The Development of HF Broadcast Transmitters

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

Sender 1, an STC 10/15kW transmitter, at Daventry in 1932

The development of HF broadcast transmitters had slow beginnings. Compared to the rapidly expanding government VLF and LF Morse services, and the commercial and government LF and MF 'Amplitude Modulated' (AM) broadcast services in the early 1920s, the HF spectrum was largely ignored. It was left to enthusiastic radio amateurs to discover exactly what could be achieved on HF for 'Carrier Wave' (CW), used for Morse code, and AM services in terms of transmission and propagation.

To begin with, as high power valves were yet to appear, HF transmitters often just had tens or hundreds of Watts of power. The trend from the 1920s was to try to increase transmitter power. By the late 1920s G5SW at Chelmsford in the UK was running an HF transmitter at 8kW, Deutschlandsender at Zeesen in Germany had a Telefunken shortwave transmitter at 8/12kW in August 1929, AWA's VK3ME station at Pennant Hills in Australia was at 20kW (from where they made their first 'Empire Broadcast in September 1927), and W8XK had a transmitter at 40kW at Forest Hills in the USA. By the mid 1930s the United States had a growing audience in Europe for relayed commercial programmes using HF via, for example, W2XAF and W2XAD owned by General Electric, W2XDV owned by the Atlantic Broadcasting Corporation and the National Broadcasting Company's W3XAL.

The international coverage of HF had not gone unnoticed by governments, nor had its potential as a propaganda tool. The result was that almost limitless state funding for HF broadcasting became available causing a large increase in the number of manufacturers making transmitters and a significant effort to improve the performance of the valves which were one of the key elements in achieving more powerful transmitters and therefore stronger signals.

The valves (or 'tubes') were used to generate a low-level carrier wave on the required frequency and then amplify this in further tuned stages to the required output power. CW transmitters were the simplest, as the carrier wave was just keyed on and off for the Morse characters. All transmitters employed a series of Radio Frequency (RF) stages, often composed of multiple valves, to amplify the power and achieve the required power output from a Final RF (FRF) stage.

For broadcasting it is necessary to apply modulation to the amplified power. Modulation entails adding an information-bearing modulation wave, for example an audio signal, to the carrier wave which, having a much higher frequency than the sound modulation wave, carries the information. In AM, the amplitude of the carrier wave is varied. For example, a continuous wave RF signal (a sinusoidal carrier wave) has its amplitude modulated by an audio waveform before transmission.

One of the first ways of producing AM with valve transmitters for LF, MF and HF was to employ Heising anode, or 'Class A', modulation. Here the current to the FRF valve is fed through a high-value inductor (or 'choke'). The audio amplifier (or modulator) valve anode is fed through the same inductor, which makes the modulator valve divert current from the RF amplifier. The choke acts as a constant current source in the audio range. The Heising modulator had a power efficiency of only around 30%.

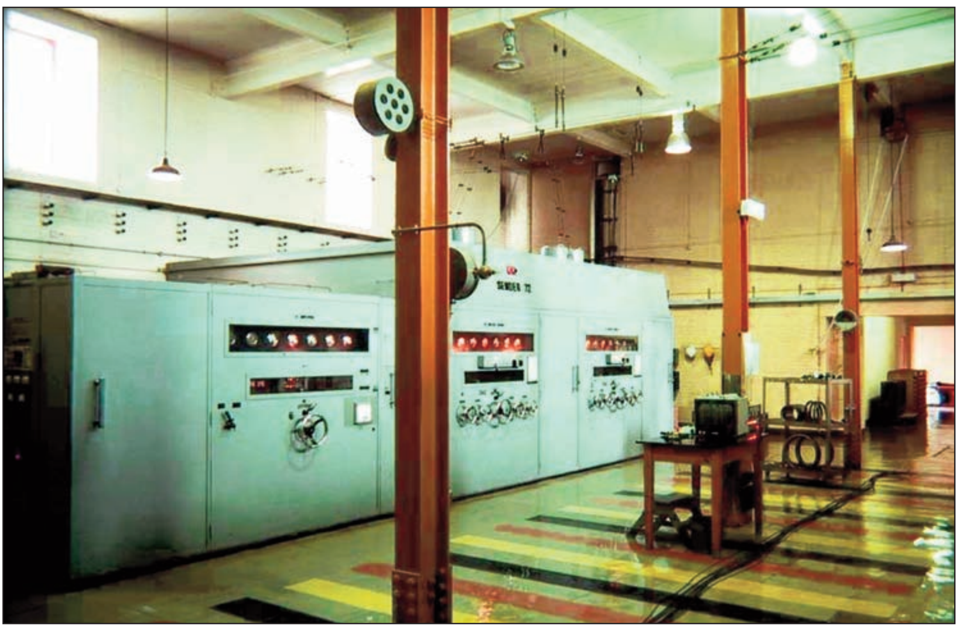
The modulator stage was composed of low-level amplifiers which raised the programme signal to a level sufficient to drive the modulator output valve, typically around 75W output. The FRF output would normally be about 100-125W and could then be amplified linearly (to preserve the modulated waveform) by more stages to reach the desired power output.

The BBC's experience is typical and by 1932, after some low-power tests, Senders 1 and 2 – both STC 10/15kW transmitters – had been installed at the newly-built Empire Station at Daventry; Sender 3 at Daventry was the relocated G5SW from Chelmsford, now upgraded to 12kW. They employed Heising modulation and then linearly amplified it up to the full RF output power. The disadvantage with linear amplification is that its overall efficiency is at best only up to 20%. Overall efficiency also suffered as the electrical power source at the RF stage was low-powered motor generator sets. This poor efficiency limited the amount of power that could be obtained from the valves and components, and created a problem over the removal of the waste heat generated by the process.

