Tricks of the Trade

Dave Porter G4OYX

In the last ToTT **[1]** we looked at the requirement for antenna matching networks for LF and MF antennas. We continue, again using the BBC's Technical Instruction TT.5, first to explain a little more about the mathematics involved and secondly to investigate the actual networks needed to transform a pure resistance upwards and downwards. These are the simplest and easiest to deal with as no complex impedances are involved.

Series-to-parallel impedance conversions

It was fortunate that, in issue 59 of *Signal*, the use of the operator 'j' notation was demystified by G8FHL **[1]** as that can be seen by some as a barrier (rather like the Morse requirement was to obtaining a Class A amateur licence). Luckily though, TT.5 was written with mentions of the operator but many of the worked examples were almost j-free. Essentially, all that one required to know was that +j indicated a term that was inductive and a –j, capacitative. Mention is made in TT.5 of series-to-parallel impedance conversions and, again, these can strike terror into those of us who shied away from too much mathematics at school and college. As with the operator j, this point has been covered before in *Signal*, in this case by Peter Chadwick G3RZP and those interested in delving more into the subject can search out the information in **[2]**.

Suffice to say, any impedance represented by a resistance in series with a reactance is equivalent, at any given single frequency, to a particular parallel combination of resistance and reactance. So, for example; the parallel equivalent of 38–j76 ohms is 190//–j95 ohms and the conversion is derived totally by mathematics. TT.5 quotes as follows: *A far-reaching consequence of the series-parallel equivalence impedance rule is that, even though an impedance may actually consist of elements connected in series, it is perfectly legitimate to treat it as though it existed in the form of its parallel equivalent and the converse holds good. It must also be emphasized that the equivalence holds good at one particular frequency.*

For the purposes of this ToTT, it is appropriate to say that the vast majority of measuring and test equipment available during and after WWII would present the impedance measurement in parallel form.

The Wayne Kerr B 601

The standard RF bridge that was found on the BBC transmitter sites and no doubt within the BBC Research Department was the Wayne Kerr B 601 (**Figure 1**). The company began as the Wayne Kerr Research Laboratories in London in 1946. The company, named after their favourite actor and actress, Naunton Wayne and Deborah Kerr, was started by two engineers who had been working for the BBC. Their first product was an admittance bridge used to test broadcasting equipment.

On the BBC main high power LF/MF sites by the late 1960's at least, it was common-place to see an RF test trolley fabricated from Dexion components (a sort of professional Meccano, no doubt very familiar to many in VMARS). Within the trolley would be four vertical compartments: the uppermost would contain the Wayne Kerr B 601, usually surrounded by rubber or similar foam as side and rear cushioning supports, the base being made of plywood. The connection plate of the B 601 would be proud at the top and in the clear to allow the test leads to be terminated. Next down would be a communications receiver, usually one by Eddystone, the 680X being typical in both performance and size, again on a plywood base. In the third compartment would be the matching Wayne Kerr oscillator with a vernier panel drive and separate switched output attenuator, along with an option to select carrier only, CW or modulated (at about 1 kHz) carrier, MCW. Below that in the fourth compartment would be the mains power supply for the test oscillator. The whole frame was on rubber-wheeled castors so it could be trundled from the building and then outside to the ATH.

Figure 1. The Wayne Kerr B 601

The practicalities

It was customary to plan a scheduled bridging session in advance as various criteria would have to be met:

- A fine, dry preferably summer night (as, of course, the site would be on air during the daytime carrying domestic services, usually Home Service and Light Programme) as the trolley had to be wheeled from the main building to the ATH. Summer is better as the period of the Continental interference coming in is of a shorter duration than that in mid-winter. It is important to remember that a 500-foot mast or large Tee transmitting antenna also makes for an excellent *receiving* antenna. Co-channel and adjacent stations, for example RAI Milano on 899 kHz, caused great difficulties with sideband splash at Brookmans Park when listening for a tuned null on 908 kHz during the hours of darkness.

