Tricks of the Trade

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Having looked at the considerable variations in directional antennas for MF and LF broadcasting in recent ToTT **[1–5]** it is opportune to turn now to a rather more basic, but nevertheless, very essential subject, namely that of Antenna Tuning Units for MF and LF. In amateur-speak, the term ATU is employed but in broadcast, the BBC at least, coined the rather more grand term of Aerial Transformer Houses or ATH. Over the years, the acronym has been doubly corrupted, especially on smaller installations, as Aerial Tuning Huts. In the early 1990's after the higher-BBC management universal decision to drop "aerial" and replace with "antenna", they became Antenna Tuning Houses/Huts, *etc.* Our friends across The Atlantic are somewhat more descriptive and often refer to them as "Doghouses". So, to begin with, the technical reasons for having ATH facilities will be described and then, over the next few issues, there is more on the reasons for and then the actual installations will be examined with anecdotes along the way.

BBC Technical Instructions

After the first ten years or so of the BBC it became apparent that, in the Engineering Division at least, a formal technical documentation scheme was required. Such documentation was issued as Technical Instructions (TI) and by a policy of documented recorded revision, their contents were kept both up-to-date and corrected if and as required. New members of engineering staff on a site were encouraged to read all the TIs relevant to their post and transmitter station or studio site. So, in June 1944 was published the first issue of *Technical Instruction TT.5* entitled *Medium-Wave Impedance-Matching Networks. Rejectors and Acceptors.* It should be appreciated that this TI was published in wartime and would have been printed on 'economy' paper.

For a description of the functions, *etc*. of an ATH/ATU, it is probably best to quote from the actual paragraphs of TT.5 and the exact quoted text is in italics below.

(TT.5) Introduction

This instruction deals with the basic principles of design of medium-wave impedance matching networks, with particular reference to circuits used in aerial transformer houses (ATH) and with rejectors and acceptors.

The purpose of the matching network in an ATH is to bring about an impedance match between the aerial and the feeder which is used to convey the RF power from the transmitter to the aerial.

The correct termination for the feeder is a non-reactive resistance, equal in value to the characteristic impedance of the feeder and usually very different from the impedance of the aerial.

In practice, the setting-up of such networks is done usually with the aid of an RF bridge, very exact calculations not being attempted owing to the influence of factors the magnitude of which is not readily predictable, e.g. stray capacities between components and from components to earth, stray mutual couplings, etc.

Calculations of networks, even though approximate, are however, most necessary in order to reduce the amount of trial and error work in setting-up and to ensure that the components used are properly rated.

Facility in handling problems involving network calculations is very largely a matter of practice. Certain worked examples are contained in the text and a number of problems in Appendix B. As the worked examples in the text are intended to illustrate basic principles the calculations are carried out to a higher degree of accuracy than would, in many instances, be necessary for practical purposes (or even warranted in some situations that occur in field work).

As a general rule it can be taken that the accuracy obtainable by reasonably careful use of a 10-inch slide rule is adequate.

The use of the operator j is then explained in a basic form.

So what detail can be gleaned from the above?

For broadcast work, it appears that a form of RF measuring bridge is needed and, by extension, some sort of calibrated oscillator to generate an RF test signal. Extreme accuracy of measurements is not required but the ability to make reasoned practical adjustments in the field is. Worked examples provide a chance to see if there is a network already described that would meet a requirement to save having to start from 'scratch'.

By 1943, certain BBC MF transmitter powers were singly at 200 kW and combined site output powers on MF were at 400 kW. On LF, combined site output power was to 600 kW in service and 800 kW on test. All the frequencies quoted in the TI were to the 1934 Lucerne Plan, some examples being 668 kHz, 767 kHz, 804 kHz, 877 kHz, 977 kHz, 1013 kHz, 1149 kHz, 1384 kHz and 1474 kHz.

