The transmitter

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This article outlines the major developments which have taken place in sound transmitter equipment and techniques – from the first experiments before the invention of the thermionic valve, up to the present time.

Over the years, high-power transmitters have developed into very sophisticated systems. Their progress was initially driven by a thirst for ever-increasing power and audibility. Today, like with many other things, their development is driven by the quest to reduce capital and operating costs.

1. *How it all began*

Before we can attempt to chart the progress of a new technology, we must first attempt to define a starting point. In the case of sound radio, this is no easy matter as the pioneering efforts of many people were necessary before radio transmission or broadcasting could be attributed to any one individual.

Most people – in the Western hemisphere at least – will immediately think of Marconi [1] although we should perhaps attribute the conception to Clerk Maxwell, the first quickening to Hertz and the actual birth to Marconi. The Hertz transmitter consisted of an induction coil connected to a pair of metal plates, across which was connected a spark gap. When the coil was sufficiently charged, the spark gap broke down, resulting in a sudden disruption of the electric field which in turn created a magnetic flux in space. The receiver consisted of a broken metal ring with a very small gap formed by the open ends. The signal was detected by small sparks seen to jump this gap.

The range of Hertz's equipment was no more than a few metres. With refinements, the practical

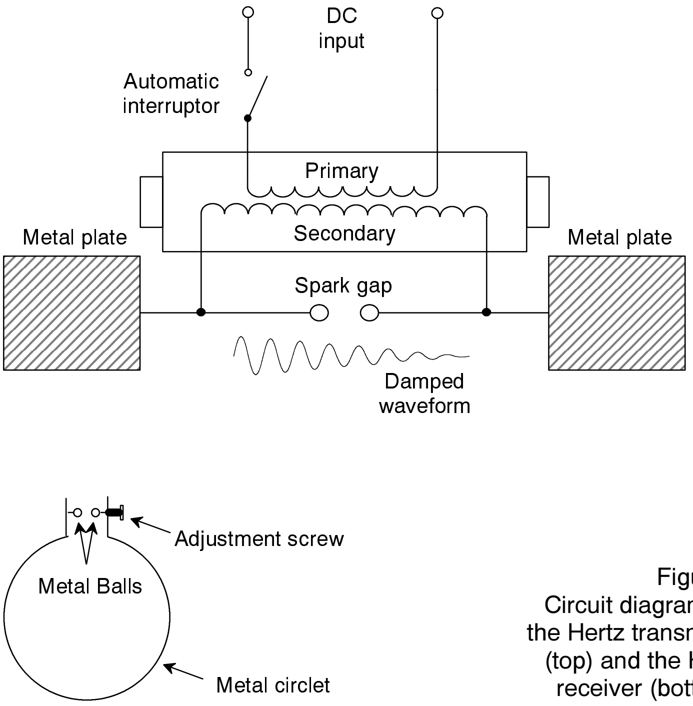


Figure 1
Circuit diagrams of the Hertz transmitter (top) and the Hertz receiver (bottom).

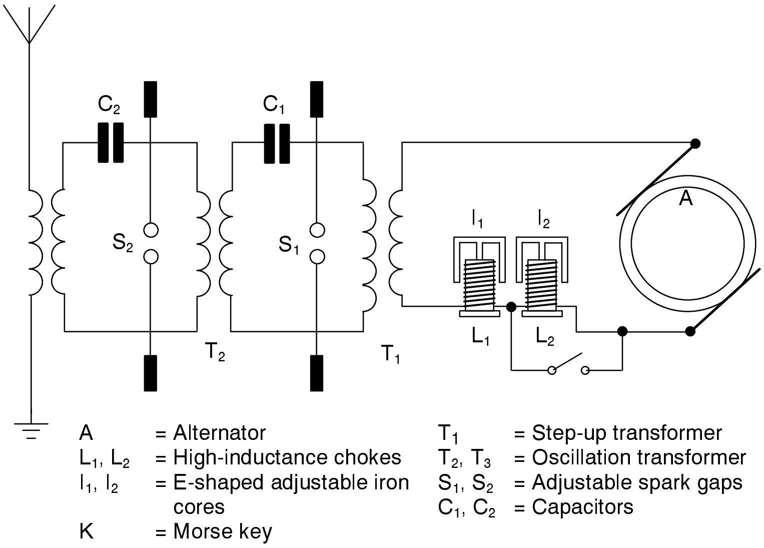


Figure 2
Circuit diagram of the Poldhu Transmitter.

limits seemed to be a few hundred metres, but it was not until Marconi had the inspiration to connect one side of the equipment to ground (earth) and the other side to an aerial of elevated wire that the range was dramatically increased to around 2 km. This distance was gradually increased until, in 1901, the Atlantic Ocean was spanned from Poldhu in Cornwall, England, to St. John's in Newfoundland, Canada. The size of the Poldhu station, in comparison to earlier battery-powered equipment, was enormous. Power was supplied by a 32-horse-power Hornsby-Ackroyd oil engine, driving a 25 kW Mather and Platt alternator which delivered 2000 volts at 50 Hz.

This was stepped up to 20 000 volts to feed the closed oscillatory circuit in which a capacitor was discharged into the primary of an RF transformer by the usual spark gap. The wavelength was thought to be about 366 m.

So far, all transmissions had been telegraphy. Attempts at telephony had consisted of putting a "water-cooled, asbestos-covered microphone" in series with the aerial of a continuous arc transmitter.

Possibly the first radio broadcast was conducted by Nathan B. Stubblefield, a now-forgotten eccentric inventor who demonstrated a strange phenomenon in 1892 – the wireless transmission of speech across the small town square of Murray, Kentucky. Unfortunately, he died destitute in 1928 but his gravestone in Murray records him as the "Father of Broadcasting".

