The Further Development of HF Broadcast Transmitters

*Former BBC Senior Transmitter Engineer, **Dave Porter** G4OYX, continues to outline the history and development of HF high power broadcast transmitters*

The Sender hall at Rampisham with AEG S4005s in the foreground and Marconi B6127s beyond (Neale Bateman)

The development of HF broadcast transmitters from their beginnings in the 1920s, and the significant technological advances from then to the late 1960s, as detailed in WRTH 2021, resulted in transmitters that were up to 50% energy efficient. Many of the problems experienced with the early transmitters had been solved by then and ingenious solutions found to overcome operational difficulties. Class B audio modulation had increased the power available from the supply voltage, valve design had improved, and various cooling systems allowed the valves to be operated at higher temperatures. These Class B modulated analogue all-valve units became the most widely used transmitters.

In the 1970s, with the Cold War still raging, there was a continuing need by governments and state broadcasting agencies to have a presence on HF. The bands were consequently well used, and very crowded at times, with 49m and 41m carrying the heaviest load. Not surprisingly, this resulted in a power and audibility race, and transmitter developments were encouraged by the number of orders placed for upgrades. Many of the transmitter manufacturers were designing and offering 300kW or 500kW units and were able to do so because of the development of a new class of vacuum tubes or valves.

The valve improvements came about in part with the introduction of a second grid in the tube to make a tetrode with the four active electrodes having much higher gain than the former three-active-electrode triode. The four electrodes are, in order from the centre: a thermionic cathode, first and second grids and an anode. There are several varieties of tetrodes, the most common being the screen-grid tube and the beam tetrode. In these, the first grid is the control grid and the second is the screen grid.

A second innovation was the much-improved power handling capability initiated by Thomson-CSF in France in the mid-1970s who put into practice the ‘Hypervapotron’ concept first suggested in 1933. Here the cleverly designed ribbed surface of the copper anode is encased in a boiler jacket and the steam produced is immediately condensed within the jacket itself. The resultant water can be pumped out at up to 100°C and fed to a secondary plate heat exchanger to extract the heat, which can be reused. Ceramic cylinders replaced the glass envelopes on the valves which, being more rugged, could run at a much higher temperature. The ceramic to metal seals for the valve connections were also more reliable than the old glass to metal seals.

Variable tuning capacitors are used for the constant wave changes needed on HF transmitters. Originally these were large air-spaced units and prone to spectacular and noisy high voltage flash-overs. Jennings in the USA, in the 1950s, perfected vacuum variable capacitors, which could work with RF voltages of up to 55kV at 30MHz, and carry RF currents of up to 1000 amperes. Healthy competition between Comet in Switzerland and Jennings resulted in some impressive components. These now motor-driven units, along with the tetrode tubes, enabled much physically smaller transmitters to be built.

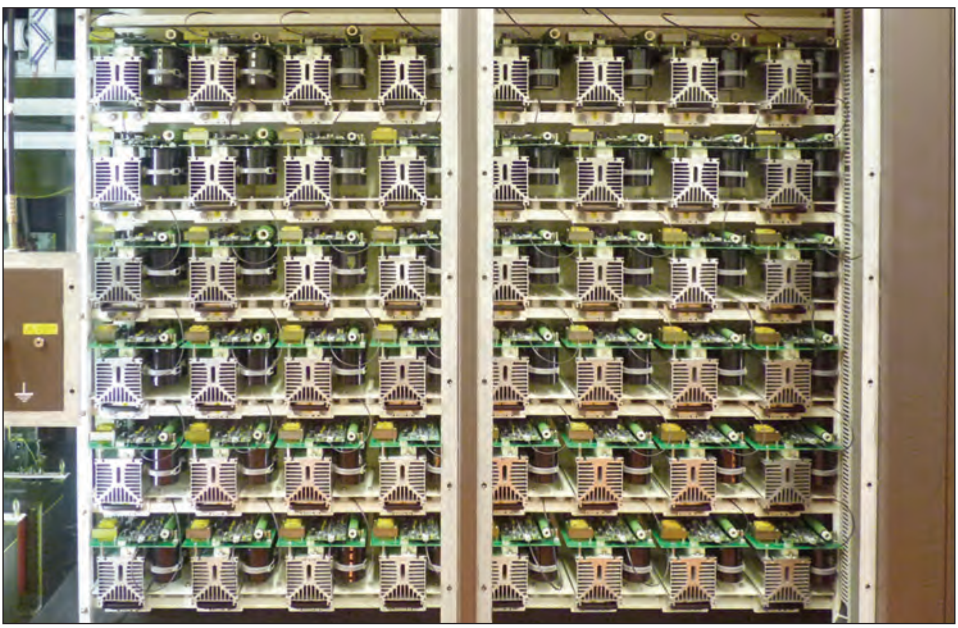
In the early 1970s the Swiss company Brown-Boveri & Cie offered the SK51 100kW, SK53 300kW and SK55 500kW HF Class B transmitters. Interestingly, the SK53 and SK55 also had an option of solid-state Pulse Step Modulated (PSM) units in place of Class B modulators.

