Tricks of the Trade

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In the previous ToTT **[1]** we looked at a simple two-mast directional antenna system for dual frequency operation; in this issue of Signal, another directional antenna (DA) system is explained. It was referred to in **[1]** as *Option 3*, whereby a DA may be used to enhance the field strength in a specific direction. To fully realise the whys and wherefores for this requirement, it is best that the historical aspect be reviewed.

Nearly a century

When the first radio broadcasts were heard on LF and MF nearly 100 years ago, the airwaves were clear and uncontested and the transmitter power was measured in watts. When more broadcasters joined the fray, aiming for wider audiences they wanted more power to transmit ‘louder’ than their rivals. As better valves became available, it was possible to design AM transmitters with carrier powers of a few kW and then, by the mid-1930’s, the average power was 50 kW with a few notable exceptions, *i.e*. Radio Luxembourg (LF) running 200 kW and WLW Cincinnati running 500 kW.

In pre-war Europe, LF was the desired frequency range for broadcasters as it does not suffer from fading or seasonal variations and is not subject to the hazards of ionospheric reflection within the intended service area.

MF is very much more affected by ionospheric reflections at night which, for domestic services, caused selective fading near to the edges of the service area and, if synchronised operation was used with a number of sites co-channel, the effects were even worse.

With the political situation in Europe becoming unstable after WWII and the start of the Cold War, there was a move towards ‘International Information Broadcasting’; after all, it had been used to advantage by The Allies with Aspidistra from the UK for the wartime White (BBC), Grey (for example, Soldatensender Calais) and Black (Political Warfare Executive) 600 kW multi-directional services. This was on MF and the night-time effect of complete sky-wave coverage was now a virtue in disguise. To its LF service, Radio Luxembourg had, by the early 1950’s, added MF on 1439 kHz (208 m) initially running 200 kW then, by the 1960’s, 600 kW and, by the early 1970’s, 1200 kW switchable into two different DAs; one for Germany during daytime and the other for UK and Ireland at night-time.

In 1954, the Americans commissioned a 1000 kW LF unit in Munich on 173 kHz which was now co-channel with the USSR Moscow legitimate 300 kW service. The ‘ink on the paper’ of the Copenhagen Plan of 1950 was hardly dry when the Munich out-of-plan service was listed. There were, by 1977, almost as many out-of-plan listings on the ITU/EBU chart as there were the legitimate ones.

Technical author James Wood put it nicely in June 1990 when he wrote, “Broadcasting by Long Wave is stable, but it is also very expensive. To provide a reasonable signal at a distance of several hundred kilometres takes a carrier power of 1000 kW or more. Nevertheless information broadcasting has become a part of every nation’s foreign policy; cost, therefore, becomes a secondary consideration” **[2]**.

Almost all in Europe have one… and in Taiwan

With Governments usually paying for broadcast output, there was a flurry of new installations, some were omni-directional, for example the Norwegian, Kvitsoy 1314 kHz site running 600 kW and a three-mast directional site at Cyclops, Malta for Deutsche Welle relay on 1557 kHz running 600 kW in the 1970s, where the masts were used in a line to give not only a beam on a certain bearing but also with nulls at 0°, 22° and 325°. There were some transmitter installations in West and East Germany typically running 600 kW or 800 kW ‘dispensing’ the thoughts of the Western and Russian Governments. Most of the antenna arrays were ‘straight-up’ NVIS sky-wave radiators on MF. Berlin-Britz on 854 kHz in the Allied Sector within the city was an example.

Not all broadcasting was Government-funded, as the French programme private broadcaster Europe 1, employed in 1954 a four mast in-line antenna near Saarlouis, each mast averaging 276 m in height, at their Felsberg-Berus site right on the French-German border, in fact just the distance of one field into Germany! The transmitter was on 180 kHz and by the 1970s was running 2000 kW. It was a classic Cold War compromise as there was only one LF channel available for Germany, 182 kHz: but two Germanys at the time, East and West. The East German Oranienberg, Zehlendorf site had a 500 kW transmitter on 185 kHz and an omnidirectional 357 m mast. Note the split frequencies on the ‘official 182 kHz channel. The RF from Europe 1 was heavily attenuated in the direction of East Germany and with four masts concentrated into France; a ‘win-win’ situation… but at great engineering cost. This station closed down at the end of 2019.

