Tricks of the Trade

Dave Porter, G4OYX, with Andy Matheson, G3ZYP and Pete Edwards, G8EFM

Readers will recall that last time in ToTT we had investigated the MWT/BBC Bridged Tee LF/MF combiner and were moving on to other methods of combining AM transmitters.

BBC/RCA ET4336

Just after WW2, the BBC purchased over 150 of these, then war surplus, 250 W HF transmitters. This was a prescient move as they were to be used from 525 kHz to over 60 MHz over the next 50 years.

Their first employ was usually in combined pairs for UK domestic MF service in two roles; either as regular Home, Light, or Third “filler” transmitters at 500 W output, or in “Deferred Facility” DF service at certain sites in anticipation of a Civil Defence requirement in the event of a nuclear attack during the Cold War.

Conversion to MF

Some of the ETs had been modified by the BBC Equipment Department to cover the whole of the MF band, which with the BBC’s allocation, spanned 647 kHz to 1594 kHz. The low power DF frequencies were mainly above 1200 kHz, with 1295, 1457, and 1484 kHz being most common.

For both increased reliability and power output the ETs were paralleled using a BBC-designed ferrite-cored Hybrid Transformer/Matching Combiner, HTMC.

To fully understand the HTMC we need first to examine the simpler Hybrid Transformer.

The Ferrite Cored Hybrid Transformer

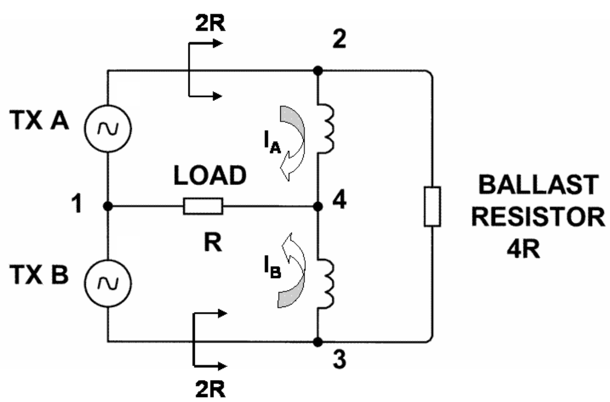

Figure 1. The ferrite-cored hybrid transformer

This transformer consists of two tightly coupled windings with very low leakage inductance. As usual, provided the two inputs from TX A and TX B are equal in amplitude, and correct in phase, i.e., terminals 2 and 3 are always at equal potential, no current will flow in the non-inductive ballast resistor.

The inputs from the two transmitters are fed in opposite directions through the windings, appearing in parallel at the centre tap, terminal 4. Due to the tight coupling the resultant fluxes cancel and the windings present negligible impedance.

If the load has an impedance of R Ohms then each transmitter sees an impedance of 2R Ohms and the combined power output of the two transmitters appears in the antenna port, R.

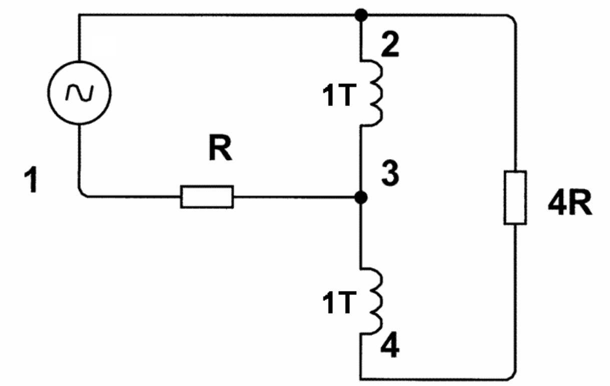

Figure 2. The set-up of Figure 1 in the event of one transmitter failing

Should one transmitter fail, the circuit can be redrawn as in Fig 2. The Hybrid Transformer now acts as an auto-transformer with a 2:1 turns ratio, stepping down the ballast resistor impedance 4R across terminals 2 and 3, to an impedance R across terminals 2 and 4.