What is clear from the 1944 detail is that there will not be an opportunity to 'poke and hope' on ATH settings on power-up of 50 kW+ transmitters; tune-up on-power, as with amateur transmitters and even linear amplifiers, will not be possible. The broadcast staff will have to have confidence in knowing that the input port to the ATU will have be close to correct as regards a pure resistive load before the full transmitter power is applied.

It must be borne in mind that, on the transmitters at that time, there were no VSWR or output power meters; so upon powering there was no direct clue to the actual match. Hopefully, many transmitters used raise/lower HT control so they could be powered up at reduced HT and then carefully taken up to the full nominal power. Observation of the meter readings on the final stage would be the main clue as to the correct operation. In addition, thermocouple (TC) ammeters were regularly employed in the transmitter units and in the ATH and records kept. Best practice on those TC meters that were in direct series connection was to run them shorted (they would still read something) and record both shorted and un-shorted measurements. It was a maintenance item to un-short them and confirm/record that reading once a year.

Having said that, there is reference in the TT "to reduce the amount of trial and error" work so maybe this instruction was deemed at the time to be a definite requirement compared to what might have been done in the past.

Driving point impedance

TT.5 then goes on to introduce the concept of driving point impedance, dpz (aka loop impedance).

The design of an ATH network is based primarily upon the dpz and the characteristic impedance of the feeder.

In practice, the dpz is determined by bridge measurement. Under ideal conditions, when the dimensions of the aerial and the operating frequency alone control the impedance, the latter might be calculated to a satisfactory degree of accuracy, but, in practice, the dpz is influenced by masts, stays, other aerials, etc. on the site and measurement is always necessary.

The influence that neighbouring conductors have upon the dpz depends on a number of factors in addition to relative distances and orientations, for example, resonant frequencies.

When a bridge measurement of the dpz is being made, care should be taken to ensure that all other aerials on the site are terminated correctly and that masts are in their normal condition as regards being earthed or insulated from earth.

This refers almost certainly to Brookmans Park where there were the original four 200-foot towers that stood on insulators; there was the option to earth down the mast across the insulators if required.

Reasons for variation of dpz

Over the MF (and LF) band the dpz goes through considerable changes as regards both the resistive and reactive components. The reactance will be zero at frequencies corresponding with half and quarter wave operation. At frequencies lower than corresponding with λ/4 operation the reactance will be negative. At frequencies between λ/4 and λ/2 it will be positive becoming negative again between λ/2 and 0.75λ.

The resistive component of the aerial resistance is a value which includes the radiation resistance and the (mainly earth) *loss resistances. As far as the dpz of the aerial is concerned, it should be noted that the resistive component is low under λ/4 and high under λ/2.*

When bridge measurements are taken of dpz of aerials at BBC stations it is usual to make a frequency run to plot the characteristic over the waveband. ***Figures 1 and 2*** *are examples.*

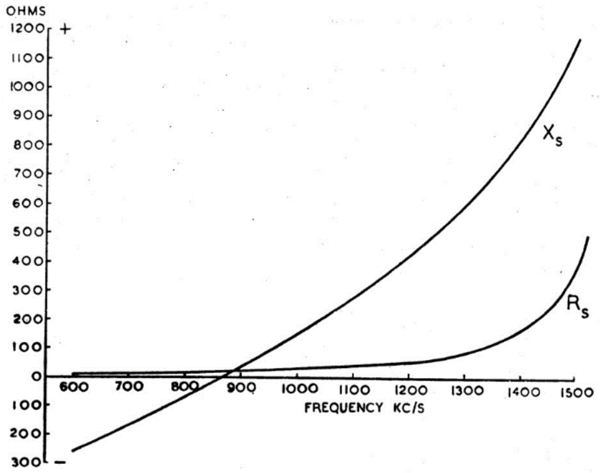

Figure 1. Impedance characteristics of a small sloping wire aerial

Figure 1 *is plotted from the results of measurements taken from a small sloping single-wire aerial. The length of the top portion is 150 ft. and the average height 75 ft. A single wire downlead, 150 ft. in length, is attached to the centre of the top portion. It will be seen that λ/4 conditions occur at 870 kc/s, the reactance being zero and the resistance low.*