PSM produces low power samples by Analogue to Digital conversion. A bank of, typically, 48 modules, each capable of producing 800V direct current (DC), are connected in series. If just one module is triggered by a sample, then a pulse of 800V DC results. If all are triggered then there is a pulse of 38,400V DC, corresponding to 100% modulation. The switching or discharge releases a pulse of energy and when re-combined enables a powerful DC voltage and current to be created. This passes to the Final RF (FRF) tube, producing AM. For a steady unmodulated carrier, half the modules produce output with the rest switched off. Some filtering of the switching pulses is needed, but the components required are far smaller than the modulation transformers needed in Class B to generate the same powerful varying DC waveform.

Thomson with their TRE2353 and TRE2355 transmitters and AEG Telefunken with their S4001, S4003 and S4005 transmitters introduced the concept of Pulse Width Modulated (PWM). For PWM the input signal to the modulator is digitally sampled at, typically, 75kHz and the amplitude of the signals are converted into digital voltage samples. These are applied to the control grid of the PWM tube switching it on or off and, once re-combined, produce a high voltage, high DC pulse representing the original modulating waveform. When combined, the pulses pass to the FRF amplifier stage and produce AM.

A further impetus for development came from the Oil Crisis in 1973. The rise in the cost of electricity resulting from the reduction in oil supply led many states to upgrade their older senders to more efficient units. Sales also increased to the oil-rich Middle Eastern states which were now in a position to use their petro-chemical dollars to purchase new transmitters and antennas.

In the mid 1970s two systems were developed to save energy costs. TFK introduced a novel modulation concept called Dynamic Amplitude Modulation (DAM). Using DAM, carrier power was reduced during periods of low modulation, just as it was in 1938 on Daventry's Sender 6 with its floating carrier! The BBC developed the total reverse concept, called Amplitude Modulation Companding (AMC). With AMC the full RF power



Thomcast TSW2250 PSM modules (Peter Bairstow)

Sender 44 at Rampisham, one the station's four AEG Telefunken S4005s (Neale Bateman)

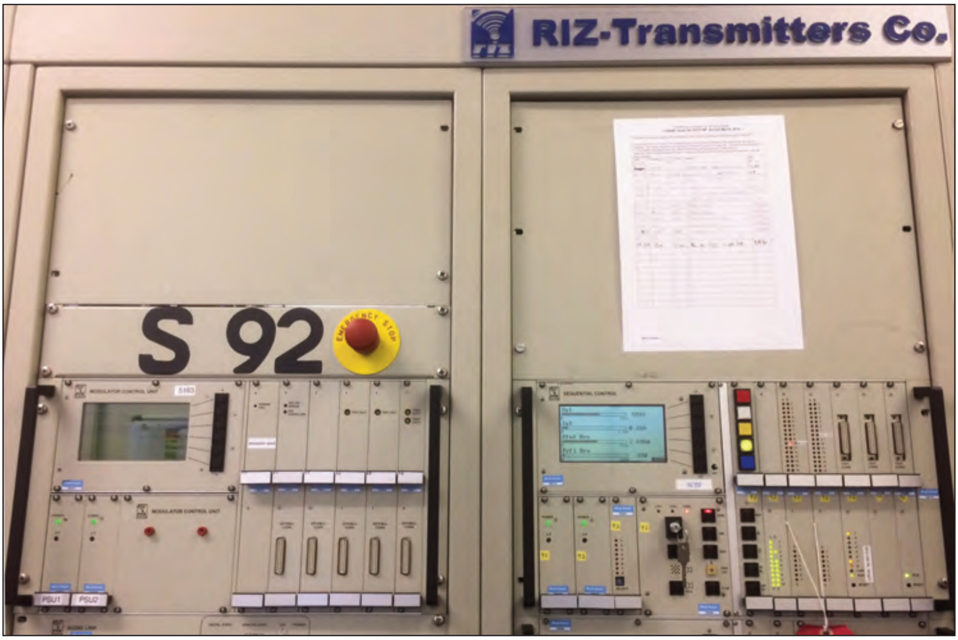
is radiated at no modulation and, as the modulation level increases, the carrier power is reduced.