This ‘off-channel’ operation was also employed by Radio Luxembourg who, in a 1964 band plan, are seen to be out-of-plan on 233 kHz rather than on the official channel of 236 kHz shared with Leningrad.

Another Cold War oddity in 1964 showed the official 155 kHz channel with two in-plan stations, Tromso and Brasov, being nudged by out-of-plan Mainflingen (West Germany) and Moscow, both on 151 kHz.

In the former USSR near Kaliningrad, was the Bolshakovo transmitter site. It was used by the Voice of Russia for broadcasting on 1116 kHz and 1386 kHz with a maximum transmitter power of 2500 kW. An SV4+4 ARRT-antenna with eight guyed in-line masts was installed. The masts, built in 1974, were 257 m in height. The station closed down on 1st November 2007.

The apogee of development and installation of high power directional systems was probably at Roumoules, France. Following on from the Radio Monte Carlo (RMC) 218 kHz original wartime Fontbonne site, Roumoules in the Haute-Provence Alpes near the Côte d'Azur was commissioned in 1974 to run up to 3000 kW carrier on 218 kHz (later 216 kHz) into an in-line three mast antenna with 5.6 dBi gain on a bearing of 309°. A 1000 kW dual frequency system for MF was installed by 1987; this employed a five-mast pentagon-shaped antenna with a gain of over 13 dBi. During the day, RMC broadcast on 702 kHz at an azimuth of 170° towards Italy. At night, the transmitter was leased to Trans World Radio on 1467 kHz on any one of four bearings with beam widths of 32° (at the -3 dB response points) with gains (dB) as follows:

- 25° towards the DDR (at the time) and USSR east of the Urals. 8.6 dB
- 85° towards (the former) Yugoslavia, Hungary, Romania and Bulgaria. 8.4 dB
- 240° towards North Africa, Spain and Portugal. 6.0 dB
- 320° towards UK, France and Scandinavia. 8.5 dB

Another multi-mast array worthy of note is at Ta-Han in Taiwan. Here 1200 kW on 927 kHz is sent on a beam of 310° to their target audience in China… What is slightly disconcerting is that the installation is right in the middle of a built-up residential area.

Many of the oil-rich Arab states had installed high power MF stations with multi-tower arrays and the next section describes a typical installation. Examples are in Kuwait, both before and after the Gulf War, and in Saudi Arabia.

High Power multi-element Yagi antennas for MF

Chris Pettitt G0EYO summed up the parameters of DAs in **[3]** which he authored and following is reproduced from that document:

"DA systems can range in complexity from a simple fed radiator with a tuned parasitic reflector to a multi-radiator system where all the radiators are fed in varying current phase and amplitude providing a careful control of the horizontal and vertical radiation pattern. Often, there is control of the direction and depths of the nulls in the radiation pattern which is more important than simple directive gain. This can only be achieved if each radiator is fed (as opposed to being excited parasitically) and the amplitudes and phases of the radiating currents accurately controlled.

The problem facing the antenna design engineer is that, whilst it is easy to determine the pattern and gain of a DA when all the proposed design features are known such as the electrical spacing between the radiators, the height of the radiators, the geographical orientation of the radiators and the relative amplitudes of both the currents and the phases in the radiators, it is the reverse of the problem that needs to be solved; a pattern template will be established which will determine the effective radiated power required to cover the service area and protect the co-channel areas. The problem then becomes one of determining the radiating current amplitude and phases to produce that pattern. The normal process is to start with an established pattern which nearly fits the requirement and make changes to the amplitudes of both phase and currents until the optimum pattern is obtained.

