Tricks of the Trade

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Readers will recall that we left the last ToTT with expectations towards achieving even greater conversion efficiency during the generation of AM, particularly for high-power transmitters. Mention was also made of the perils of restoring to service the repaired grid decks on the MCSL Advanced Pulsam 500 kW B6128 HF, 300 kW B6126 HF senders and the 250 kW B6042 LF variant at Droitwich. Following discussions with a former colleague who was based at BBC Sutton Coldfield and who, after 1992, was one of the team responsible for looking after the Droitwich station (after it had been de-staffed and declared fully automatic) the author was pleased to receive his contribution.

Days (and nights) at Droitwich

Phil Marrison writes: *Having spent many days (and nights) at Droitwich with Ray Cooper and others trying to persuade the modulator grid decks back into life after flashovers and faults, I can confirm that they were a pain to work on and were indeed temperamental. Boards of CMOS were surrounded by many power FETS mounted in a grid deck sat up at half HT or so and did not take kindly to valve flashovers or the odd lightning strike.*

We were always left wondering which modulator valve had caused the original fault and, having repaired the faulty grid decks upon which the valves sat, there was a degree of doubt, some would say trepidation upon re-powering as, unless you had fitted a new pair of valves too, there was a good chance that all your work would be undone, literally in a flash. While all this repair work was progressing, the Radio 4 service would be on reduced power, with pressure to get the faulty transmitter back on the air and the service up to full power.

International mix and match

During the 1970s, the Swiss transmitter manufacturer, the Brown-Boveri Company (later ABB), invented a solid-state pulse-step modulator, PSM, for their range of high power LF, MF and HF transmitters. It is interesting to note that, for many of the units, an option was offered of either the then newly-invented PSM or a conventional Class AB1 tetrode push-pull plate and screen modulator if the customer desired.

Brown-Boveri was not a usual supplier in the UK and for the BBC's overseas stations, the HF senders being mainly manufactured by MWT, MCSL, STC, *etc*. Indeed, at the time, as far as possible, different countries mostly used their own suppliers with, for example Deutsche Welle using Siemens, Lorenz and AEG/Telefunken equipment, Radio France International using Thomson-CSF and the Voice of America, VoA, using General Electric, Continental Electronics and Harris-Gates.

Some exceptions were Switzerland who did buy a MCSL B6124 HF sender in 1978 for Schwarzenburg and Deutsche Welle who purchased MWT 250 kW BD272 senders in the mid-1960s for Kigali, Rwanda and Sines, Portugal.

Radio Free Europe and Radio Liberty were also supplied mainly by American companies, until a tender was issued by the VoA in 1986 for the evaluation of four different 500 kW transmitters for their original 55 transmitter upgrade and later 32 x 500 kW transmitter upgrade programmes. Single units were bought from AEG-TFK, ABB, Marconi and CE-Varian. Thomson-CSF was also invited to tender but it appears that, in the event, they did not. A CE 420B (**Figure 1**) and a MCSL B6127 were installed at the Greenville A (GA) site at Black Jack, North Carolina. One ABB SK55-C3 (**Figure2**) and one AEG-TFK S4005 500 kW sender (**Figure 3**) were installed at the nearby Bear Grass, Greenville B (GB) site.