All these early radio transmissions occurred without any sign of a thermionic valve, let alone a transistor.

It was in 1899 that Guigliemo Marconi acquired the services of Dr J.A. Fleming who, in 1904,

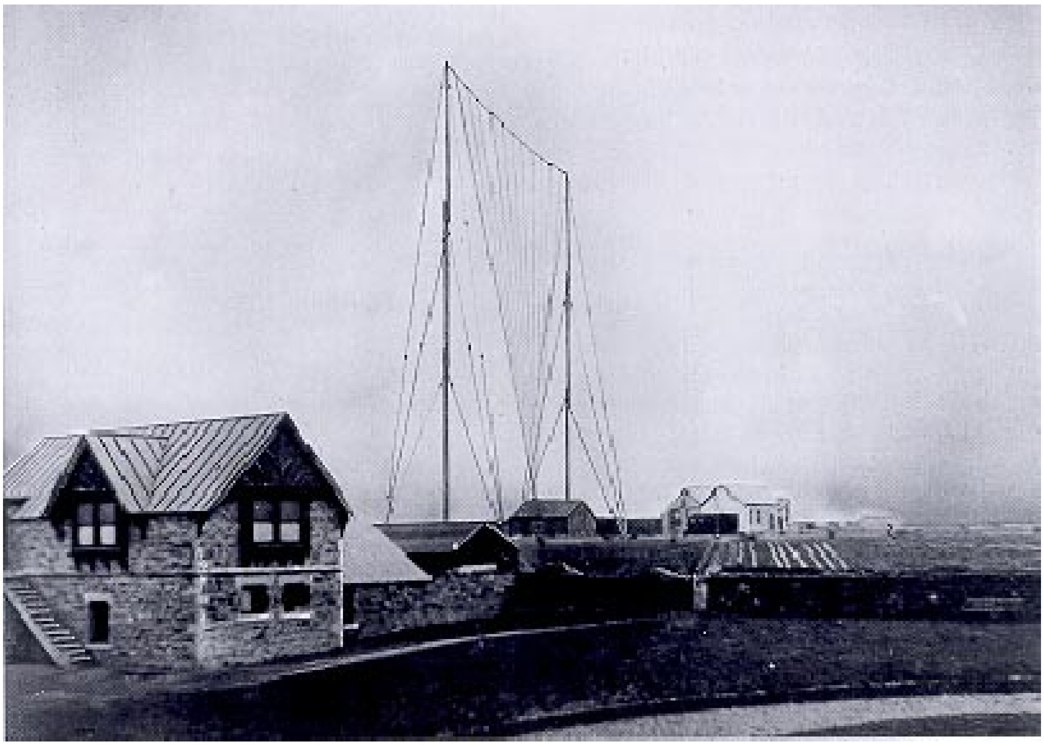


Figure 3
The Poldhu antenna system.

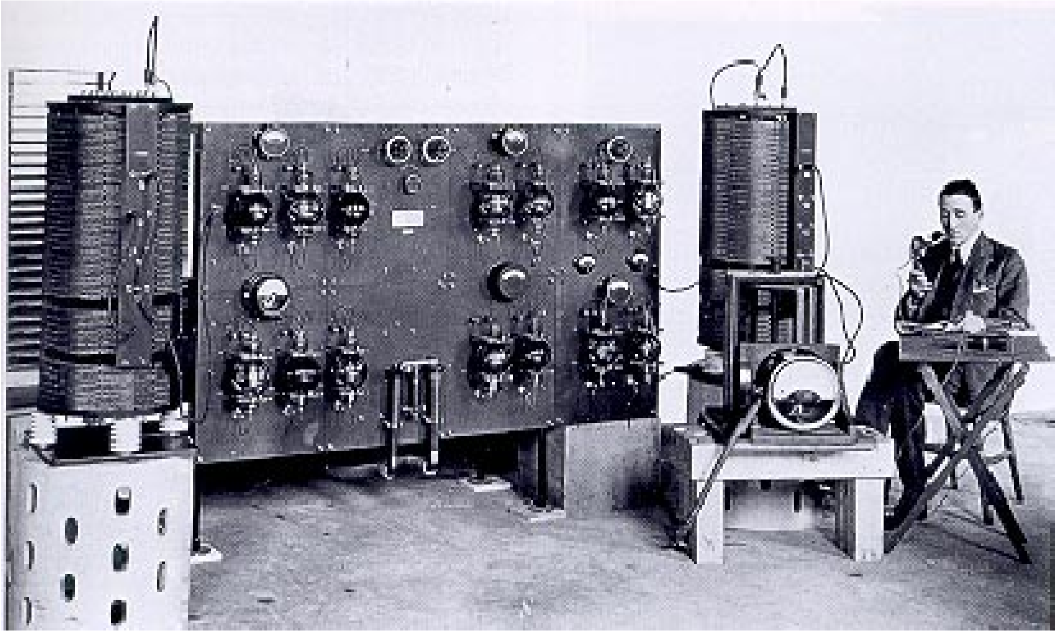


Figure 4
The Chelmsford transmitter *2MT* in 1920.

turned his attention to devising a new form of detector. He recalled his earlier work when he had added a foil inside a light bulb to try to minimise the discolorisation on the inside of the glass. By connecting an alternating voltage to the foil, he found that current flowed in one direction. The *thermionic diode* was born. Two years later, the American inventor Dr Lee de Forest added a third electrode called the *gridiron* or *control grid* to the diode and patented a device that he claimed could amplify weak signals.

The Marconi Co. and de Forest then became entrenched in legal battles over the patent rights of their two devices. The proceedings were expensive and lasted for years. In fact it was not until 1913/14 that advances in valve technology made the triode into a commercial proposition.