This effective impedance acts in series with the load impedance to provide the correct load of 2R for the remaining transmitter.

As with the Bridged Tee half the transmitter power is dissipated in the ballast and half is out to the antenna port.

The BBC Hybrid Transformer/Matching Combiner

For the ET4336, this variant was used; the RF transformer 1-5, shown in figures 3a and 3b had a four section tightly coupled toroidal winding on a ferrite core.

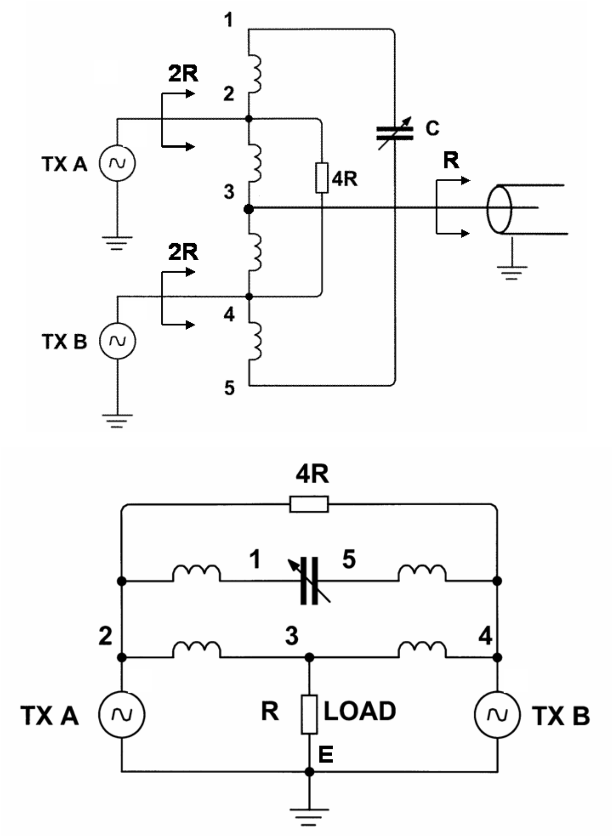

Figure 3a (above) and Figure 3b (below) as equivalent circuits of the BBC hybrid transformer/matching combiner

Capacitor C was used to cancel out any residual leakage inductance.

Windings 2-3 and 3-4 act as the simple hybrid transformer as described in Fig 2. Isolation between the two transmitters is dependent upon accurate balance of the windings and 100% coupling. This was not the case in practice and C was adjusted for minimum coupling.

The setting of C for minimum feed-through from TX A to TX B was rarely the same as minimum in the reverse situation, and a compromise setting was required.

Minimum coupling between the two transmitters could be checked easily by 40% tone modulating one unit and measuring the “tone + noise” level on plain carrier on the other transmitter; 35dB was about the best separation possible.

If the matched antenna impedance presented to the combining unit was reactive then isolation was also affected. Compared to the Bridged Tee, this aspect is a disadvantage at unmanned sites when there is a possibility of temporary icing or flooding of the site as the antenna match will alter in such situations.

The BBC MF ETs were designed for 120 Ohm output so the combiner required a 60 Ohm termination to the ATU. Two types of RF transformer were required to cover the entire MF band; one was for 550 kHz to 1 MHz and the other for 1 MHz to 1.6 MHz. The LF version had 24+18+18+24 turns and the HF version had 16+12+12+16 turns. Thus both have the same turns ratio; 1.33:1:1:1.33.

The significance of these ratios will become evident.

Should one transmitter fail, the RF toroid acts as a 2:1 auto-transformer with a 4:1 impedance step-down of the ballast resistor. The capacitor branch windings, with their opposing fluxes due to the current flowing in the output feeder branch, act as an infinite impedance which has no shunting effect on the ballast resistor. See Figure 4.