Harris-Gates in the USA marketed a SW50 (50kW) and SW100 range in the early 1970s with a PWM tube modulator. AEG-Telefunken developed their 'Pantel' version of a PWM transmitter with a single TH558 tube in the PWM modulator and supplied many to Deutsche Welle at Wertachtal and Jülich, and ten S4005 to Iran for the transmitter site at Sirjan. Thomcast of France supplied 16 500kW TRE 2352 PWM senders to Salah El Deen in Iraq.

RIZ OR250K sender, second output coil showing motorised, water-cooled coil tap (Dave Porter)

The advent of PWM/PSM did not mark the end of Class B modulation and, following a significant cash injection related to Voice of America's modernisation in the early 1980s, Woofferton in the UK was upgraded with four Marconi Communication Systems (MCSL) B6124 transmitters at 300kW. These featured a TH537 Hypervapotron tube in the RF output and two more type TH583 tubes in Class B for the modulator output. There was a low-power single valve RF driver stage. These units could auto-wavechange in under 30 seconds and recall their tuning settings, so no operational staff were needed. In common with many other manufacturers, all MCSL high power senders after this were auto-wavechange and auto-tune.

The BBC World Service required still more power, and four AEG Telefunken S4005 500kW senders were installed at Rampisham along with four MCSL B6127 500kW senders. These senders employed 'Pulsam PWM', a Marconi patented system of pulse width modulation in which the duty of the modulator is limited to the processing of sideband information only. Efficiencies were now approaching 65%. Later, two MCSL B6128 500kW Advanced Pulsam units



Control panel of one of four 250kW RIZ OR250K-02/A transmitters at Woofferton (Neale Bateman)

were installed. In the Advanced Pulsam unit, audio is processed by a solid state encoder located at the transmitter front panel. The resulting output is a string of constant amplitude pulses at a high repetition rate; the duration of the pulses varied in accordance with the audio amplitude. Transmitters for VOA, Radio Free Europe and Radio Liberty had formerly been supplied mainly by American companies, until a tender was issued by the United States Information Agency in 1986 for the evaluation of four different 500kW transmitters against a future order of 32 units. Single units were bought from AEG-TFK, ABB, Marconi and CE-Varian. Of these, a CE 420B and an MCSL B6127 were installed at the Greenville A site at Black Jack, NC, and one ABB SK55-C3 and an AEG-TFK S4005 at the Greenville B site at Bear Grass, NC. MCSL won the contract and supplied types B6127, B6128 and B6131, most being manufactured in the USA under licence.

A further major development took place in the mid 1980s when Continental Electronics introduced their version of a totally solid-state PSM unit. Being solid-state it did not need expensive valves or filament supplies, or complex cooling. It was made available to other manufacturers, including MCSL for their new 500kW units, and could be retro-fitted to remove the tubed analogue or tubed PWM modulators. With this concept, the final move could be made to maximum realisable efficiency, as the tube count was reduced to just the RF driver and FRF stages.

With transmitter efficiencies now up to around 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 produced a 500kW sender, OR500K-01/A both as the RIZ-500 and also re-badged for Telefunken as an S4050, which was installed at the Wertachtal site.

The RIZ-500 was an excellent unit with a solid-state PSM of their own design The prototype RIZ-500 was bought by VT Communications (VTC) and down-rated to 250kW for an upgrade at Woofferton and it prompted VTC to buy a quantity of OR250K-02/A 250kW units of a brand-new design, three for Woofferton, one for Skelton and four for Ascension Island. For this transmitter RIZ had redesigned the RF section to employ just one valve, the TH558. The driver valve, so long a feature of designs by all manufacturers, was replaced by a solid-state 5kW wideband amplifier. This was a tricky design challenge for the RIZ engineers but valuable because the removal of the driver valve saved both money and energy as there was no need for a separate high Voltage power supply and filament. Efficiencies were now at about 82% with all available energy-saving measures in place.

This situation is probably the best that can be achieved, and marks the end of nearly 100 years 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. The halcyon days of regular technical developments and plant re-engineering that so characterised the long development of HF transmitters are over.