to be carried and heating. For example, the slot-feed-point impedance is 140 ohms, and so the r.m.s. current at that point is

\[
\sqrt{\frac{2340}{140}} = 4.09 \text{ A.}
\]

In providing adequate flash-over distances, however, it is necessary to take account of the fact that the voltages of the separate transmissions can at particular instants add in phase to give a voltage three times as much as for one 25-kW transmission, and hence equivalent to an instantaneous power of 9 x 25 kW = 225 kW. All parts of the main transmission line and distribution feeder system were designed to carry voltages equivalent to this instantaneous power with an adequate safety factor. Fortunately there were no very serious problems in this respect; the corresponding r.f. voltage peak on the main 5-in. 51.5-ohm transmission line is 4812, and at the slot feed point 1400.

In order to meet the very low standing wave ratio specified for the complete aerial system, it was necessary to divide the frequency range from 87.5 Mc/s to 95 Mc/s into two overlapping parts, and to provide for separate adjustments at the slots. Thus, with one set of adjustments the range from 87.5 Mc/s to 93 Mc/s can be covered, and with the alternative adjustments from 89 Mc/s to 95 Mc/s. Over both parts of the range the standing-wave ratio measured at the input of the main transmission line transformer is less than 1.1. An explanation of the wide-band impedance compensating action of the double quarter-wave transformer is given in Appendix I.

(To be concluded)

APPENDIX I

Double-Quarter-Wave Transformer

If a quarter-wavelength of transmission line with a characteristic impedance of \( Z_1 \) is terminated by a resistance of value \( nZ_2 \), then the input impedance of the line is a resistance value of \( Z_1\sqrt{nZ_2} \). Alternately, if a resistance of \( nZ_2 \) ohms has to be matched to a line of characteristic impedance \( Z_1 \) ohms, a quarter-wavelength of line of characteristic impedance \( Z_1 = \sqrt{Z_2} \), \( \frac{nZ_2}{Z_1} = Z_2 \) is terminated. The input impedance of this line is then:

\[
Z_1 = \frac{nZ_2}{Z_1} = Z_2 \sqrt{nZ_2} \text{, required value for match.}
\]

This is illustrated on the Smith Chart Fig. 1. Here \( n \) is taken as 0.5 and the point P1 represents the value \( nZ_2 \); \( Z_1 \) must be made equal to 0.707 \( Z_2 \), and \( P1 \) is 0.707 \( Z_2 \) as shown at \( P_2 \).

At the other end of the quarter-wavelength line \( P_2 \) becomes \( P_1 \). P1 has to be normalized to \( Z_2 \) by \( Z_1 = \frac{1.414 \times 0.707 \times Z_2}{Z_2} = 1 \).

This is satisfactory enough at the single frequency for which the length of \( Z_1 \) line is exactly a quarter wavelength. A higher frequency, the line has a greater length, so that the \( P_2 \) point finishes beyond the resistance axis, as, say \( P_4 \) on Fig. 2, and this when renormalised becomes \( P_4' \) which certainly does not match \( Z_0 \).

Using a double quarter-wave transformer effects a considerable improvement. For this, the first line has a characteristic impedance \( Z_1 = \frac{\sqrt{nZ_2}}{Z_2} = Z_0 \sqrt{n} \) and the second line has a characteristic impedance \( Z_2 = \sqrt{nZ_2} \), \( Z_2 = Z_0 \sqrt{n} \).

At the end of the first length, the impedance is then

\[
Z_1 = \sqrt{nZ_2} = Z_0 \sqrt{n}, \text{ and at the end of the second length,}
\]

\[
Z_2 = Z_0 \sqrt{n} = Z_0, \text{ giving the required match.}
\]

This is shown again on the Smith Chart Fig. 3, for the values in the earlier example. \( P1 \) is as before.

\[
Z_1 = \frac{1}{\sqrt{0.5}} = 0.595 \times Z_0, \text{ so that } P_3 \text{ is at } 0.5 \times 0.595 = 0.84. \text{ P4, at the junction between the lines is } 1.0 \times 0.84 = 1.19 \text{ in terms of } Z_1.
\]

This is shown on the Smith Chart Fig. 4. Renormalising \( P_4 \) to \( Z_0 \) gives \( P_4 = 1.19 \times 0.595 = 0.84. \text{ P5, thus superimposes on } P_4 \), and at the end of the second line, \( P_5 = 1.0 \times 0.84 = 1.19 \text{ in terms of } Z_0. \text{ Finally renormalising to } Z_0 \) gives 1.19 x 0.84 = 1.

Again consider a higher frequency, \( f_1 \), for which both transformer lines are above a quarter-wavelength long. \( P_1 \) on Fig. 4 is now beyond the R axis at \( P_5' \), and when renormalised, goes to \( P_5'' \), still to the left of the R axis. But the second line length now brings this to \( P_4'' \) almost exactly on the R axis again, and final renormalising in \( Z_2 \) shows an almost perfect match.

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