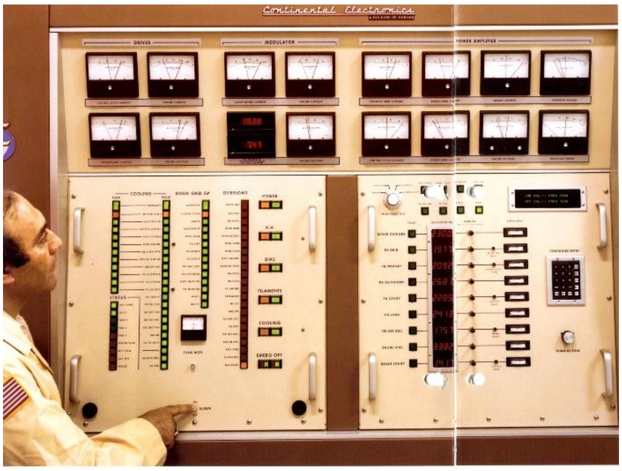

Figure 1. CE420B sender

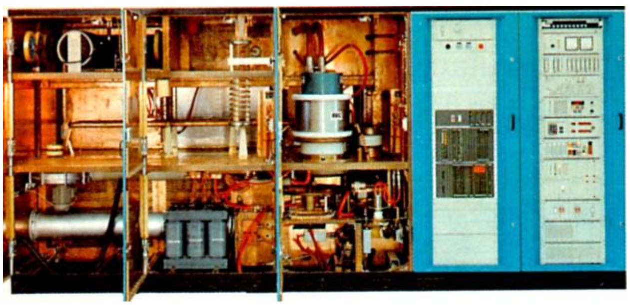

Figure 2. BBC/ABB SK55-C3 sender

Figure 3. AEG/TFK S4005 sender

Four different senders would have been an operational nightmare for the transmitter engineers at GA and GB as the spares-holding would have been quadrupled over that from a single supplier and operationally, in the event of a fault, there would be no other unit with which to compare meter readings or to exchange modules, *etc*.

Swiss BBC/ABB senders were often purchased by the Arab states and large-order customers were Iraq and Iran as well as United Arab Emirates for the Al Dhabbaya site. Presumably, this was for political reasons so that no links could be made to right or left leaning countries as a 'neutral' country had supplied them. Taking it one step further, it is possible that export sanctions were in place against supply to certain nations. For his Transmitter Documentation Project **[1]** Ludo Maes in Belgium has researched who-supplied-what-to-whom-and-when and it makes for interesting, sometimes very political, reading.

The Pulse-Switch Modulator to the rescue

With the problems arising from final valve flashovers and faults on the Advanced Pulsam modulator at Rampisham and Droitwich, an American derivative of the original Brown-Boveri PSM made by Continental Electronics was retro-fitted by about the mid-1990s and the complex MCSL grid-deck eliminated.

The principles of PSM were fully explained in *Signal* **[2]** where an even later version of the technology was detailed as RIZ in Zagreb had incorporated their version of it in the 500 kW and 250 kW HF transmitters delivered to VT Communications in 2006.

Phil Marrison again comments:

As installed at Droitwich, the Continental Electronics, CE, modulators were not without initial problems. There were a few thermal incidents – luckily only resulting in small fires with burn-ups on 700 V switched PSU panels **(Figure 4)** *and some fibre optic cabling; future re-occurrences were soon averted with some modifications. The main benefit of the CE PSM was that they were very much less susceptible to catastrophic failures from antenna lightning strikes or static discharges and final RF valve flashovers or failures.*

Just prior to the modification being carried out by MCSL at Droitwich, I am reminded of a night shift with John Temple from Marconi, who I think had been involved in the original design. John was detailed to do some preliminary checks prior to the Continental PSMs being fitted. John turned up with a fairly rough-looking AVO 8 and a brand–new Fluke DVM among his test gear. There must have been some doubt in the Marconi New Street laboratories about peak voltages and currents within certain parts of the modulator enclosure hence the choice of instruments. The AVO was viewed as expendable and, if it survived, the Fluke was to be used to make more precise measurements, provided it could cope with the harsh RF environment or did not prove to become expendable, too. The instruments were to be supported, in an insulated fashion, in mid-air within the modulator enclosure and viewed through the observation window of the modulator enclosure door. The Fluke relied on the manufacturer's calibration and had not been through the usual Marconi calibration procedures – no doubt to save some pennies, just in case it succumbed during the tests. Luckily, both instruments survived.

Figure 4. An example of fire-damage

Mention was made by Phil of Sutton Coldfield colleague Ray Cooper, Ray adds: *The original Pulsam modulators in the Marconi B6042s were replaced by Continental Electronics switched-mode modulators, which are even more efficient and all solid-state, to boot. In later years, Amplitude Modulation Companding, AMC, was implemented on these units, to save even more power – effectively this is 'downwards modulation' where the peak carrier power remains fixed (at 250 kW per unit) and the mean carrier power reduces with increasing modulation depth; these units consume less power from the mains when they are 100% modulated than when they are just radiating plain carrier – an interesting phenomenon.*

(If readers enjoy such 'on-site' contributions to ToTT then they will be further entertained by Ray Cooper's superb account of technical and political life at the BBC Sutton Coldfield Transmitting Station entitled *Tales from a Cold Field* **[3]**.)