- The test oscillator and communications receiver would need to be switched on by the evening shift staff, a good few hours before use to warm-up thoroughly.
- As late as possible, before wheeling out the trolley, the calibration of the oscillator would be checked by zero-beating against the station's crystal drive for the required frequency. There were no calibrated digital frequency counters in those days.
- Great care was needed in transporting the trolley as the wheels were small in comparison to the sometimes pot-holed pathway surfaces, over what could be a good distance. For example, again at Brookmans Park, it was 200 m from the main building to the F1 mast radiator and ATH that carried the 908 kHz service. Even the two Tee antennas, north and south, have ATHs that are 125 m from the building, the reflector mast ATH for what was the Light Programme on 1214 kHz was 60 m distant. In wartime, the 200-foot masts themselves were sometimes employed as base-fed antennas and they each were 160 m from the building.
- Time constraints needed consideration. With a 0205 local finish and a 0500 start for the Light Programme by the early 1960s, this only left a three hour window. It was trickier at Droitwich as, in the winter on GMT, the domestic 200 kHz LF service would close at 0205 coming back on at 0300 GMT for the overseas Russian transmissions until 0430 with the regular domestic service on for 0500. It was slightly better in the summer as the Russian transmissions would not start until 0330 local time, again 0230 GMT and be on for just the 90 minutes. It was far easier at Washford from March 1950 until the start of Radio 1 in 1967 as there was only the single 881 kHz Welsh Home Service which closed after the shipping forecast around midnight and came on for 0600
- If bridging and then major adjustments were required, then it was easier to split proceedings over a few nights so that the required calculations from the readings could be done during the daytime by the wide-awake dayshift and components/ assemblies fabricated in the main building, ready for night-shift transfer, actions and measurements.

Henry and Tom in Somerset

Scouser Tom Reston was a colleague of the author at Brookmans Park. Prior to his transfer there, he had been the Station Engineer at Clevedon in Somerset. This had been a minimally-staffed site for many years previous and was automatic outside of office hours. Starting in 1939 as the Home Service for Bristol, it transmitted on 1474 kHz and was staffed 24/7 as 20 kW water-cooled transmitters were employed. Later it was re-engineered with air-cooled sets so constant staffing was not required. In Tom's time, it was to be re-engineered again with the addition of a second, local radio service.

The antenna requirements for combining the two services were allocated to a head office field engineer, Henry Willis. He was very experienced in both antennas and fabricating BBC home-built MF and LF transmitters. Tom described the series of nights when Henry had been on site after closedown at 0005. Previously, Henry had been mooching about bridging the antenna and taking measurements, *etc*. but this night was to be the changeover.

Tom had left Henry to his own devices setting-up outside and was busy in the building closing down the transmitter to make safe and ready for the works outside. He gave Henry the safety "all-clear". Tom being Tom thought a cup of tea to start with would be agreeable.

A one way street – no going back!

Tom took the tea out on a tray (no mugs in those days) and was instantly horrified to see Henry attacking the copper tube components in the ATU with an 18 t.p.i.-bladed hacksaw; he was even more horrified to see there was already a pile of said scrap on the grass outside and that its size was ever-increasing. There was absolutely no way that this original ATH configuration could be re-instated.

Tom need not have feared as Henry had done all the planning properly and had the new components and connections to hand. In the near six hours available, he had all he needed in place. His bridge measurements and the settings subsequently applied ensured a match to the original feeder at 908 kHz. The other network for the new 1546 kHz service was ready to go and was tuned up the following night.

As an aside, a little more on Clevedon

It would appear that this work at Clevedon may well have been intended to be only of a temporary nature anyway as, after the consolidation of Home Service channels after September 1972, there was a rush to give existing and future BBC and ILR services an MF outlet. Radio Bristol had been on air since September 1970 on VHF/FM only and, with the clearing of 1546 kHz for both BBC and ILR use, MF was then available. Few funds were allocated to this expansion as local radio was run on a shoe-string, hence the idea to co-site it at Clevedon using the single mast radiator. This is why Transmitter Department operational staff effected the ATU and transmitter build and not the BBC specialist, Transmitter Planning and Installation Department. Whilst it provided an omnidirectional service area covering most of north Somerset including the city of Bristol, reception in the south of the county around Taunton was patchy. The fix could have been more power than the 2 kW allocated but with ILR London, Capital Radio on-air in 1974, there was not to be too much radiation in that direction.