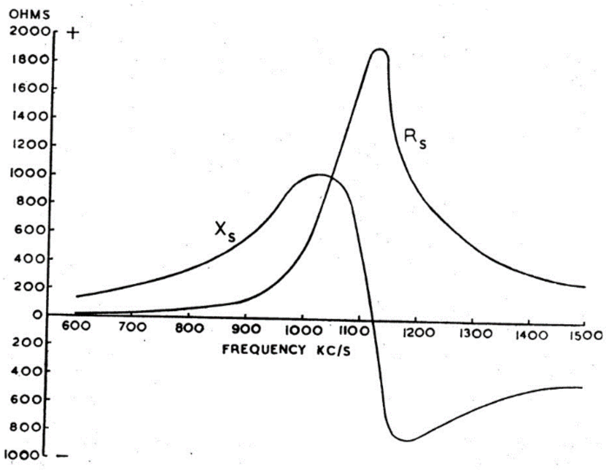

Figure 2. Impedance characteristics of a large Tee aerial

The curves of Figure 2 show the impedance characteristic of a certain large aerial of Tee type. The top span is of a 4-wire construction with a length of 417 ft. while the downlead consists of a vertical cage 160 ft. long. It will be seen from the figure that λ/2 conditions occur at 1125 kc/s the reactance being zero and the resistance high at this frequency.

It would appear that **Figure 2** does again refer to Brookmans Park and the Tee antennas there as the quoted dimensions fit. Also much trouble was experienced there in 1978 with voltage flashover using the north (side) Tee antenna for Radio 1 at 150 kW on 1089 kHz as operation was attempted very near the λ/2 resonance; so over the years, the physics stayed just about the same even with the single cage dropper being replaced post-war with a four wire, in-line drop.

To the author, it is the fact that the physics of the situation over the last 100 years, and certainly since TT.5 was published, has not changed at all. All the points, rationale, calculations and outcomes are exactly the same and TT.5 is as valid today as it was in 1944.

RF feeders

TT.5 then describes the theory behind RF feeders and all that needs to be stated here is that the load placed on the far end of the feeder needs to be the same as the characteristic impedance. At the time of publication of TT.5, commercially manufactured feeder was not available so feeder lines had to be constructed on site with wire, metal spacers and insulators. The theory to measure the Zo is described in TT.5.

Measurement of Characteristic Impedance

A convenient length of feeder should first be short-circuited at one end, while a measurement of the impedance (series aspect) looking into the feeder, is made by a RF bridge connected to the other end. Next a measurement should be made with the end of the feeder remote from the bridge open-circuited.

Then:- $Zo = \sqrt{Zsc \times Zoc}$

Where Zo = characteristic impedance of the feeder

Zsc = bridge measurement with the far end of the feeder short-circuited

Zoc = bridge measurement with the far end of the feeder open-circuited

Note:- The symbol Ro will be used for Zo in this instruction because in all cases the characteristic impedance will be assumed to be purely resistive.

Types of RF feeder

The various types of feeders (in BBC MF/LF use in 1944) *may be classified into two groups: Balanced with respect to earth and Unbalanced with respect to earth.*

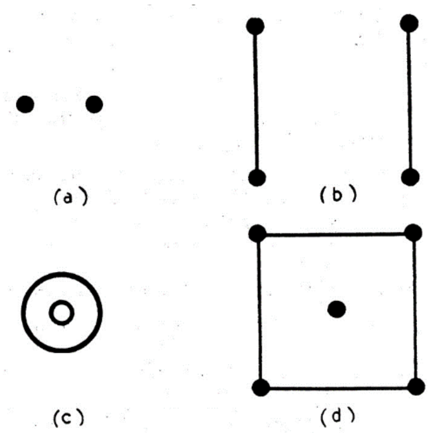

Figure 3. Cross-sectional sketches of certain feeders in common use at BBC stations

Sketch (a) illustrates the 2-wire balanced feeder. Using 19/.64 wire with a spacing of 18 in. between the two conductors, the measured Ro is 550 Ω, the calculated value is 566 Ω.