It was this additional power-saving feature that really gave Continental Electronics the 'edge' as they were able to offer many transmitter operators a chance to save DC input power dramatically through Dynamic Carrier Control (Dynamic Amplitude Modulation, DAM, or AMC **[4]**) and the removal of the modulator switch tube saving filament supplies which for 300 kW and 500 kW senders could be between 10 and 20 kW. The water cooling requirement was also reduced; again more power saved.

A Time Stamp

It is interesting to be aware of the timing of the developments described above as there had been significant changes in many aspects of HF operations over the same period of time.

First, there was the fall of the Berlin Wall in 1989 which essentially was the start of the demise of Communism in the USSR and the Warsaw Pact countries. International relations continued to be fragile, possibly for five to seven years after the event so there was still the perceived need to keep broadcasting towards the Bloc.

Secondly, following the fall of the Wall, jamming of transmissions from the 'West' had stopped and transmissions were being received reliably and successfully. As a result fewer parallel frequencies were required and consequently less transmitter plant. For example, in 1992, the BBC Daventry HF site had been closed completely and its on-going commitments transferred to the three remaining sites in the UK. Its six, almost brand-new, B6126 senders were also transferred to other sites to replace older equipment.

Thirdly, when installed on each sender at a site, the US-manufactured Orban Optimod 9105A unit could very effectively process the programme audio such that high modulation levels were obtained with a real clarity and punch to overcome interference, fading and static. By 1993 it was found that a 250 kW sender would pack a punch with Optimod equal to or better than a 500 kW sender with a simple limiter/compressor. With the cessation of the jamming coupled with the fact that most services were now one-hop from antenna to target (as there were plenty of relay sites in operation) then a 125 kW service with AMC or DAM would not be far behind in audibility terms. This saving of (mains) input power was significant particularly to the accountants and a far more cost-effective operation was now possible.

Fourthly, with new automatic senders on the market and in operation, broadcasters saw the possibility to reduce the 24 hour shift staffing and, in some cases run, the sites automatically with minimum attendance.

Thus, by 1995 the previously expensive broadcasting exercise was seen to be steadily reducing in operating cost. However, there was always the continuing increase in kWh costs from the generators that offset some of the savings, especially if certain governments were placing carbon loading tariffs on heavy electricity users as a result of climate change legislation.

More savings

Inevitably, further savings were being looked for; an attractive option to save on power particularly for HF transmitters throughout the 24 hours when the sender was not scheduled on programme and on stand-by was called 'Black-Heat'. Thus, at the end of a service transmission the filament supply voltages were reduced, typically from 17.5 V to 6 V over a five minute cycle and then ten minutes prior to service the voltages were ramped up to normal. One might ask why the filament supplies and auxiliaries were not just turned off after a transmission and then turned on from cold 15 minutes before service as they had been done for years previously on the older transmitters. Regrettably, it had been discovered the hard way that these modern hypervapotron tubes did not take kindly to on-off-on-off filament supply interruptions as the filament structure distorted and a permanent short-circuit contact was made to the control grid. The typical spacing in the valves between filament and grid 1 and grid 1 to grid 2 was only 1 mm and grid 2 to anode was 10 mm.

When the senders were used heavily before the introduction of Black-Heat, a few hours per day of stand-by time on full heaters did not matter too much but, as the transmission schedules got lighter with less on-air time, it was an energy loss that could not be tolerated. Nowadays, in Black-Heat, the air blowers and water cooling pumps are throttled back by thyristor control.

Stars in their eyes at Daventry

From the above it is evident that the high power, high gain transmitter valves needed careful handing to be reliable. Another feature of the measures needed for their steadfast employment is illustrated by the following, again from Phil Marrison, relating to an incident at his time at Daventry around 1986.

Phil writes: *A condition of the guarantee of the Thomson TH-series of valves used in the range of Marconi 300 kW and 500 kW senders was that they must be protected by HV crowbar circuits.*

Upon the detection of a valve flash-over or transient short circuit, a range of protection circuits would trip off the transmitter. However, there would still be considerable stored energy to continue to flow through the fault that initiated the trip and prolonging the length of the fault event resulting in possibly more consequential damage.