To better-cover the required area, a new site had been obtained at Mangotsfield to the north east of the city and the BBC MF specialists in the then newly-named Transmitter Capital Projects Department did the installation. It came on air with a two-mast directional service replacing Clevedon in March 1976. A few years later, Taunton was given an MF relay as well – again from a converted DF site and Radio Bristol was re-named BBC Somerset.

Clevedon again reverted to a 908 kHz single-frequency service; even the previous change in frequency had not been without problems as, after the September 1972 Home Service changes, the people of Swindon were denied a decent Radio 4 MF service, being situated not only in the 908 kHz 'mush' area between Brookmans Park and Clevedon but also in the 1052 kHz 'mush' area between Droitwich and Start Point. The eventual solution

was to provide a 500 W local service by repurposing a pair of RCA/BBC ET-4336s at the former Deferred Facility site in the town itself on the borrowed/piggy-backed Northern Ireland Home Service channel of 1340 kHz.
With the prospect of the 1978 wavelength changes, a proper solution was expedited at Clevedon in 1977 and a second 100-metre mast was erected to null radiation towards London, the Home Counties and the south east for 908 kHz (and later 909 kHz). This moved the ‘mush’ area into the countryside to the west of Swindon and the town’s 1340 kHz service was closed at the start of the 1978 major changes. A Marconi B6034 transmitter was installed; so an output of 50 kW was available if required, but 25 kW was the service option initially.

Transforming a pure resistance up and down

One may ask the question as to why would you want to transform a pure resistance up and down at RF? Surely, most of the networks needed are in ATHs and match the antenna to the feeder. Well, yes that is true but there are occasions, particularly when dealing with legacy equipment, when just an impedance/resistance change is required.

A good example of this was again at Brookmans Park, coming up to the November 1978 changes for the then new Geneva Wavelength Plan. Major changes were happening at all the BBC MF sites, often with the addition of one or even two more high-power channels.

Plan A

Brookmans Park gained 1089 kHz at an output of 150 kW. The original plan was to provide a directional service on this new frequency from the southside-Tee antenna with the Wincharger™ mast at a nominal quarter wave distance. This directional system had been in use since the late 1940s, first on 1149 kHz at 50 kW and then, after 1950, on 1214 kHz at 50 kW and, in the early 1970s, with a combined additional 20 kW on 1457 kHz for BBC Radio London.

Later, the output was increased from 20 kW to 50 kW with active power splitting to achieve nulls in certain directions. From November 1978 and onwards, the new 1089 kHz 150 kW Radio One service was to be added to this southside system.

EMI Antennas of Hayes, Middlesex were awarded the contract to build, equip and set-to-work new ATHs. In the event, after many months of work, much of it overnight, it was found impossible to achieve a working system with what would eventually have a combined total power output of 250 kW and the many constraints of the phasing for 1458 kHz and general parasitic λ/4 reflector for 1089 and 1215 kHz. There were many flashovers in the cabinets and undesirable impedance variations over the 9 kHz passbands on the now three frequencies, and that was when powered on just the two existing 50 kW + 50 kW, 1214 and 1457 kHz channels.

Plan B

By now there was only a month or so to go before November 23rd, so a hastily contrived Plan B was initiated. The southside was to stay as it was with just the two (1458 kHz and 1215 kHz) services, albeit with a transfer at some time in the future to the new EMI ATH, and with just the addition of one additional network in the old southside ATH, a 1089 kHz rejector circuit.

