Tricks of the Trade

Dave Porter G4OYX and Chris Pettitt G0EYO
with contributions from Malcolm Hancock G8EYY

Readers of the last instalment of ToTT **[1]** will recall that had examined various mast and tower options for MF and LF broadcasting and specifically considered the original antenna installation at Droitwich in 1934. Mention was made of the earth system on the site that, with hindsight, looked rather rudimentary. In this issue we look at the detailed arrangements that would be used today for a typical 50 kW service for both the antenna itself and the earth system. Chris Pettitt G0EYO described this in a Marconi Antenna Systems Technical Sales and Marketing document R5100 published in 1980 **[2].** It essentially contains the near 100 years of experience that we have now accrued in this field as, even since 1980, the techniques are little changed, having been well-proven.

Ground (or Earth) Systems

The MF radiator sets up large currents in the surrounding earth. If the earth were a perfect conductor, there would be no resistance to this current and the system would have minimum losses and a high efficiency. The conductivity of the earth has been documented by the CCIR (in English: The International Radio Consultative Committee) and varies from dry land to sea water is given in **Table 1**.

Conductivity of various earth conditions (CCIR Rec.527 Annexe 1 Kyoto 1978)

	Siemens/metre (S/m) (σ–sigma)
Sea Water	5
Wet Ground	10^{-2}
Fresh Water 20°C	2×10^{-3}
Medium Dry Ground	10^{-3}
Very Dry Ground	10^{-4}

(Above figures remain constant between 525 and 1605kHz).

Table 1. Conductivity of various earth conditions

In order to minimise earth losses it is necessary to use a system of radial earths. Experiments have shown that, at distances greater than about 0.33 λ from the base of the radiator, the earth losses are almost independent of the radiator height however, the losses increase rapidly as the height of the radiator is decreased. Normally, therefore, radial earth wires between 0.25 λ and 0.4 λ in length are extended out from the base of the radiator. The more radials used, the more efficient the system will be. However, it is a law of diminishing returns and the economic optimum number of radials is usually between 90 and 120. Low power and transportable antenna systems can use between 30 and 60 wires. The diameter of the wire used for the radials has little effect on the performance of the ground mat but 12 SWG (2.6 mm) wire is preferred as it is workable but robust if the soft copper version is employed. The radials are buried at about 15 cm (6 inches) deep protecting them from damage or theft. Systems employing very high power up to 2 MW generate large currents in the ground radials and parts of these can run warm or even hot.

It is not unknown for dry surface vegetation to be ignited by hot earth wires. A good connection must be made whenever a radial earth is connected to the matching unit and radiator base.

The trials and tribulations of earths at VLF

A former engineer and then Station Manager at BT Rugby, Malcolm Hancock G8EYY, has recently published a book on the history of the station **[3]** and within are some personal recollections which he has kindly agreed to reproduce in Signal and two are particularly pertinent at this juncture. G8EYY writes:

Personal Memory – Smoke Rings

During winter sometime in the 1970s, whilst walking from the car park into the “C” building, I noticed what looked like smoke rings emanating from the ground.

On investigation, I found them to be rings of steam coming from the earth enclosure. The earth wires on the GBR transmitter came out of the building all around the first floor rather like the spokes of a wheel. This was known as a semi-counterpoise earth system and allowed all the underground pipes, cables and roadway to be worked on without disturbing the earth system. The wires passed over the surrounding road and then down into the earthing enclosure. This is where they were connected to the earth mat. The wires then radiated out over the most of the site just a few inches underground.

Some of the joints were corroding and were getting hot enough to boil the water in the soil, producing perfect rings of steam every minute or so. These, together with the clip-on ammeter readings from each earth wire, enabled the failing joints to be located and then repaired on a maintenance shutdown day.As can be seen, the 350 kW or so of transmitter power was enough to show these deficiencies and similar ones have been seen at Orfordness with the 2x500 kW services that operated there until 2012/2013 and at Droitwich in the 1970s.