To dissipate this stored potential energy, an electronically controlled fast-acting, high-current mercury rectifier, known as an ignitron, was installed across the 26 kV DC HV supply. It was fired upon the detection of a fault current into the load. It was also arranged that the HV was turned off just before the ignitron was fired.

The installation test (and subsequent important on-going maintenance item) for the HV crowbar was to place a length of 31 SWG TCW from a suitable HV supply point within the RF amp, without the valves installed, to a normally-open (NO) vacuum switch on the floor, giving a length of 5 A fuse wire of around 8 feet. The other side of the NO vacuum switch was connected to earth.

A simple method had been devised for remotely operating the vacuum switch.

The mechanical door interlock for the HV supply point was bypassed, safety signs placed, the area barricaded off and cleared of the already gathering crowd of itinerant staff, moving them to a safe distance. The transmitter was now ready to be run up for the test after, of course, observing any safety issues that may ensue.

Once the transmitter has run up and the HV established, a final safety check is made and the vacuum switch is triggered. The manual states that the 5 A fuse wire will be seen to sag 'gently' while passing a very small proportion of the available stored energy while the ignitron would dissipate the balance of the energy.

As this was the first of the Daventry B6126s to have this particular test carried out, word quickly spread through the station of this significant step in the new transmitter's installation. The Marconi engineer, Bob Calver if I recall correctly, explained to the now ever-growing engineering and non-engineering crowd what the procedure was and that he would now run up the sender.

Picture the scene of a group of 25 or so, staring intently at the 5 A fuse wire waiting to see it sag 'gently' as the vacuum switch was triggered. Unfortunately, for some reason, the ignitron did not fire so the fuse wire was vaporised instantly with a blinding flash. The onlookers were a little surprised and for the remainder of the day they could be seen blinking and rubbing their eyes from time to time, while still having the flash overlaid on their vision as they blinked.

The author was at Daventry for a few months in late 1989, early 1990 and recalls having to devise a heating arrangement for the ignitrons that were in the valve store awaiting future use. It had been discovered that they were not effective in clearing a sender fault unless they were always kept warm. To this end MCSL had installed a 100 W sun-ray lamp that shone on them in the sender but, if a rapid replacement was needed, then one which was already warm must be used to afford the correct immediate operation. In the event a 24 V 50 W stuffing box heater was bolted on to each one in store and powered continuously.

ITU X3E (SSB) instead of ITU A3E (AM)

The 1987 WARC-HFBC Conference in Geneva was an important event in the broadcasting calendar. It finally put a deadline on the time when SSB broadcasting was to be introduced on the HF broadcast bands. The switch was to be complete by 2015. By 1989 most manufacturers had incorporated the facility into their transmitters. The method used was termed Envelope Elimination and Restoration (EER) and was effected at high level to the final RF amplifier stage; it retained all the advantages of PDM and none of the disadvantages of the low-level/linear amplifier methods. For a while, after the introduction of new HF senders that could offer this mode, certain broadcasters, *i.e*. ORF in Austria, DW in Germany, NRK in Norway and Vatican Radio did try it with experimental transmissions but now it does appear to have sunk without trace and the ITU directive has been ignored. It was heralded as a means of having more channels available on the broadcast bands but, of course, with the decline in HF transmissions coupled with the expansion in the frequency bands allocated to broadcasting it is not required anyway, channel availability now not being a problem.

The final efficiency push

Mention was made earlier of the evaluation by VoA in 1986 of the four types of 500 kW sender leading to the transmitter supply contract award on 31st May 1988. These senders were for stations in Morocco, Thailand, Botswana and Sri Lanka. The total order value was over $56M. MCSL in the UK was the successful bidder after the Greenville 12 month evaluation and the contract was a joint venture of Marconi Electronics Inc. of Virginia and the Cincinnatti Electronics Corporation, Ohio. In effect, UK-manufactured transmitters would be supplied in kit form, assembled in Ohio then sent to site.

Many commentators and observers in the industry were surprised that US-based CE-Varian did not win the contract.

With an order for up to 32 units, MCSL (later GEC-Marconi) were going to be kept busy and the supply at first was for B6128 500 kW senders with the later ones being B6132.