Also in 1906, General Dunwoodie of the US army discovered that a material called carborundum exhibited a phenomenon which did not obey Ohms Law. This soon gave rise to the crystal detector.

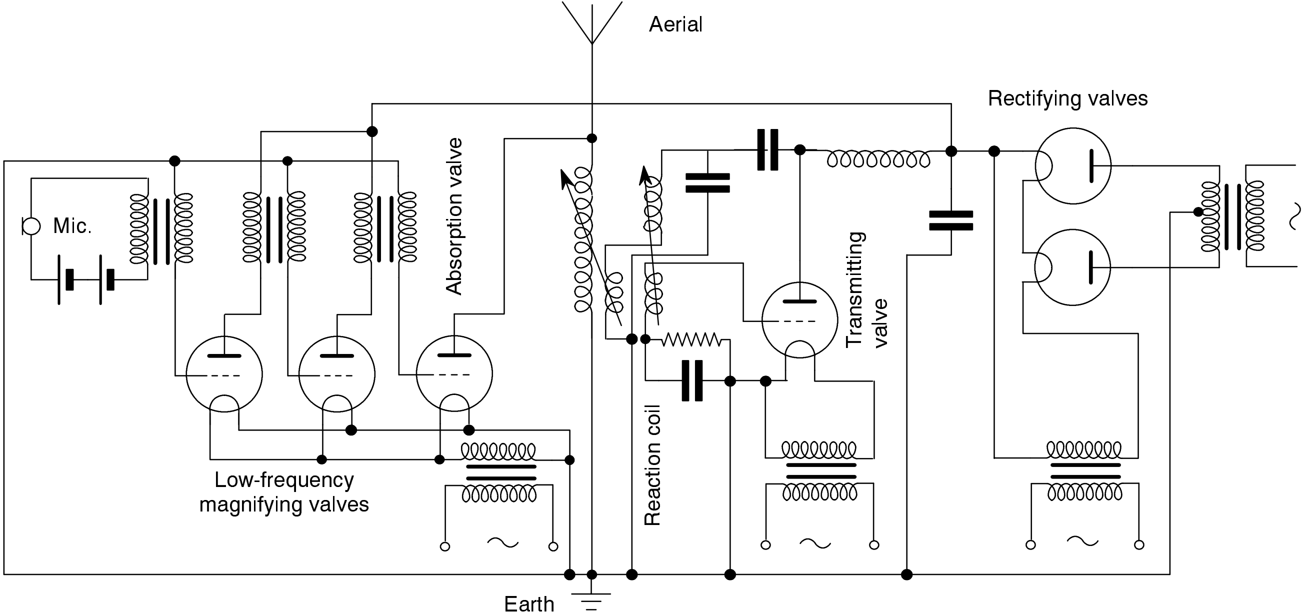


Figure 5
Circuit diagram of the Chelmsford transmitter.

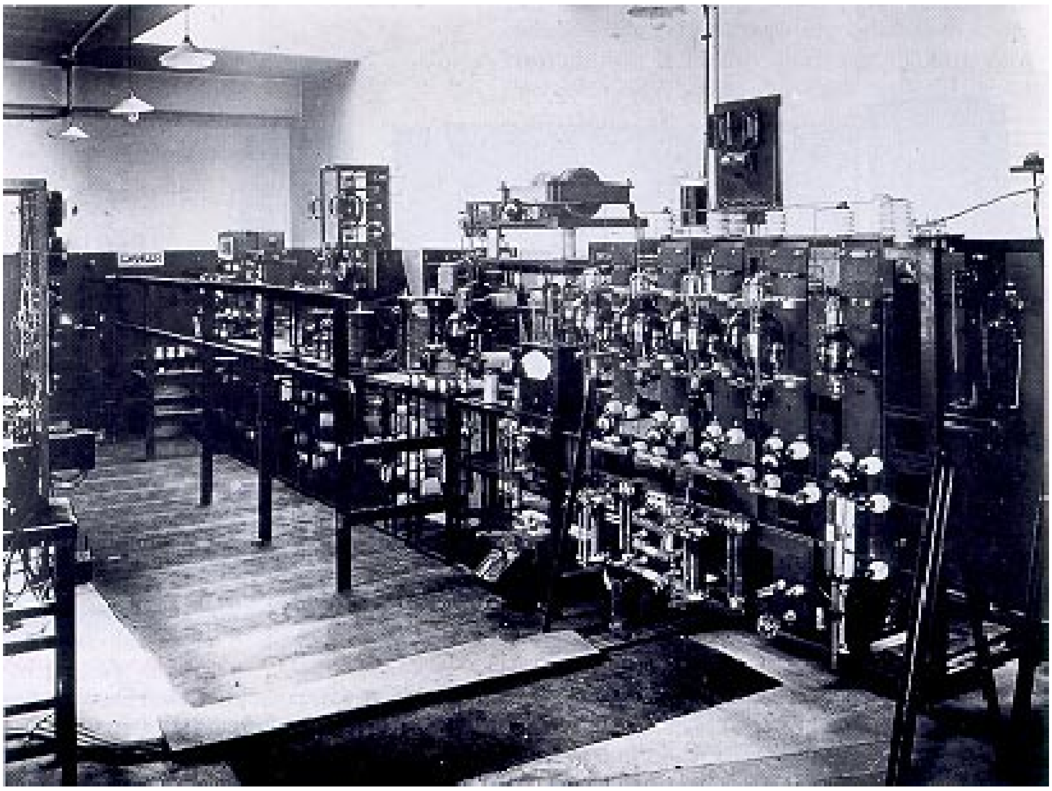
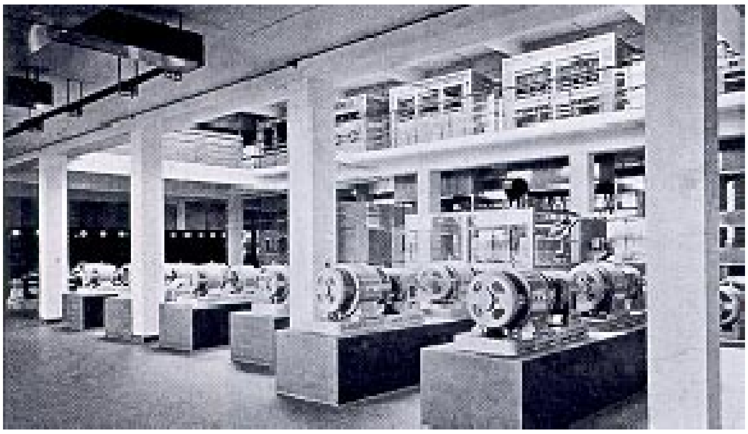