Malcolm Hancock also detailed another “earthy” occurrence. He writes:

Personal memory – how to sketch with a cast iron pipe

The fire main/hydrant system, which was fed *via* a diesel-powered pump from the old cooling water ponds near to the “C” building was, by the 1990s, becoming rather old. So it was hardly surprising that we were having more and more leaks from the underground cast iron pipes. After several leaks had occurred over a short period of time along different points in the pipework, further investigation was decided upon.

A piece of the broken pipe was brought into the office. The burst was in the top of the pipe but the pipe itself did not seem to be badly corroded. It was found that the top of the pipe could be easily broken and, upon handling a broken piece, it felt far too light to be cast iron. Cast iron is a brittle alloy of iron and carbon and contains up to 4.3% carbon. It seemed that, over the years, all the iron had leached out of the top area of the pipe. The GBR transmitter was using the pipe as a parallel earth return. Only the top of the pipe had been damaged as that only had water up against it when the fire diesel was running and the pipe pressurised. The lower parts of the pipe contained water most of the time which would have helped to carry the currents. The broken piece of pipe was virtually pure carbon. You could write with it just like a piece of charcoal.

A typical 50 kW MF system as offered by Marconi Antenna Systems

A typical quarter wave-length high mast system is shown as **Figure 1**. It is a design to operate at up to 50 kW carrier power with 100% modulation capability at 1200 kHz. It comprises a 62 m high, hot-dipped galvanized lattice tubular steel mast, mounted on a 50 cm high base insulator which sits at the centre of a ground system comprising of 120 copper wire radials of 12 SWG and each 62 m long. The radials are connected to a copper sheet which sits under the base insulator and covers the mast base foundation block.

The mast guy wires are 12 mm diameter galvanized steel rope and each guy is connected to the radial ground system. Ceramic walnut insulators in the guy wires break-up the total electrical length of the stays so that they do not significantly affect the polar pattern of the radiator. Special housing insulators at the top of each guy isolate the guys from the voltages distributed along the mast. Static leak resistors are usually fitted across each walnut insulator to protect them from the damage caused by static-induced arcs and coronas.

Antenna Matching Units AMU

The antenna matching components are housed in an all-aluminium kiosk situated at the foot of the mast. Marconi use two basic kiosks: one, 1.75 m wide x 0.75 m deep x 1.5 m high for up to 50 kW and another 1.75 m wide x 1.5 m deep x 1.5 m high for up to 100 kW. The kiosks are fully weather-proofed and do not require additional buildings. For powers above 100 kW, components are usually mounted on aluminium trays housed in a brick or block building. Smaller kiosks are used for powers between 1 kW and 10 kW.

The RF output is a copper tube routed via a glass insulating panel. The AMU has a meter which enables the output current to be permanently displayed. Repeat meters for location in the transmitter building can also be provided. Marconi prefer to use an RF current transformer at the AMU output to sample RF current on the transmission line rather than the standard ‘in-circuit’ thermocouple ammeter which is liable to error from temperature variation and damage by lightning.

Obstruction lighting

If the structure height is 45 m or more the ICAO recommendations state that the structure must be painted in alternate bands of orange and white (starting and finishing with an orange band) for daytime obstruction marking and lit every 45 m for obstruction marking at night. The exception to this rule is that if the structure is very close to an airport when it is usually painted and lit regardless of its height. Generally, a low intensity lighting system will suffice and a double obstruction lantern with two 60-watt (or equivalent) lamps at the mast head and another two such lanterns at an intermediate point. Because the mast is isolated from ground then the lighting supply must also be isolated. This is achieved by an Austin-type ring isolating transformer mounted outside across the base insulator or by same within the AMU and feeding the now isolated supply out and up through the centre of the RF connecting tube. The latter is the usual approach as supplied by Marconi. Where circumstances and the regulations demand it, a high power two 600-watt (or equivalent) beacons can be fitted at the top of the mast and controlled by a flashing circuit.