The B6132

The B6132 (**Figures 5 and 6**) was to be the last 500 kW HF transmitter ever made in the UK. It produced either a regular 500 kW AM output (2 MW PEP) or up to 750 kW in Enhanced-AMC, E-AMC (see later). Normal 500 kW AMC was possible as well as DAM. In addition, SSB with a –6 dB or –12 dB programme-controlled carrier was installed to the ITU X3E specification and to the EER method. The bought-in Continental Electronics solid-state PSM modulator was used and the overall transmitter efficiency was quoted as 80% which would have appealed to the accountants.

Figure 5. GEC-Marconi B6132 sender

Well-proven fixed contacts and moveable cross-heads were used for band changing on the driver and final stages. The fixed contacts were noted to be welded-in rather than into threaded bosses as on the earlier senders, presumably to prevent excessive burn-ups.

One other feature worthy of mention is a quoted wave-change time typically of twelve seconds from service off to resumption on a new (previously stored) frequency. In practice some of the changes could take a little longer particularly when moving from 4 MHz to, say, 21 MHz owing to the fact that time had to be allowed for the water-cooled bellows in the vacuum variable capacitors to empty of water as they tuned LF to HF.

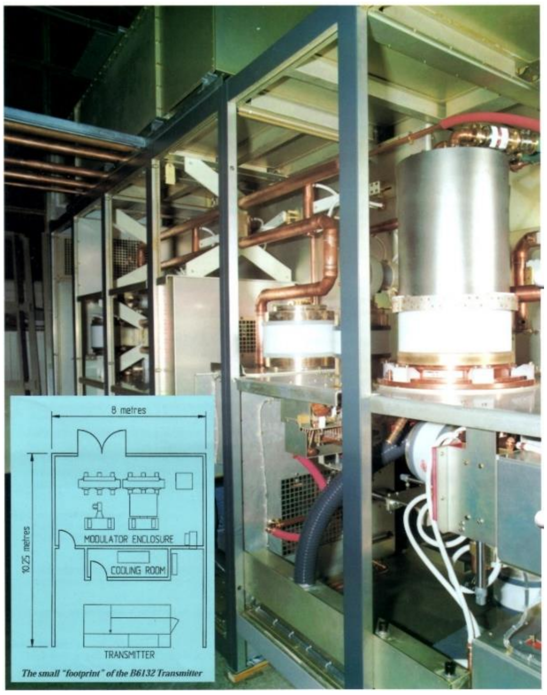

Figure 6. Inside the B6132

Ewan Fenn G3RTF, who was the Engineering Manager in HF Development at GEC-Marconi at the time of transition from the B6127/8 to the B6132 recalls:

Compared to the B6128, the B6132 was quite a different beast. One of the parameters I was tasked with was to reduce the Works Cost Price. If I remember correctly, the B6128 was £640,000 and we managed to reduce the cost of the B6132 to £416,000; quite a margin and I believe the product was better as well; certainly it was more efficient.

Technically, the only major problem was driving the final valve at 26 MHz; the input capacitive reactance was about 6 Ω at this frequency and we had to deliver about 1000 V peak at the grid. This was made especially difficult by the cathode lead and grid structure inductance at the terminals. We overcame this difficulty by forming the π-coupling with the output capacitor in series with the inductor, giving effectively a fully variable inductor and using the valve input capacitance as the π-loading capacitor thus generating the driving voltage in the grid structure where it was really needed. However, there were still some quite large circulating currents in the driver stage to final coupling.

Unlike the B6128 and previous single-ended HF senders, there was no C43 in the B6132, the notorious anode tuning capacitor forming a parallel tuned circuit to isolate the RF from the DC power supply as now we had three sections to an RF choke.

The first (from the anode) was water-cooled and held down by a 7500 pF water-cooled ceramic capacitor. There were then two further sections of heavy gauge wire well-spaced on a former with the combination feeding in the DC at a hot point just as on an amateur rig.

This arrangement was possible due to the higher current rating of some newly-introduced vacuum variable capacitors. One, as the anode tuning capacitor, enabled us to achieve the required Q in a single body. The 1600 pF type I believe, was rated to carry up to 1000 A of RF at 16 MHz.