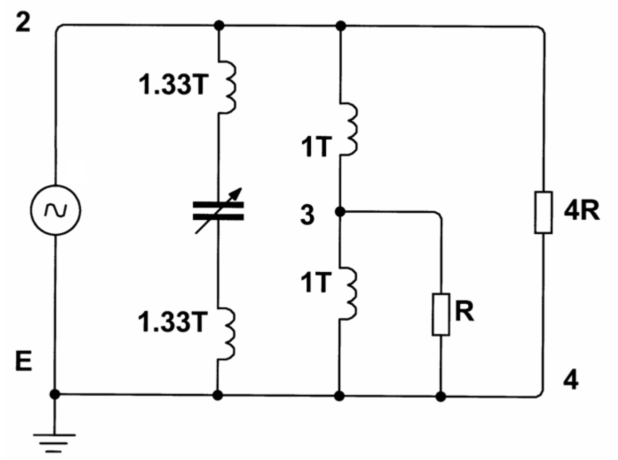

Figure 4. The set-up of Figure 3 in the event of one transmitter failing

As usual in the single transmitter condition half the transmit power is dissipated in the ballast resistor.

Cunning Plan

By recycling what was a surplus rotary switch from the ET4336 HF to MF conversion, the BBC were able to install a manually operated switch in the unit to restore full power output of one transmitter to antenna. The ballast resistor was switched out and one end of the transformer winding was earthed. The windings then were such that the auto-transformer section has a turns ratio of 3.33:2.33 = 1.4:1 and thus the antenna port of 60 Ohms becomes 1.4^2 x 60 = 120 Ohms at the transmitter port. Figure 5 shows this condition.

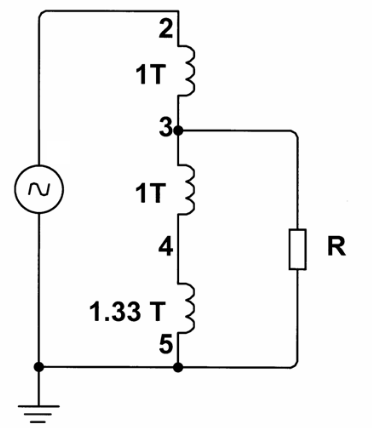

Figure 5. Restoring full power to the antenna

With a quick flick of the wrist, the switching break from -6dB to -3dB single transmitter working was imperceptible—provided the correct, working, transmitter was selected!

Radio Gloucestershire

The author used a pair of BBC ETs for this temporary, introductory Local Radio MF service in 1988 from Twigworth, just north of Gloucester. Being a former DF site the HTMC available was the HF type for 1 to 1.6 MHz, but now the frequency required was 603 kHz. No LF version was available so extra capacity, about 200pF, was added in the HTMC to achieve minimum coupling.

Later, when these same transmitters were re-commissioned by the author for the Shropshire, Sunshine 855 service, the Bridged Tee was employed as previously described.

Limitations of ferrite

The use of ferrite-cored transformers is limited by the power handling capacity of the cores. In later years on a BBC/IBA site, Shrewsbury MF, the author encountered on the IBA equipment a two input ferrite-cored device for 500 kHz to 2.5 MHz made by Minns Baluns that was rated at 2kW + 100% modulation with 50 Ohm input and output. A 50 Ohm dummy load was needed for the load port. It was unswitchable so there would always be the -6dB condition with the loss of one transmitter. Figure 8 details the unit.

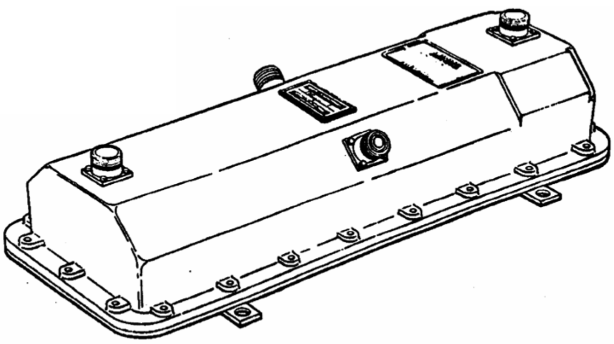

Figure 6. The general appearance of the Minns Balun

From about the 1970s, much use was made of the ferrite hybrid transformer principle, and high power AM transmitters for LF and MF were made using the hybrid ferrite system where the outputs of many low power modules were added together.