Climbing facilities

Most masts have a climbing ladder incorporated on them. This is either an integral part of the mast (in the cross bracings) or bolted on to the face of the mast. It is now standard practice to fit a Railok™ track adjacent to the ladder which is used with a safety harness although, in the UK and USA, safety regulations still require (in 1980) the supplier to provide safety loops on the ladder

Lightning and static protection

Both lightning and static can cause serious problems for a MF antenna system. The antenna, the feeder and even the transmitter can be destroyed by a stroke of lightning. In addition, the effect of static may build up on the antenna even when there is no lightning in the area. The effect of static can result in occasional arcing over the guy wire insulator resulting in damage. Lightning behaviour is unpredictable but there are a number of remedies open to the antenna engineer.

The most obvious ‘fix’ is to use a lightning finial at the top of the mast. There is no guarantee that any lightning will strike this rather than some other point but it does provide some protection to the obstruction lantern. At the base of the insulated mast a spark-gap is fitted. In the event of a direct strike or accumulation of static charge, the air in the gap ionizes and dissipates the charge before it reaches the components in the AMU or the feeder. The gap can take the form of a ball-type or horn-type, the latter is preferred because it is self-extinguishing. One of the problems with arcs or coronas is that, when the air ionizes, the RF energy from the transmitter tries to sustain the arc. With the horn gap the ionized air rises in the gap as it becomes heated by the arc. The distance between the electrodes of the gap increases with height so a point is soon reached where the gap is so large that the arc cannot be maintained and so the arc extinguishes. Insulators used in guy wires such as walnuts cannot easily be protected by spark gaps but they can be protected by the static leak resistor mentioned above. A similar device can be fitted across the base insulator. An alternative is to put a static leak inductance in the AMU to leak away the charge.