Previous to this development we incorporated a parallel tuned circuit on the anode (C43 and tapped inductor) and, as well as providing an earthy point to feed in the HT (if there is ever an earthy point in a large HF transmitter), this split the Q required at the anode between this parallel tuned circuit and the first π-circuit. As designers you have to watch what happens to the Q as you cover a band, a Q below 6 is not good for waveform distortion, i.e. harmonic attenuation and a Q above, say, 10 results in unacceptably high circulating currents. It must be borne in mind that a hard-driven Class C amplifier only conducts for about 110° and the harmonic current is thus high, approaching 50% (from memory).

There were then two switched 'dustbins' of about 12-inch diameter; short sections of rigid feeder with a pushrod switch that changed the length of the centre conductor which was open at the far end. I do not remember, if I ever did know how this worked, but it looks like a very short stub tuner and made a dramatic improvement to the valve conversion efficiency, probably by modifying the harmonic resonances. I think we looked at patenting this, but it never happened.

All vacuum capacitors were by the Swiss manufacturer Comet; the anode tune component was 1000 pF at 60 kV test and the π-capacitors were 1600 pF 60 kV test with 1000 A of RF at 16 MHz in a 12-inch diameter body.

The output π-network incorporated a 2^{nd} harmonic trap using a 90 kV test vacuum capacitor. That one used to push the Comet HV tester to its limit of 100 kV maximum open-circuit. We tended to keep our distance when doing this test as we suspected there might be some quite energetic X-rays produced at this voltage. The anode blocking capacitors were water-cooled ceramics.

I am pleased to report that we did not lose a single vacuum tuning capacitor during development.

The tuning drive gearboxes for the variable capacitors all used toothed belt drives from the stepper motors, very simple.

The TH576 output valve ran at 14 kV HT at a current of c. 40–45 A from the Continental step modulator.

To save money, several low voltage power supplies were done away with and the power contactors all ran with 230 V coils.

G3RTF was correct in suspecting the potential production of X-rays as, in the BBC, we had discovered that significant amounts of X-Ray radiation could indeed be emitted from capacitors both under HV test and in service. For this reason a special lead-lined test enclosure was constructed at each site and connections made to the instrumentation of the Comet tester *via* a feed-through system from the test plate and HV components under test inside. It was interlocked by Castell key so that the tester could not be used with the door open.

G3RTF did comment in a later note to the author that it was most satisfying to be in the Moroccan, Briech transmitter hall at the time of final handover to VoA when the automated command went out to every one of the ten senders to wavechange at the same time and watch them all repower and come back on the air in less than some 20 seconds.

Days (and nights) at Skelton

Whereas the Droitwich and Rampisham transmitters were upgraded to Continental Electronics modulators to solve rapidly the grid-deck problem, this was not so for the remainder of the 300 kW senders. The author's former Babcock colleague Russell Barnes G4YLI from Skelton offers the following explanation of what they did there to alleviate the modulator problems:

The six B6126 transmitters at Skelton C, SKC, had series PWM modulators, comprising one grid-deck and a valve in series between the 26 kV HT supply and the final RF stage. From the early days they had been modified from regular AM to BBC-designed AMC and the overall sender efficiency went up to almost 70%.

At the very end I developed a plan and modified the senders to work AMC at 150 kW (they had only worked AM on reduced power hitherto) by 'shifting everything up one' using the 'Enhanced' position as 'On'. We had not used the E-AMC mode for years but this is how it worked:

When operating E-AMC, the carrier power was increased by 1.76 dB over 'regular' AMC, equating to an output of 450 kW from the B6126 where the 'normal' AMC resting carrier power was 300 kW. So the carrier would equate to 450 kW on 'Enhanced' (or c. 14 kV HT instead of 11.5 kV, *achieved by altering the mark-space ratio), as the PEP on 'normal' AMC equated to 300 kW, having 6 dB of compression. HF AMC was set thus, where the PEP of 100% modulation did not exceed unmodulated carrier power, as opposed to domestic LF/MF AMC with 3 dB compression. With no modulation the E-AMC carrier increased to 450 kW (on silent passages, say, or after the closing announcement), then the transmitter would occasionally trip on 'over temperature' after a couple of minutes and fall back to 'normal' AMC. A timer circuit was meant to remove the enhancement but, occasionally, the 'over-temp' trip would get there first.*

It was considered that E-AMC would increase the audibility of the transmission in the days of the 'power race'.