Figure 6
The London
transmitter *2LO*
in 1922.

In 1920, with the development of larger valves by H.J. Round of the Marconi Company, more powerful transmitters were built in Chelmsford and range testing consisted of the continual recital of railway-station names. Becoming bored with this, Round and Ditcham pressed into service a number of Company employees with musical talent. Two hundred and fourteen appreciative reports were received from experimenters, the greatest distance being 1450 miles (2334 km).

A turning point in the history of British broadcasting was the first broadcast of a recognised professional artiste, Dame Nellie Melba, who gave her historic 30-minute concert from the Chelmsford works on 15 June 1920. Within days, enthusiastic letters poured into Chelmsford from the four corners of the world. Dame Nellie was paid one thousand pounds for the concert (by the English daily newspaper, the *Daily Mail)*.

Figure 7
A typical machine
room in the 1920s.



Experimental broadcasting then continued from Writtle, near Chelmsford, using call-sign *2MT Emma Toc,* before transferring to the *2LO* transmitter at the Marconi head office in the Strand, London. On 18 May 1922, a proposal was put to some 400 eligible manufacturers to form a broadcasting consortium to bring broadcasting under a single controlling company. The British Broadcasting Company (later the British Broadcasting Corporation) was thus formed with an initial capital of £100 000.

By now the pioneering work been done, basic components were available and the theory of operation was understood.

2. Early technical progress

The trend from the 1920s – as it seems to have been ever since – was to increase the transmitter power. The efficiency of the equipment was not of paramount importance, except that poor efficiency limited the amount of power that could be obtained from the available valves and components, and required the removal of waste heat. For this reason, valves with water-cooled anodes soon appeared. Their operation in the HF bands generally meant that it was not possible to obtain as much power at the top of the band, as could be obtained at the lower frequencies. This was due to internal inductances, particularly of the cathode lead, and heating of the glass-to-metal seals by the higher RF currents.

By the end of the 1930s, HF transmitters with carrier powers of 100 kW were available. They used rotating machines for many of their supplies; the valve filaments were still made of pure tungsten and required many hundreds of amperes for heating. In fact, filament generators of 2000 amperes at 30-40 volts were typical. Some of these machines, when used with series modulators, operated at a high voltage above earth and were mounted on large insulators, with insulated couplings between the dynamo and the driving motor.

The high-tension (10-12 kV) supply for the anodes was also provided by multi-pole, large-diameter, dynamos. These high-tension generators were ultimately replaced by multi-phase transformers which fed mercury arc rectifiers. Initially these were steel-tank rectifiers, which had to be continually evacuated by means of a pump. They could, however, be opened for repair or servicing.

A typical example for use on the short-wave bands was the Marconi SWB18. It was able to change frequency by means of circuit trucks which, effectively, were the output-circuit variable components mounted on a wheeled assembly. Four of these were supplied and could be pre-tuned to the next frequency; a system of miniature railway lines, with points, enabled the appropriate truck to be wheeled into position when required. The "wave change" time was quoted as less than eight minutes.

The transmitter, although rated at 100 kW output, only gave 80 kW at 22 MHz, which was its top frequency. It was offered with two alternative types of modulator.

- a series modulator which offered *floating carrier*, an energy saving system that reduced the carrier under low-modulation conditions;
- a push-pull class B modulator, which was becoming the preferred type.

The overall efficiency was quoted as 33 % The variable-tuning capacitors were air-spaced metal plates which were meshed by rotating a shaft carrying the moving plates. It was not until about 1944 that Jo Jennings produced the first vacuum capacitors.