The pro-tem fix

The seven and later eight B6034 50 kW Doherty transmitters had been installed by Marconi Communication Systems in what had been the old machine room from 1929. This room had been completely stripped bare prior to the installation. However, the old transmitter units were still in place in what had been the fairly untouched original transmitter hall next-door. For one of these Regional transmitters T1, its output pair of 25 kW “C” Units was combined in the “D” Unit. An 80-ohm coaxial feeder ran all the way from the D Unit out to the northside ATH. It was decided to employ both the feeder and the north Tee antenna for the Radio One 1089 kHz service. This feeder was rated at up to 80 kW and comprised concentric copper tubes and ceramic support insulators. It was of 1940 wartime construction and had replaced the original 550 Ω balanced twin open wire feeder from 1929.

At last: the pure resistance transfer

Les Rottier G6BTQ (now SK), who was a BBC Antenna Project Engineer, was “volunteered” and put in charge of this emergency exercise. Within the now redundant D Unit, he designed and built, mainly from station surplus, a pure resistance transforming network; he had a 1.625-inch diameter incoming 50-ohm Andrew feeder from the triplexed set of B6034s and the 80-ohm outgoing feeder. On this exercise, G6BTQ was possibly slightly out of his comfort zone as his ‘normal’ antenna and feeder work was some 600–800 MHz higher, being UHF TV. Due to the constraints of the 80 Ω feeder, the 1089 kHz service was set to 75 kW at the start. The Tee antenna provided an omni-directional pattern, so this power reduction was sensible so as not to affect the service area of co-channel sites, Moorside Edge and Washford. It was noted on shift that, as the temporary 50-ohm feeder wended its way *via* the crypt in a circuitous route from what was now the new transmitter hall to the old transmitter hall, it did run fairly warm to the touch on the deliberately gentle bends, that was another good reason to run only half allocated power.

The Old Timer’s adjustment

Eric Spicer (now SK) was an OT Senior Maintenance Engineer at Brookman’s Park having been promoted to there in the 1950s and many years prior to that he had cut his teeth at OSE3, Rampisham. On shift we had noted that the VSWR shown on the output of the Marconi triplexer was about 1.15:1. While unimportant for many, for Eric it was probably a little annoying as he was a stickler for having things done properly.

One Monday morning when Marconi engineers were in installing their eighth and final B6034 (Radio 3 on 1215 kHz replacing T6 from 1962) they noted that the VSWR meter for the 1089 kHz service was not reading at all (or so they thought). In actual fact, on night shift over the weekend, there had been a station shutdown for some (other non-RF) reason and Eric had used the Wayne Kerr B 601 and Dexion trolley to make a few adjustments to the G6BTQ network. The transfer of 50 Ω to 80 Ω was so good now that the VSWR meter showed a perfect 1:1 match. MCSL were relieved to know that they did not have to effect a monitoring repair under guarantee.

G6BTQ had also been involved in the temporary 75 kW 1089 kHz networks in the north Tee ATH and we'll look at that next time as it was upgraded later to 150 kW.

TT.5 and the up/down transformer

TT.5 describes resistance transformers as L-Type transforming networks; they were also known as "Green transformers" in the trade but there was no clue as to the derivation of that name. TT.5 also describes in great detail the derivation and mathematics behind the formulae but, for our purposes, it is easier to adopt the old adage of "thus it can be shown" and then proceed with the subject. On the night shift measuring sessions, with perhaps a rough calculation or two, this was altogether a better approach. It was possible to substitute the measurements into the TT.5 worked example and achieve the required result.

The pages that follow are an adapted transcript of the relevant information from TT.5. These show data on transformation downwards from 1900 Ω to 550 Ω at 668 kHz with the component values required. This is followed by an example transformation upwards from 139 Ω to 300 Ω at 1013 kHz and again component values are detailed.

Design formulae: L-transducer

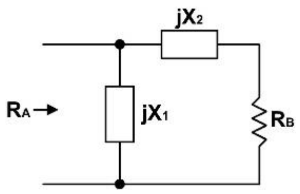

Figure 2. Downwards L-transducer

Figure 2 shows an L-type transducer which is transforming the resistance value R_A down to a lower value R_B. The required values for X_1 and X_2 can be calculated by the following simple formulae:

$$X_1=\pm\frac{mR_B}{\sqrt{m-1}}$$

$$X_2=\mp R_B\sqrt{m-1}$$

where

$$m=\frac{R_A}{R_B}$$

This design is reversible in so far as if R_B were to become the source resistance then this can be transduced to a higher value R_A using the same formulae,

In treating the above formulae as general design formulae, applicable to either downwards-L or upwards-L trans-ducers, possible confusion will be avoided if the following are noted:

(i) X_1 is the shunt reactance and X_2 the series reactance.