This modification was a desperate attempt to satisfy the accountants who kept kicking the Senior Transmitter Management who passed the kicking down until it reached me and so I decided to do something about it. The mod worked fine but was never deployed: economics beat engineering once again.

As time moved on, the grid-decks actually became more reliable. Duncan Wood re-built a switching stack with new PCBs to make FET replacement easier and he designed a modified triggering arrangement. At the time of cessation of transmission from SKC in March 2013, this particular grid-box was pending repair after being in service: a 50 Ω resistor on the 2N6661 driver FETs was getting excessively hot because of an undamped switching 60 kHz frequency resonance.

Harry Crossley (now SK) once tried another FET rather than the standard IRF350 in an attempt to improve reliability. The grid-decks fitted with alternative FETs went into service but, by this time, we had sufficient spares that all grid-decks were 'pooled' and eventually the new FETs were replaced with IRF350s as, fortunately, we had by then the ex-Rampisham decks to cannibalise. In the early days, MCSL modified the timer and driver board and the FET triggering pulse-widths were different. In general, decks with these boards were more reliable, although we did use both. We changed out a lot of capacitors for Evox-Rifa higher temperature-specified components as they became available and took extreme care with timing pulses when setting up and I think this helped matters.

We passed on our findings and research to the other BBC sites with B6126s: Cyprus, Seychelles and Hong-Kong.

It was a shame that after Droitwich was modified to solid-state modulators we never managed to inherit their displaced grid-decks.

Finally, Ewan G3RTF adds the following regarding the timing cycle of E-AMC:

We know that the RMS power of a fully modulated 500 kW transmitter is 750 kW and the peak envelope power is 2 MW. The transmitter, for economic reasons is not rated to do this continuously, but only for a maximum for 10 minutes in the hour followed by 50% modulation for the remaining 50 minutes. To take the argument of the large carrier reducing the noise level at the receiver further (due to AGC action in the receiver) from the above statement, the transmitter carrier power can be increased to 750 kW in the absence of modulation providing this does not happen for more than the 10 minutes per hour. The restriction on continuous modulation is driven by the rating of large components with a high thermal inertia, usually the main HT transformer.

E-AMC was configured with a built-in timer which reduced the carrier power to its nominal value if modulation did not appear after a pre-determined time. The outcome is a quieter received signal at low modulation depths and which still retained the power-saving option at the transmitter. This 500 kW/750 kW feature was demonstrated to VoA but I do not know if they ever used it 'in anger'. However, I remember their almost scared faces when we put it into that mode and they saw 750 kW carrier on the output power meter for the first time!

The final flourish

With transmitter efficiencies up to *c*. 80% one would think that there was little more that could be done, but the Croatian manufacturer, RIZ Transmitter Company, did have one final flourish in design. They had manufactured a 500 kW sender type OR500K-01/A both in their own marque, RIZ, and a second rebadged for Telefunken as type S4050, installed at the Wertachtal site (site now closed down, masts demolished and the S4050 moved to Nauen near Berlin) in 2004. The prototype RIZ-500 was bought by VT Communications for a discounted price and down-rated to 250 kW for an upgrade at Woofferton. It was an excellent unit with a solid-state Pulse Step Modulator of their own design and prompted VT to buy four 250 kW OR250K-02/A of a brand-new design with three for WOF and one for Skelton. In the time between purchases, RIZ had redesigned the RF section to employ just one valve, the TH558. The driver valve, so long a feature of these designs by all manufacturers, had been replaced by a solid-state 5 kW 50 Ω output wideband amplifier. As G3RTF alluded to in his piece about the B6128, the input impedance of the output valve varied greatly over the operating frequency range and matching to 50 Ω was a tricky design challenge for the RIZ engineers. The removal of the driver valve saved both money and energy as there was no need for a separate HV power supply and filament supply. Efficiencies were now at about 82% with all the energy-saving measures (Black-Heat, DAM/AMC/SSB, waste heat to building heating, *etc*.) in place. This situation is probably the best that can be achieved over the near 100-year period of high power HF transmitter development.

It would be fair to say that most HF operations from now on will be on legacy senders with just the occasional upgrade at some sites but the halcyon days of regular technical developments and plant re-engineering that so characterised the period from 1980s to the end of the 20th century, are over.

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