Determining the radiation pattern of a DA with more than two radiators is complex as the parameters increase rapidly with extra towers. For two towers, there are three parameters. With three towers, there are now seven parameters and with a four radiator design there are eleven.

The effect of changing the radiating current amplitudes and phases will be to control the position of the nulls and their depth. Basically, the phase differences determine the angular position of the nulls and the amplitude its depth.

There is a fundamental relationship between the width of the main lobe and the gain and vice-versa. Therefore, for an end-fed array of four λ/4 masts having a main lobe width of ±40°, a gain of 12.8 dBi must be accepted and, as such, the appropriate transmitter power must be selected to satisfy the ERP requirement.

R5600 **[4]** describes the standard six-mast solution and is reproduced here:-

The six element MF Broadcast Yagi Antenna is a λ/4 high tower radiator with a reflector tower and four director towers each spaced approximately λ/4 apart (**Figure 1**). The radiator tower is surrounded by a vertical monopole cage of 4, 5, or 6 wires (**Figure 2**). By folding the monopole, the driving-point impedance can be made to be about 100 Ω and be directly matched to the MAS R3005 100 Ω high power feeder without the need for any high power matching components (**Figure 3**). In addition, the tower is earthed and so major savings will be made by the absence of base insulators, obstruction lighting transformers and static leak devices.

The system includes a radial earth comprising copper wire radials λ/4 long every three degrees (120 in total) on each tower. Each system is designed for a discrete frequency on the MF band. The other specifications were: maximum carrier power 1.5 MW plus 100% modulation, forward gain 10dBi, vertically polarised radiation and a VSWR of 1.1:1."