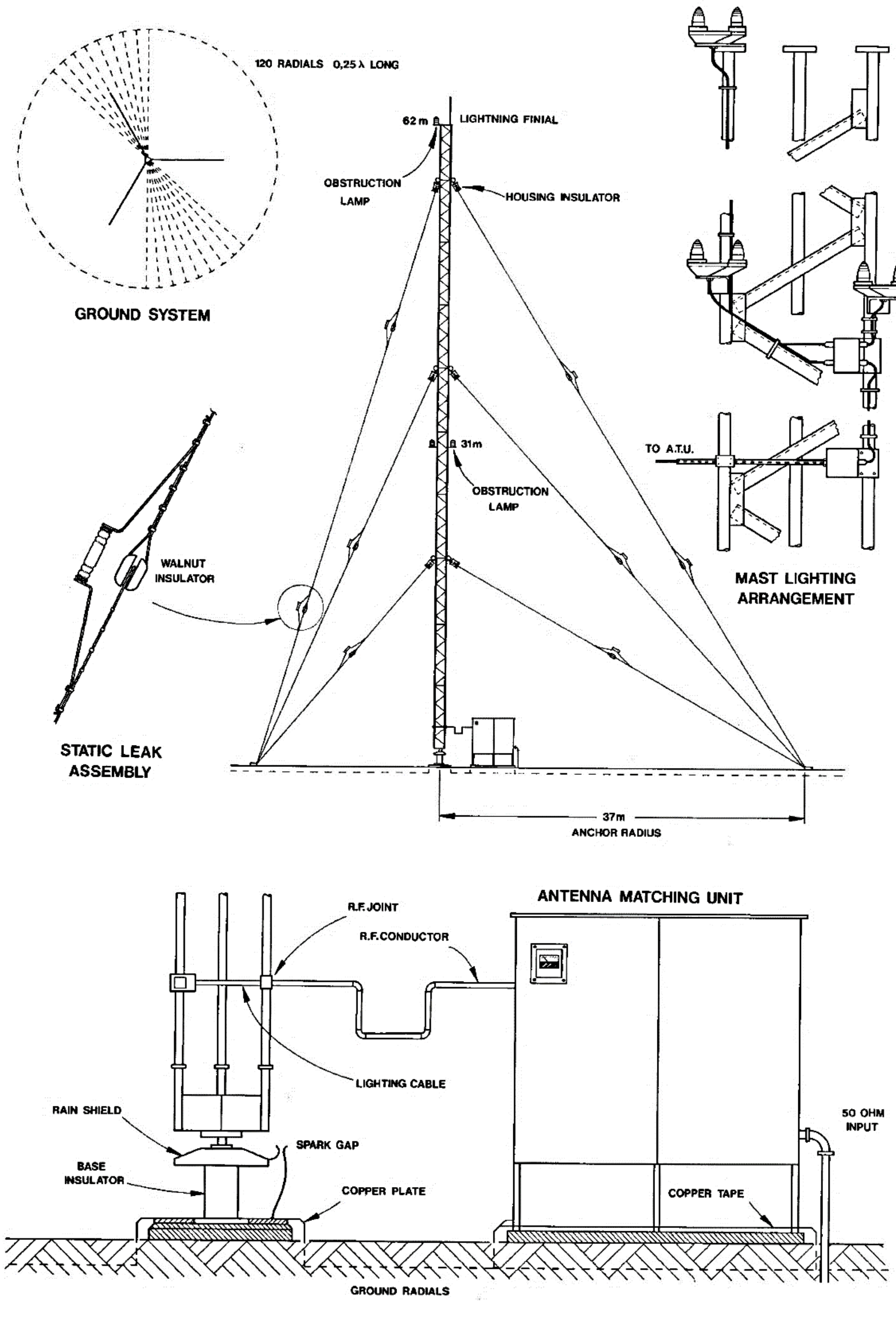

Figure1. A typical 50 kW quarter-wave radiator system for 1200 kHz

A more recent development is the use of ultra-violet detectors, particularly in the AMU itself, to pick up any arcs within. The detectors are photo-cells filled with gas to make them sensitive only to light in the narrow range of wavelengths 190–220 nm. This range is chosen as there is very little natural radiation at these wavelengths and the detector is, therefore, insensitive to false activation by daylight. To prevent false triggers by individual impulses of the ever-present atmospheric radiation, a suitable logic circuit ensures that at least two impulses must be detected within about one second for the transmitter to be tripped. The detectors are very sensitive and arcs can be detected at up to a distance of 600 m. Hence versions of these can be used to monitor activity on the entire mast if based outside.

BBC/DWS/FCO/IBA/other commercial variations

Chris G0EYO has presented the Marconi methods for MF antennas and earthing but it is interesting to note that variations have been employed.

In the BBC, it was often the case that a brick or rendered concrete block building was erected to situate the AMU. There was absolutely no use of steel Rebar™ in the walls or floor as localised heating with RF current would be a problem. The walls, floor and ceiling were lined with copper sheets and the edges were soft soldered. Substantial connections to the earth mat were made by copper strips. There was no attempt to run a copper plate or mesh under the mast. Instead the earth wires terminated on a (finally buried) copper tape usually 37–50 mm wide and 3 mm thick, each wire was bent round the tape and silver soldered. More flat tape was attached to the ring and brought up to the antenna matching unit and again terminated. For low-power installations under say, 1 kW, regular lead/tin solder can be used and the entire ring is painted with bitumastic paint and buried.

Incoming RF feeders, either coaxial or open wire coaxial, had their earthy outer securely bonded and soldered to the screening in the building. The antenna tuning components would often be placed in screened enclosures with through-links between the boxes rather than on shelves on the sides. The use of screened boxes were essential if a multi-service frequency AMU was built so as to prevent cross-modulation on the outgoing services.

Chris's diagram (**Figure1**) showed the use of a 'U-section' between the lead-out insulator and the mast but, in the BBC mainly the connection was straight and direct in copper tube at powers above 10 kW. In IBA installations, particularly those contracted to C and S Antennas Ltd., a single turn coil of about 450 mm diameter was used in that run. This was supposedly used to permit flexing and to act as further protection against lightning strikes attacking the AMU components. The coil could be formed conveniently from some Andrew™ coaxial cable off-cut using the ribbed copper outer as the RF connection.