Let's go large from 500W to 500kW

Andy Matheson, G3ZYP, has first-hand experience of the work done initially at Crowborough by the HMGCC/DWS/CED of the FCO in the combining of two MF 250 kW Doherty transmitters. The work there culminated in the arrangement at Orfordness where, until recently, the two Doherty transmitters were in service.

Here, 500 kW working was achieved by combining in the antenna system. Separate feeders leave the transmitter building and terminate in two ATHs in the field.

G3ZYP has written an information sheet for amateur radio clubs and other interested visitors to Orfordness and part of it, pertinent to 1296 kHz, is reproduced below and in Figure 7

This 6-element array was built by Eve Construction for the FCO in 1977, and commenced operational service in 1978. There is only this one 1296 kHz antenna at Orfordness. No standby antenna was provided for this frequency.

The driven central towers are configured as 'umbrellas' i.e., as folded monopoles with grounded base, top-driven with a wire cage.

These central towers were originally driven in-phase by separate transmitters (ORF 2A and 2B), each of 250 kW carrier power. Phase is monitored at driven tower bases and at the ORF 2 transmitter units.

In the event of a failure of one of the Doherty transmitters, auto-switching inside the transmitter building ensured that from the remaining transmitter, 125 kW went down one feeder and 125 kW down the other.

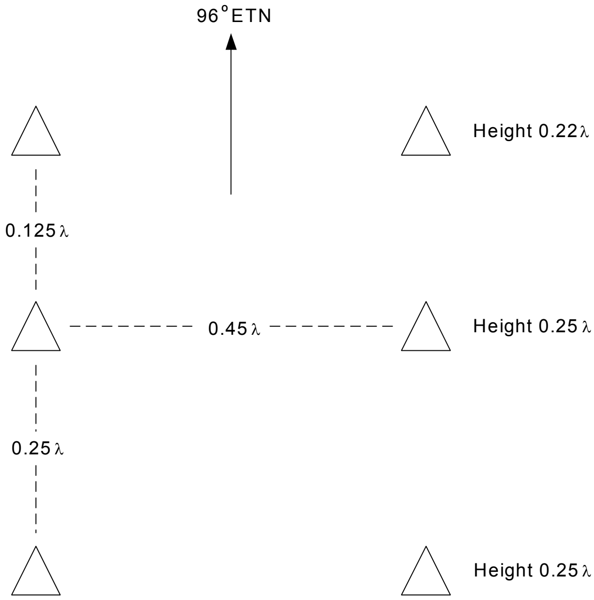

Figure 7. Orfordness; six tower 1296 kHz antenna

When used by the new Nautel 200 kW transmitter ORF 4, the coax feeds from both driven towers are paralleled at the 1296 kHz Antenna Switch and fed via a 50/25Ω L-network.

The beam width is 55° at the -3dB points. The take-off angles are between 4° and 20° to the horizontal. The maximum gain is 8dB relative to a single quarter wave radiator, which at 500 kW working, equates to about 3.5 MW ERP. This antenna was designed for optimum sky wave radiation.

Provided the phase of the RF sent to the (effectively separate) antenna systems is kept constant then maximum power is on the 96° bearing.

During 2000-2001, Orfordness serviced a contract for a Dutch domestic broadcaster Radio Nationaal, with a bearing of 86° required for the most favourable signal placement into Holland. The slew to the beam of 10°, was accomplished by adding an extra length of RG-58 coaxial cable to the 50 Ohm drive input on one transmitter. It was auto-switched out for the BBC transmission as required.

It's the Cold War… We need more Watts to get to Russia!

The idea of combining using the antenna system was not confined to MF services. Indeed it had been initially tested at Daventry in the 1950's using Array 51.

Pete Edwards, G8EFM, has kindly ventured into the recesses of his memory to recall…

"The outputs of two MWT 100 kW SWB18 senders were sent to opposite (side) corners of a Wheatstone bridge arrangement of quarter-wave lengths of twin feeder. The feeder out to Array 51 was from the (top) port and the (bottom) port was connected to a dummy load which was a fat, folded dipole, essentially directing any power sent to it directly into the ground.