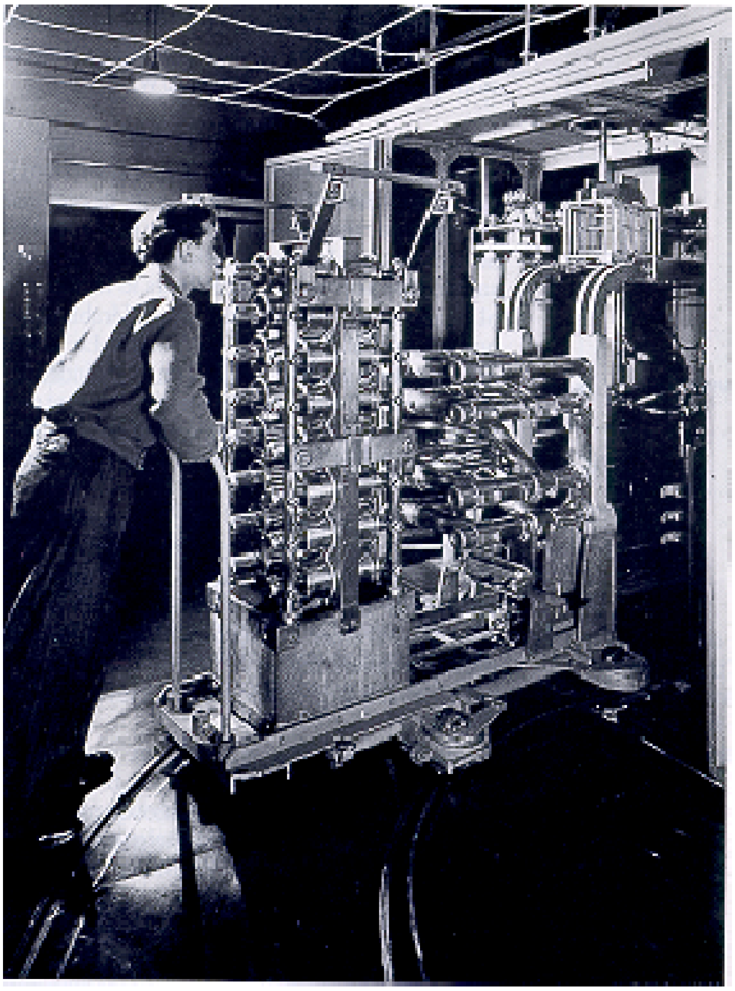


Figure 8
A frequency-change truck.

Modern-day vacuum capacitors are high-technology devices. They are available with working voltages in excess of 50 kV, at 30 MHz, and with capacitances of several thousand picofarads; they can carry RF currents of a 1000 amperes. High-power variable-vacuum capacitors, which rely on bellows to maintain the vacuum seal as the meshing cylinders are moved in and out, use water cooling to remove the heat which is dissipated in the bellows as a result of the high RF current. Their maximum speed of tuning is limited by the speed at which water can be added to, or removed from, the bellows chamber without damaging the thin bronze bellows. This is typically 10 seconds for the full travel.

Larger variable capacitors – more suited to LF and MF operation – use nitrogen or, more recently, sulphur hexafluoride at elevated pressure as the insulating gases. These capacitors are generally de-mountable for repair. Because of their physical size, their internal inductance generally precludes their use at HF.

3. Improvements in valve technology

As mentioned above, the early valves used pure tungsten filaments. These had to be heated to 2550° K to produce an emission of 7 mA/W and consumed a significant proportion of the transmitter total input power.

A considerable improvement was obtained by Langmuir [2] from a filament which contained 2 % of thorium oxide. Even at a reduced temperature of 2000° K, this device could produce a specific emission of 70 – 100 mA/W.

The addition of a second grid – the *screen grid* – brought further advances. As its name suggests, it screened the control grid from the anode, to reduce internal feedback and to ease problems of neutralization. It also increased the amplification factor, thus considerably reducing the driving power required. The earlier grid structures were formed of a cylinder of crossing wires. These wires were spot welded at each crossing point, such that the wire cage had many irregularities where the wires crossed.

Courtesy of Thomson Tubes Electroniques

Figure 9
A Thomson TH558 tetrode.

Large modern tetrodes are now made with grids formed from pyrolytic graphite. The grids are made from cylinders of graphite which are “grown” from gas (methane/acetylene) in a furnace. The cylinders are then machined and cut away to form a grid structure, either by a laser or by shot blasting through a mask.

They have numerous advantages: there are no joints or overlapping wires, they are strong, and they are less likely to distort when heated. Furthermore, they do not suffer from secondary emission and may be operated at higher temperatures than conventional wire grids.

Cooling of the anodes is now accomplished in several different ways. In small transmitting and receiving valves, the anodes may be cooled by natural convection, by radiation or by forced air blown over the glass envelope. In larger valves, the anode is the outer surface and may be fitted with fins through which air is blown.

On large transmitting valves, water is used exclusively as the coolant. In the early days, the water was pumped over the outer surface of the anode and carried the heat away, with a fairly low rise in the water temperature. This was wasteful, as large water flows were required and the removed heat was of too low a grade for further use.

A better arrangement was to have the anode immersed in a container of water (a boiler) and to allow the water to boil; the heat was removed by the latent heat of evaporation. (170 kW will evaporate one gallon of water each minute at 100° C). The resultant steam rises naturally to the heat exchanger where it is condensed and returns by gravity to the boiler, with the added advantage that no pump is required.

Today’s super-power valves also use latent-heat cooling but the steam is condensed inside the anode jacket. The resultant water can exit at up to 100° C and is useful for heating the building if required.

We have talked about technological progress in components and will now investigate further improvements in the techniques and equipment design. However, before we proceed, we should look at the signal and the spectrum which is produced by a broadcast transmitter.