Sketch (b) illustrates a 4-wire feeder with equal horizontal and vertical spacing and with the wires paralleled in two vertical pairs. A certain feeder of this type constructed on No. 6 SWG wire with a 12 in. spacing has a measured Ro of 320 Ω, the calculated value is 310 Ω.

Sketch (c) illustrates the concentric feeder. This is unbalanced with the outer conductor being earthed. At the pre-war Regional/National transmitting stations, concentric feeders were installed, employing an inner copper tubular conductor of 1⅜ in. outside diameter and an outer tubular copper conductor of 5 in. inside diameter. The measured Ro was 80 Ω, the calculated value being 77 Ω.

Sketch (d) illustrates a 5-wire unbalanced feeder with the four outer wires all paralleled and earthed. A certain feeder of this type employing four outer conductors of No. 6 SWG wire spaced 12 in. horizontally and vertically and with a centre conductor of 19/.044 wire has a measured Ro of 300 Ω. If 19/.044 wire was used throughout then the calculated Ro would be 310 Ω.

Backwards and forwards, to and fro, with resistor(s) in hand!

The author was at Brookmans Park just prior to the (1978) wavelength changes and modernisation starting in 1977 and saw for himself the 80 Ω concentric feeder just before it was scrapped; the central support insulators were ceramic and substantial, as was the metal thickness – the scrap man must have had a field day.

In addition, a new feeder had been run for the 120/140 kW 908 kHz Radio 4 service from the wartime STC transmitter. The feeder replaced in 1977 was according to sketch (d). The replacement was of similar 4-wire outside dimension but the inner was doubled up 19/.044 (or metric equivalent). On measurement, it was no longer nominally 300 Ω as before but 10% different at 330 Ω.

Much walking was done from the building to the ATH to clip on different terminating resistors to determine and confirm the new Ro accurately. What was really odd was that the previous feeder had been in use since 1941 without trouble and then came the project to change it in 1977. In November 5th 1979 the new feeder was made redundant and soon scrapped along with the wartime transmitter as, on that date, three new triplexed Marconi B6034 50 kW transmitters took the (then) 909 kHz 150 kW service and, of course, used a modern 50 Ω Andrew hard-line feeder.

It begs the question as to why the 5-wire to 6-wire feeder change was even proposed and effected for such a short (life) time?

The basics and reasons for matching

The two impedances which have to be matched by the network are the aerial impedance on one hand and the characteristic impedance of the feeder on the other. This implies that the combination of aerial and network must in the ideal case present to the feeder a load of Zo Ohms where Zo is the characteristic impedance of the feeder.

Except where the aerial is being operated under λ/4 or λ/2 conditions, the impedance will be complex. (The term complex is used here in its mathematical sense and does not mean "complicated"). The Zo (or Ro) of the feeder, however, will be non-reactive (assuming a dissipationless *feeder). It will be seen, therefore, that one possibility regarding an ATH network is that it consists of (a) reactive elements, the purpose of which is to balance out the reactive component of the aerial impedance and (b) reactive elements which convert the resulting non-reactive resistance to a value equal to the Ro of the feeder.*

This network is often called a "transducer".

A complete ATH network, however, cannot always be regarded in such a simple manner as described above, i.e. regarded as comprising two separate parts, one balancing out the aerial reactance and the other providing the necessary resistance transformation, although this sometimes applies.