(ii) *m* is the ratio of the larger resistance value to smaller resistance value.

It would be normal in many applications for the series reactance to be inductive and the shunt reactance to be capacitative, thereby allowing DC continuity between the source and the load, in which situation the positive value of X_2 and the negative value of X_1 would be adopted. The alternative designation of the two reactances, *i.e.* the series reactance becomes capacitative, leads to a DC-blocking arrangement, but one where any DC at the source is shorted out.

Example 1. What are the reactance values for an L-type transducer of the form illustrated in **Figure 2** which will transform a resistance of 550 Ω to a resistance of 80 Ω?

Answer:

$$m=\frac{550}{80}=6.875$$

$$\sqrt{m-1}=2.424$$

From **equation for *X₂***, X_L = +80 x 2.424 =+193.9 Ω

From equation for *X₁*, X_C= –6.875 x 80/2.424 = –227 Ω

Example 2. Calculate L and C values and draw the circuit of a transducer of the form illustrated in **Figure 2** which will transform a resistance of 1900 Ω to a resistance of 550 Ω at a frequency of 668 kc/s.

Answer:

$$m=\frac{1900}{550}=3.45$$

$$\sqrt{m-1}=1.565$$

From **equation for *X₂***, X_L = +550 x 1.565 =+860.8 Ω

$$L=\frac{860.8\times10^3}{2\pi\times668}=205\ \mu H$$

From equation for *X₁*, X_C= 3.45 x 550/1.565 = –1213 Ω

$$C=\frac{10^9}{2\pi\times668\times1213}=196\ pF$$

The diagram is shown as **Figure 3**.

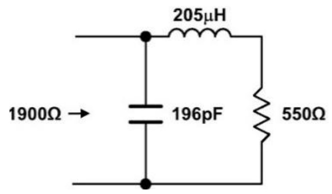

Figure 3. Answer to example 2

Example 3: Sketch the diagram of an L-type transducer of the type illustrated in **Figure 5**, which will transform a resistance of 139 Ω to a resistance of 300 Ω at 1013 kc/s. Mark in L and C values.

Answer.

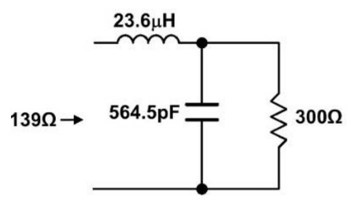

Figure 4. Answer to example 3

$$m=\frac{300}{139}=2.16$$

$$\sqrt{m-1}=\sqrt{1.16}=1.08$$

From **equation for *X₂***, X_L = +139 x 1.08 =+150.1 Ω

$$= \frac{150.1 \times 10^3}{2\pi \times 1013} = 23.6\ \mu H$$

From equation for X_1, X_C= 2.16 x 139/1.08 = –278.1 Ω

$$C = \frac{10^9}{2\pi \times 1013 \times 278.1} = 196\ pF$$

Conclusion

As can be seen from TT.5, the documented procedure is thorough and, even on night shift, it was possible to achieve something… but it may have taken a few attempts.

Next time we will look at the practicalities of setting up the transformers and the pitfalls awaiting.

Luckily, by the late 1970s there was an alternative available to the Wayne Kerr B 601 that was a lot easier to drive… and it was rated to 10 kW.

References

1. D Porter G4OYX. Tricks of the Trade. *Signal* 2021, **59** (May), 41–44.
2. D Green G8FHL. j-Demystified. *Signal* 2021, **59** (May), 45–47.
3. PE Chadwick G3RZP. Antenna couplers/ATUs/ Transmatches. *Signal* 2018, **47** (May), 25–30.

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