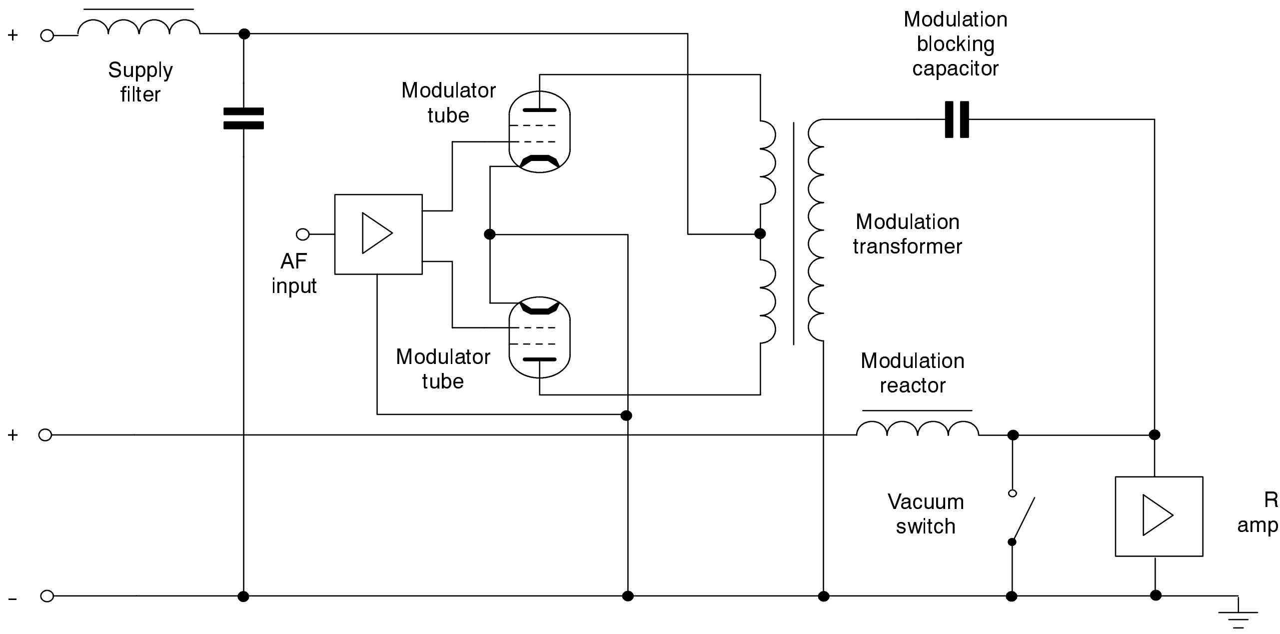


Figure 10
Circuit diagram of a class-B push-pull modulator.

4. *Signal characteristics*

Double sideband (DSB) modulation comprises a carrier, and a spectrum of side frequencies which is centred about the carrier.

Broadcast transmitters are normally specified by their unmodulated carrier power. The carrier is then amplitude modulated until, at a modulation index of $m = 1$, the carrier is reduced to zero in the trough and to twice the carrier voltage at the crest of modulation. The RMS power from a transmitter obeys the familiar expression:

$$P_{RMS} = 1 + m^2 / 2$$

where: P_{RMS} is the RMS power, 1 is the carrier power and m is the modulation index, in the range 0 - 1.

Therefore, at 100 % modulation (i.e. when $m = 1$), the RMS power is equal to 1.5 × carrier power. However, the peak power at 100% modulation is 4 × carrier power. Thus, in the case of a fully-modulated 500 kW transmitter, the RMS power is 750 kW and the peak power is 2000 kW (assuming no carrier compression). The radiofrequency amplifier has to handle all these conditions.

5. *Class-B modulation*

After the early days of inefficient linear-series modulators, the standard way of modulating a high-power transmitter (up until the mid-1970s) was by means of a class-B push-pull modulator. Its efficiency approached 70% at $m = 1$, but decreased quite dramatically at lower modulation depths. (Average modulation levels seldom exceed 30–40 %, even with compressed programme modulation.)

The side-band energy (i.e. the modulation) was supplied by a push-pull class-B audio amplifier, which was coupled to the RF amplifier by means of a large modulation transformer. The modulator was required to produce half of the total DC input to the RF output stage. At high powers, an additional modulation choke (reactor) was used, to avoid having to pass a large unbalanced DC component through the transformer secondary winding. The transformer and choke weighed typically more than 5 tonnes each and could contain several hundred gallons of insulating oil, with its attendant risk of fire.

6. *Efficiency improvements in class-C amplifiers*

In 1958, while working for Marconi, V.J. Tyler [3] published a paper describing a means of improving the efficiency of the class-C amplifier. This was achieved by adding harmonic resonators in the anode and the grid circuits of the RF amplifier valve.

In practice, these resonators were tuned to the third harmonic frequency and consisted of parallel-tuned circuits in series with the valve electrodes. They presented high impedances at the harmonic

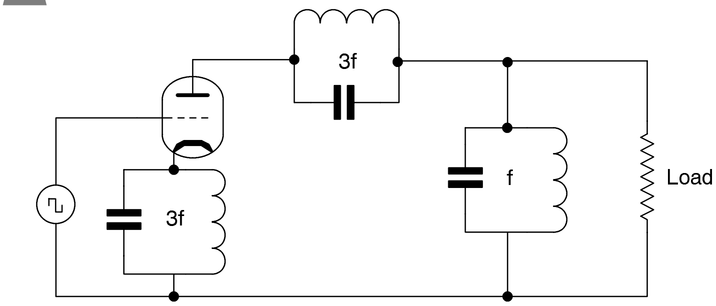


Figure 11
Circuit diagram of the Tyler Resonator.

frequencies and allowed a third harmonic voltage to be developed at the anode. This had the effect of allowing the valve to operate as an approximate square-wave switch, by means of the pulse of grid current that resulted when the grid was driven positive. The Tyler resonator offered only a small reactance at the fundamental frequency, which was taken up by the tank circuit.

At LF and MF, anode efficiencies of 90% were attainable with this system. However, at HF, there were severe difficulties in realising the third harmonic circuits for use at high power. Since the original Tyler patent lapsed, this technique has been adopted, almost universally, by other manufacturers.

7. Alternative means of generating AM DSB

So far we have only considered the side-band energy that is supplied to the RF amplifier by a separate modulator which varies the instantaneous value of the HT supply. As stated earlier, the requirement of an AM transmitter is to be able to vary the carrier power from its nominal value down to zero in the trough of modulation, and up to four times its nominal value at the crest of modulation.

Obviously this has to occur over the bandwidth of the modulating frequencies. If we consider the RF amplifier as a constant-voltage generator that has the ability to vary dynamically the load presented to the valve, we could vary the power dynamically, or produce modulation, without having to vary the HT supply. A novel system to achieve this was devised by W.H. Doherty [4] in 1936.