Most BBC installations employ a hand- or sometimes foot-operated BIG 'knife' switch connected across the mast base to earth so that, under maintenance, the mast can be reliably earthed down; it is possible to lock the action so that it cannot be opened or closed at will. The 'normally-open' contact is always on the mast with the earthy side having the handle + copper section. Similar 'knife' switches are employed in the AMU building to earth down the incoming feeder(s).

It was not always necessary to fully bury the 12 SWG earth; at Orfordness, a number of radials were laid on top of the shingle and secured by wire hoops pushed downwards.

The use of a static leak within the AMU was universal in the BBC and consisted, typically, of a choke wound on a 50 mm diameter ceramic or varnished SRBP former with up to about 300 close-wound turns of 28 SWG enamelled copper wire. Inductances of c. 1 mH were common. G4OYX once wound such a choke as a replacement while walking adjacent to a public road at Twigworth, Gloucester towards the termination, on a farmer's gate post, of the tensioned and stretched wire for what seemed like both an age and a mile to achieve something that did not self-resonate at 603 kHz. Quite what drivers thought in the passing traffic remains a mystery. G4OYX was surprised that in the American-sourced and beautifully equipped AMU cabin at the local Radio Maldwyn 756 kHz commercial radio service installed in 1993 at Newtown, Powys there was no static leak at all with an isolated 62 m mast; needless to say one was wound and installed.

What appears to be common to the UK is the lack of orange/white sectionally and sequentially painted masts, whilst they seem common on the Continent and in the USA; most, if not all, masts here are the standard galvanised grey or the Craig and Rose painted grey. Quite how the UK broadcasting authorities have managed not to fall in behind the ICAO rules is a mystery!

Most obstruction beacons are now of the red-bulbed or neon-lamped type. Droitwich went through a particularly bright period during BBC-operated times with many high-power red neons but the present arrangements appear to be more toned-down. Likewise Sutton Coldfield sported a change from red lanterns in the 1980s to 1990s with some white strobe-like flashing devices, but it was understood that local residents in Four Oaks objected to the light randomly illuminating their bedrooms. The latest arrangement there appears to be toned-down red lanterns.

Walnut or similar insulators are the norm on most BBC/IBA masts; sometimes ribbed ones are used at high power installations but what appear to be missing are any of the static leak devices across them as suggested by Marconi Antenna Systems.

Austin Insulators Inc. of Mississauga, Ontario have the following additional information about their transformers: *The traditional Austin™ air-spaced ring transformer is designed for both exterior and interior usage. The purpose of this product is to provide a means of coupling the 50/60 Hz supply voltage for tower lighting to the tower while maintaining RF isolation between supply and load.*

Austin's Ring Type Isolation Transformers are developed for use on AM radio towers, where the incoming AC power line must be isolated from the tower lighting system. These transformers utilize a high quality, low loss steel toroid core. This unique design allow the necessary 50/60 Hz AC power to be magnetically coupled through to the tower lights, while at the same time blocking the flow of RF energy from the tower to the AC power line by virtue of the extremely low primary to secondary capacitance (10–15 pF).

For sites which experience rain, fog, salt spray or sand/dust storms, a housing enclosure can be supplied to protect the transformer from the atmospheric elements.

Oil-filled tower lighting transformers with RF isolation values up to 250 kV RMS and beyond are also available. This type of transformer has its windings immersed in oil contained within a porcelain cylinder placed between steel end plates, thereby forming a transformer "module". These modules can be stacked on top of one another, in series, for very high RF voltage requirements.

Next time

The absolutely unique antenna system at a BBC MF site will be examined with the help of an Antipodean contributor.

References

1. D Porter G4OYX and Chris Pettitt G0EYO. Tricks of the Trade. *Signal* 2018, 49 (November) 13–16.
2. C Pettitt *MF Broadcast Antenna Systems*. R5100 Marconi Communications Systems Ltd., 1980. pp. 5–8.
3. M Hancock. *The History of Rugby Radio Station*. Urban and Civic Headquarters London, 2017. pp. 116–117. ISBN 978-1-5272-0540-6.