The valves needed to be cooled and two means of cooling them were used in the early transmitters. These were air cooling by natural radiation or forced draught, and water cooling. Later developments included vapour steam cooling and Hypervapotron cooling.

Valves with water-cooled anodes soon appeared. Unfortunately, the way they operated in the HF bands generally meant that it was not possible to obtain as much output power at, say, 21MHz as at 6MHz. This was mainly caused by the extra heat generated at the glass-to-metal seals in the valves by the higher RF currents as the frequency increased.

This problem was addressed by using a technique developed in 1919. In that year W G Houskeeper from Coatesville in the USA, and then working for Western Electric, devised a technique using thin copper sheets to achieve a knife-edge seal where effectively the expansion and contraction coefficients of the metal matched that of the glass. Valves using this technology were gradually introduced to HF broadcast transmitters, making them significantly more efficient.



An STC CS8 at Skelton

Six BD272 Senders at Woofferton in 1963. (the late Lee Davison)

A second cause of extra heat gain were the valve filaments. Originally these were made of pure tungsten and had to be heated to 2550°K to produce an emission of 7mA/W. These filaments consumed a significant proportion of the total input power to the transmitter. A considerable improvement was obtained from a tungsten filament which contained just 2% of thorium oxide. Even at a reduced temperature of 2000°K this produced an emission of 70-100mA/W, reducing the energy needed to light the tube or, on the other hand, allowing much more power to be extracted from the same tube.

A BY1144L triode valve in the LH modulator position in a MWT BD272 transmitter (Neale Bateman)

With international tensions increasing, governments requested higher RF power in order to increase global reach. To this end Daventry acquired two STC C50 transmitters at 50-80kW which had the new Class B audio modulation system. This employed a modulator with two or more valves in push-pull in the output stage, increasing the power available from the supply voltage, and helping to increase power efficiency to 55% . This increase was also partly because motor generator sets had been replaced by transformer power supplies, and also because efficient mercury-arc rectifiers (invented in 1902 by Peter Cooper Hewitt in the USA to provide reliable power for industrial motors) were used to supply the high voltage current, typically 11kV DC, that was required along with other high-power components to make this system work. These continued to be used until the advent of solid state semiconductor rectifiers in the 1970s.

Sender 6, an SWB14 by Marconi's Wireless Telegraph (MWT) and installed at Daventry in 1938, was the exception in that it had a 'series modulator'. Series modulation dispensed with the modulation transformer and instead had a Class A modulator with one large valve, It was not very

The MWT BD272 at Woofferton showing (L to R) Modulator and Control, RF stages and 5kW driver transmitter (Neale Bateman)

efficient and needed a high voltage supply of 22kV. It did, however, have the energy-saving feature of 'floating carrier' where the 100kW output could be reduced to about 30kW when no modulation was present. This concept was later used by AEG-Telefunken from the late 1970s.

For Class B systems it was convenient to use four identical high-power tubes; two to generate the RF output carrier wave and two in the modulator. The days of multi-tubed stages with small valves in parallel were over.

Sender 7 at Daventry was a dual channel STC type CS7, which went on air in 1940. This transmitter had the innovation of four RF channels. Up to two channels could be in use at a time with a common Class B modulator, so the same programme could go out on the two channels at 70kW on each or 100kW on a single one. As the schedule changes rolled round over 24 hours the spare channels could be set ready to go to the next frequency as soon as the previous channel ended, with no time lost changing wavelengths. Two additional MWT 100kW SWB18 transmitters were installed as Senders 8 and 9 in 1939 and a a further pair as Senders 10 and 11 in 1940.

Skelton B was equipped with six dual-channel STC CS8 100kW transmitters making the Skelton complex the biggest HF site in the World by mid-1943, and in the same year six RCA MI-7730 50kW transmitters were installed at Woofferton. All of these were Class B modulated.

In 1962, Senders 4, 5 and 6 were replaced by MWT BD253 100kW dual-channel transmitters. These were some of the first HF transmitters in the BBC with 'vapour steam cooling'. Vapour steam cooling, or 'vapour cooling' as it came to be known was effected by the valve anode being immersed in a water tank or boiler. The heat from the valve made the water boil which meant, in effect, that the heat was removed by evaporation. This was an ingenious solution as 170kW will evaporate one gallon (or 4.5 litres) of water per minute at 100°C. The resultant steam rises naturally to a heat exchanger where it condenses and is returned by gravity to the boiler.

From 1963 the MWT 250kW BD272/B6122 was to become, and remain for many years, the standard workhorse at all the BBC sites, replacing ageing equipment. It was again Class B modulated and about 50% power efficient overall. It had just two RF output type BY1144L vapour steam cooled valves for the 250kW, with two more in the modulator. The first six of these transmitters were installed at Woofferton in 1963 for the Voice of America relays, and in 1964 Continental Electronics in the USA produced a Doherty version Type 420A at 500kW for Radio Free Europe/Radio Liberty and Voice of America sites. This transmitter used eight tubes in the output, cleverly configured to produce AM.

The evolution of valves continued until the introduction of solid state components for broadcast transmitters in the late 1970s. But for the moment these Class B modulated analogue all-valved units marked the apogee of High Frequency transmitter development.