Basically it uses two similar power valves. The first produces the carrier power and the negative modulation. The second valve produces part of the additional power which is required for positive modulation and, at the same time, it reduces the load impedance seen by the carrier valve so that it also contributes extra power at positive modulation. In fact at 100% modulation, both the carrier valve and the peaking valve each contribute half of the total power.

This system has been particularly successful when used with modern high-gain tetrodes. The RF drive is applied to the control grids and the audio signals are fed to the screen grids. Transmitters which use Doherty modulation have been built successfully by numerous manufacturers, notably Continental Electronics in the USA who have produced LF and MF transmitters of 2 MW carrier power.

The Doherty system offers several advantages. It does not require a modulation transformer or reactor; the RF amplifiers do not have to tolerate the HT voltage being doubled at the crest of modulation and, consequently, they can be operated at higher mean anode voltages. This improved efficiency and output power has been achieved by using HT voltages in the range 15 – 20 kV.

The Doherty principal can also be used at HF but it suffers from difficulties in maintaining the RF phase relationships, particularly at frequencies above 20 MHz.

The basic output circuit for a Doherty-modulated amplifier is shown in *Fig. 12*. The load is matched to the impedance at the anode of the peaking valve, and a quarter-wave network is connected between the valve anodes. The effect of the network is to transform inversely the impedance presented at the peaking-valve anode. The characteristic impedance of the network (Z_o) is designed to be twice the value of the load (R_L) with the peaking valve biased off. The input impedance of the network (Z) is given by $Z = Z_o^2 / R_L$ and is therefore four times that of the load.

The biasing of the valves is arranged so that, with zero signal input, the carrier valve is just cut off and the peaking valve is biased well beyond the cut-off point. The carrier valve is driven to saturation by application of RF drive to the grids.

Increased bias, due to grid current, gives class-C operation. The peaking valve, with its extra bias, remains cut off. The modulating signal is applied to the screen grids and, on a positive cycle of modulation, the peaking valve conducts, adding its power to that of the carrier valve. At 100 % modulation, each valve delivers half of the total power.

On the negative cycle of modulation, the voltage on the screen of the carrier valve is reduced, which linearly reduces the output power, and the peaking valve remains in the cut-off condition. Modulation and amplification is therefore achieved by a combination of varying the circuit impedance and the load distribution over the modulation cycle. A quarter-wave network is usually placed in the peaking-valve input to compensate for the phase delay of the anode quarter-wave network. Exalted positive modulation can be used, if required, to allow modulation to 125 % or more. The peaking valve is matched to the transmission-line impedance by conventional matching networks.

The search for improved operating efficiency was accelerated in the early 1970s when energy costs escalated. The advantages gained at lower frequencies by Tyler and Doherty were not easily applied to HF, which still relied mainly on the class-B modulator of that period. A replacement was sought which would improve efficiency, particularly at typical programme modulation levels, and explore further savings in power consumption with controlled carrier operation. This was not dissimilar to the floating-carrier operation of the 1930s, which had used a linear series modulator.

At this time, manufacturers in the USA, Germany, the UK and other European countries began to develop Pulse Width Modulation (PWM) systems, which use the modulator valve as a switching device rather than operating it over the linear part of the characteristic. These developments eventually led to a PWM system by Harris Gates, and the *Pantel* system by Telefunken [5]. A shunt system known as *Pulsam* [6] was developed by the Marconi Co., followed by a DC-coupled system known as *Advanced Pulsam*. By using these systems, the modulator efficiency was improved to better than 90 %, giving overall HF transmitter efficiencies of between 60 and 70 %.

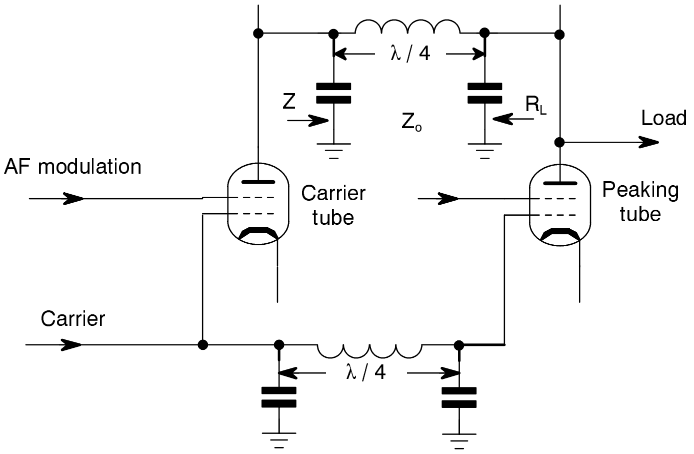


Figure 12
Basic circuit diagram of a Doherty-modulated amplifier.

8. Series-PWM modulation systems

Series-PWM systems have been described in several publications, including [5], and only a brief description of the various systems and their contrasts will be given. All PWM systems must be designed to take account of the effects of stray capacitance on the switching valve, as this results in power loss and also causes distortion of the audio signal in series-PWM systems. Thus the simplest series-PWM system, with the switching valve connected to the high potential rail and the filter in series with the RF amplifier, is unsuitable for use at high powers. The effects of stray capacitance are too great.