In some cases, for example, the whole or part of the aerial reactance is incorporated in the transducer and when this is possible the theoretical considerations are a little more complicated, although the practical set-up may be greatly simplified and costs reduced.

Conclusion

So we have now established the reasons why matching is required and the mathematical analysis that can be employed to design the necessary networks /transducers.

Next time we will look at the simple networks required to transform upwards and downwards with just pure resistance and then start on actual ATH construction before, in later articles, the actual antenna complex impedances to feeder transducers.

References

1. D Porter G4OYX. Tricks of the Trade. *Signal* 2019, **53** (November), 33–35.
2. D Porter G4OYX and C Pettitt G0EYO. Tricks of the Trade. *Signal* 2020, **55** (May), 47–49.
3. D Porter G4OYX. Tricks of the Trade. *Signal* 2020, **56** (August), 39–42.
4. D Porter G4OYX. Tricks of the Trade. *Signal* 2020, **57** (November), 17–21.
5. D Porter G4OYX. Tricks of the Trade. Signal 2021, **58** (February), 35–39.

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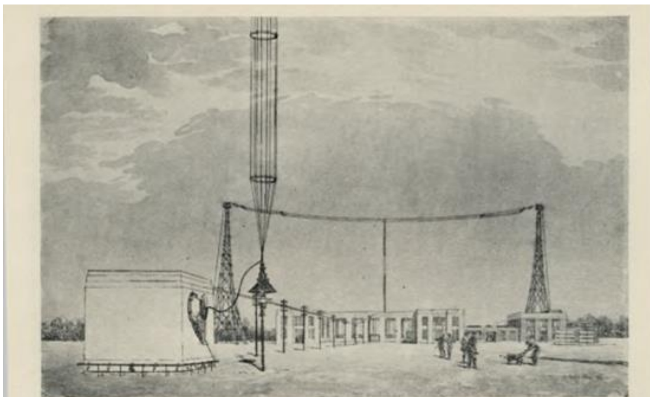
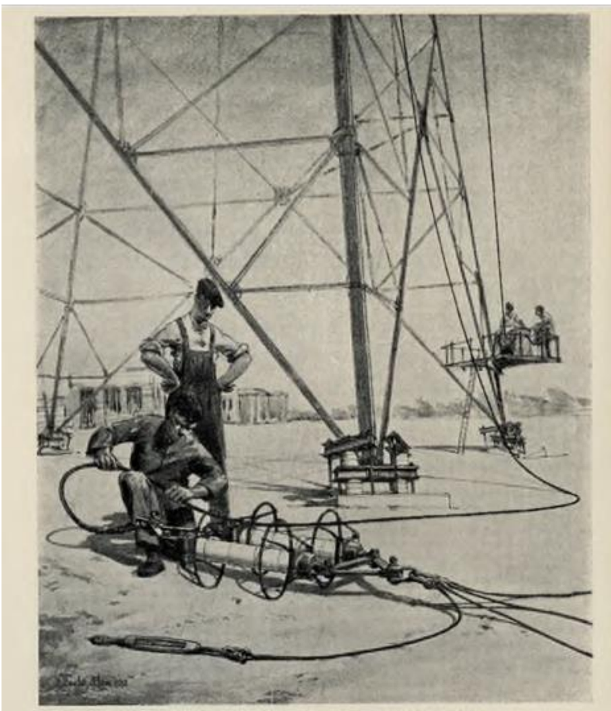


GENERAL VIEW OF THE STATION FROM THE SOUTH



ONE OF THE AERIAL INSULATORS

BIRD'S-EYE VIEW OF THE NORTH MASTS

Originals of the 3 drawings shown above used to hang in the transmitter hall at Brookman's Park and are available at www.northmymmshistory.uk/2018/01/the-london-twin-wave-broadcasting.html (Credit: A Descriptive Souvenir 1930, The British Broadcasting Corporation, Savoy Hill, London and the North Mymms History Project).

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