The RF drive input to one of the SWB18s went via a coax, the absolute length of which could be shortened or lengthened by the use of some three-position GPO key switches labelled with a coarse phase change indications of 15-30-45 and 60-90-180 degrees.

Final tweaking with a variable control for a minimum, with reference to a meter driven from rectified pick-up of radiation from the folded dipole, ensured the 200 kW was all out to the array."

Daventry Array 42A and 42B and 500kW

During the time the author was at Daventry in the 1970's, the above experimental HF A51 arrangement had been superseded by a very similar system to that used at Orfordness, where two separate antennas were used, each one fed by a separate sender. For the 5975 kHz 80° Russian (one hop) and Far Eastern (three hop) services, two 250 kW senders were used to Array 42A and 42B. In addition, it could be reversed to 260° to serve the Caribbean as well as being slewed to 68° and 92° to cover different parts of Russia and Central Europe.

Pete Edwards, G8EFM was able to reinforce my memory; here is his detailed account…

"Each half of Array 42 was driven by a MWT BD 272. The phasing monitoring was from a pair of pick-up loops, supported on nylon poles, under the same point from the bottom dipole on each half-array.

The RF from each monitor loop was rectified in diode ring units made by Matheran Products with the dc feeds sent to the transmitter building. There an op-amp circuit drove a servo that tuned the phase for a minimum; again by altering the "effective length" of the drive line to one sender".

In and out of phase!

G8EFM thinks that 2 x 250 kW working was originally introduced to overcome jamming on the BBC Hungarian service in 1968/9. He continues to recall…

"On one occasion, it was reported from the BBC Far Eastern Relay Station (FERS) that there had been a drop in received signal strength at 23.59 GMT when Daventry went to 500 kW working on the 80° bearing from the previous single, solo 250 kW transmission on 80°.

Tests at the nearby village of Norton (right underneath the correct bearing/beam) showed that we must have been reducing our output for some considerable time as there had been a reported problem with one of the Matheran loops, and it had been replaced with a spare before the query came in (eventually) from FERS.

Upon examination of the old and new detector units we found that, in the new one, the manufacturer had wired the diode ring in reverse! So with "incorrect polarity" being sent, the servo unit was doing exactly what was asked and it reversed the phase to one half of the array to compensate. Hence was produced, a 180° cancellation of RF rather than an addition!"

Postscript

It looks like my allocation of Signal pages is complete for this issue so it is intended to present more photographs and some background information in the next issue.

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Doherty output stage

Comment by Bronek Wedzicha, M0DAF

Above, the author refers to transmitters using a Doherty circuit. with which readers may not be familiar. This is an arrangement which dates back to 1934, whereby the output stage of the transmitter consists of a valve operating in class B, effectively in parallel with one operating in class C. It is used to amplify a low level AM signal which may have been produced by grid modulation of a carrier in an earlier stage. The signal is split and applied to both output valves. Their outputs are subsequently summed and corrected for phase difference. The success of this arrangements stems from the way that bias is applied whereby, at low modulation levels, the signal is amplified by the class B stage. This saturates at high modulation levels, when the class C amplifier provides the peak carrier power. High power broadcast transmitters have often used this approach because it results in much higher efficiency than may be achieved with a conventional linear amplifier.

A series on AM theory and practice

Three of our regular contributors to Signal will start a series on the theory and practice of AM in the next issue of Signal. In this they will explore both well known and less common methods of producing AM, and will describe experiments incorporating some of these techniques in amateur transmitters. Readers may be surprised by the huge number of different ways in which AM can be generated, the extent to which the carrier level can be manipulated, and how it is possible to produce in excess of '100% modulation' without 'over-modulating'. With transformers for high level modulation of QRO final amplifiers in AM transmitters becoming scarce, other ways of providing high level modulation clearly become attractive. Some solutions will be explained.

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