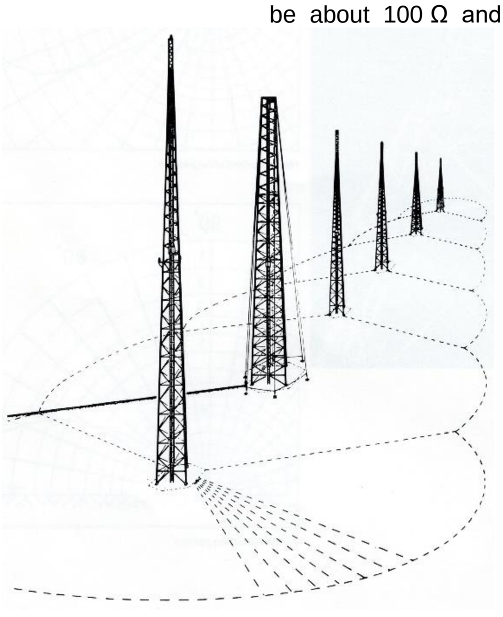

Figure 1. The 6-tower directional array

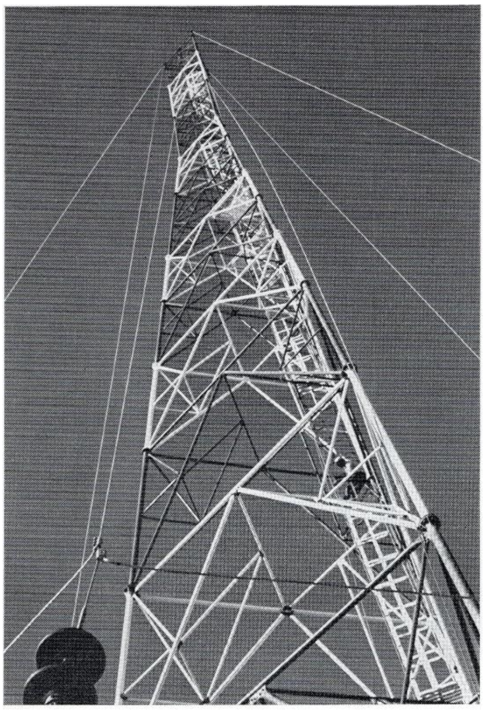

Figure 2. Radiator tower

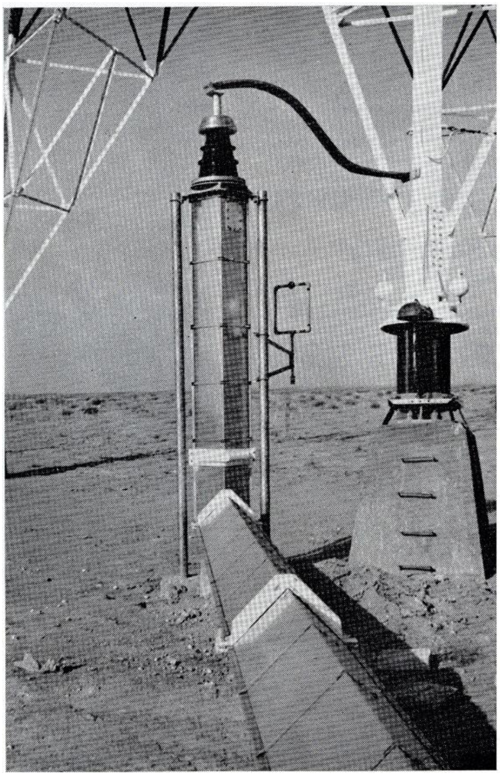

Figure 3. The 100 Ω feeder

Orfordness 648 kHz by 1981

The Orfordness site was the replacement for the then ageing Aspidistra installation. The 1296 kHz service had already moved there in 1978 with an antenna of 6 masts-in-a-square comprising a pair of driven-element radiators with parasitic reflectors and directors. ORF2A, a 250 kW Doherty transmitter, fed one radiator and ORF2B the other **[5].**

Marconi Antenna Systems (MAS) were commissioned to design and install a six-element Yagi for 648 kHz. Their R5600 design was the first proposal. The coverage template was a BBC/Foreign and Commonwealth Office joint document and the projected solution did indeed have six towers. However, during the resolution process alluded to by G0EYO, MAS discovered that a five-mast array would be fine and the template would be covered.

Now with five towers, it was decided to feed the driven tower with 600 kW *via* a 6.25-inch 50 Ω feeder and incorporating power splitting and phase adjustments in a master antenna tuning hut (ATH) at the base of the driven tower. There was no vertical monopole cage of wires; the tower was insulated from earth and base-fed. Four other slightly smaller coaxial cables would leave the master ATH and go to ATHs at the bases of the other similarly base-insulated masts. All the phase monitoring would be incorporated into the driven ATH and be sent back to the transmitter building.

The 'London lobe'

G0EYO wrote about control of the nulls and lobes and how more towers add complexity but more control. Well, it would appear that having only five towers did help as there was a considerable lobe right towards London and a good quality 648 kHz service was audible there.

G4OYX was at Orfordness when we were made aware that the 'London-signal' was a 'good few dB' down in strength. The monitoring data from the transmitter hall did not appear unusual but we did take the opportunity to run the reserve ORF3 180 kW transmitter into the omnidirectional spare antenna and check out the five-mast system. What had happened was that one of the tuning inductors in the driven, master ATH had succumbed to a lightning strike and two turns of the coil were spot-welded together; after a quick use of a hacksaw between the turns and file clean-up/burnish it was as good as new. Resumption of the service to the array returned the 'London lobe'. That inductor was probably 10–15 µH per turn and so the specified set inductances were most critical to template-covering operation of the array.

The array's main lobe was at 110° and put a solid, reliable daytime signal into Germany (as the target) and the Benelux countries with further into the Eastern Bloc in the hours of darkness. The ERP was quoted at 6 MW.

Next time

Having now covered Option 3 at high power we will look at the much lower power options of 4, 5 and 6 covering BBC and Independent Local Radio in the main.

References

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2. J Wood. Speaking unto Nations. *IEE Review* 1990 (June), 237–240.
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4. Marconi Antenna Systems Ltd. R5600. 1980.
5. D Porter G4OYX, A Matheson G3ZYP, P Edwards G8EFM. Tricks of the Trade. *Signal* 2010, **14** (February), 14–19.