One way of avoiding this is to have the cathode of the modulator valve at earth potential, but this requires the whole RF amplifier and its circuit components to be at elevated potential, which is not very convenient. Also, the switching valve and its associated components must be in close prox-

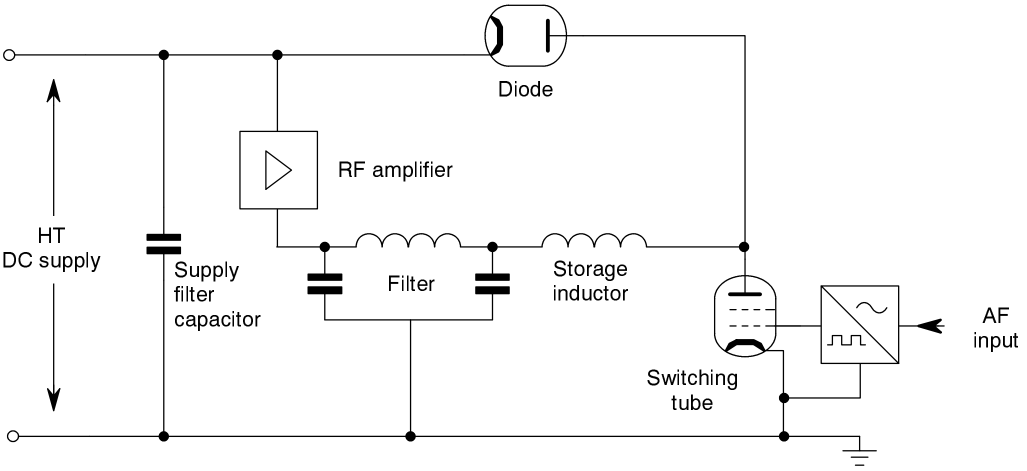


Figure 13
Circuit diagram of a series PWM system.

imity to the RF amplifier, which becomes more difficult at high power due to their physical size.

8.1. The Pantel system

The Telefunken Pantel system has the RF amplifier with its cathode at earth potential, which removes any restriction on its use at high powers. In the basic circuit shown in *Fig. 14*, the effects of stray capacitance on the switching valve are minimised in a novel arrangement which locates the unwanted effects inside the filter. The diode is necessary to return energy to the filter when the switching valve is turned off. Its connection is straightforward in the simple series system but is more involved in the Pantel arrangement, requiring a tightly-coupled winding on the storage inductor.

With any form of series system, the total power to the RF amplifier has to be passed by the modulator. Consequently, its conversion efficiency is of paramount importance to the overall efficiency of the system.

8.2. The Pulsam system

The Pulsam system [6], produced by The Marconi Co., uses a somewhat different approach in that it still only handles the sideband energy, in much the same arrangement as the push-pull class-B modulator. The RF amplifier could be the same as that used with the class-B modulator. It receives its DC input from a dedicated supply, via a modulation reactor, and can be powered independently of the modulator. This has advantages when commissioning or fault finding. The modulator requires a separate supply of just over twice the voltage of the RF supply, although it is considerably smaller, having only to contribute the sideband energy.

The audio input is processed to produce a pulse train which is applied to the control grids of the switching valves. The pulse repetition frequency is approximately ten times the required audio frequency and, consequently, is in the range 50 kHz to 70 kHz. The signal may be applied to the control grid of the lower valve as, in this arrangement, the control grid of the upper valve is automatically pulsed in antiphase. The two valves are connected in series across the HT supply, with their mid-point feeding the storage inductor. In the unmodulated carrier condition, the two valves are driven in antiphase by pulses which are on for 50 % of the duty cycle.

By the action of the storage inductor, this sets the mid-point voltage to half the supply voltage. This is approximately equal to the DC voltage which feeds the RF amplifier. The mid-point is then connected to the RF amplifier via a DC-blocking capacitor. When modulation is applied, the pulse widths vary with the amplitude of the audio frequency signal. At a modulation index of $m = 1$, the lower valve is almost backed off for a number of switching pulses, and the upper valve is almost continually conducting. At the trough of modulation, the valve conditions are reversed.

The Pulsam system offers several advantages:

- the RF stage does not depend on the modulator to be powered;
- the modulator only handles the sideband power so that it uses comparatively small valves;
- the fault energy dumped in the RF valve, under flash arc conditions, is very limited by the modulation reactor.

The disadvantages are that two separate power supplies and a modulation reactor are required, and the radiofrequency HT supply voltage cannot be varied as it can be with a series modulator.

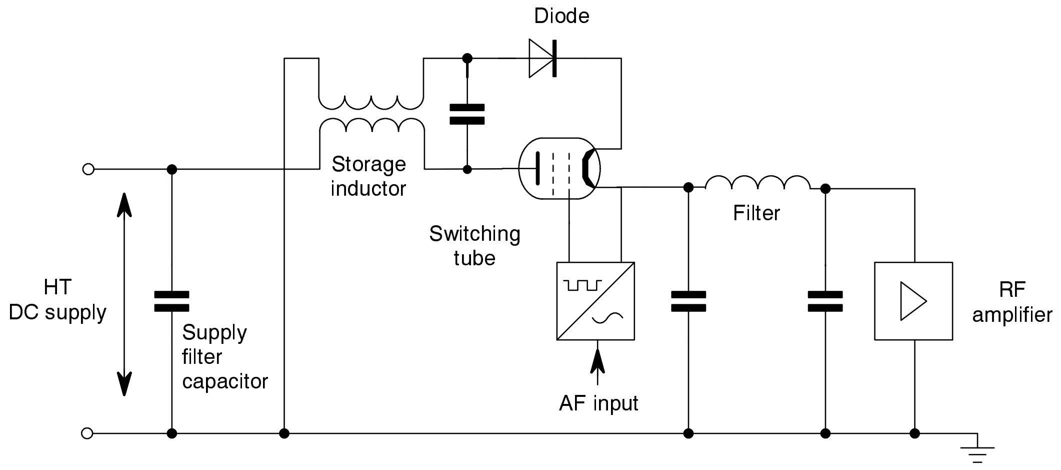


Figure 14
Basic circuit diagram of the Pantel series PWM system.

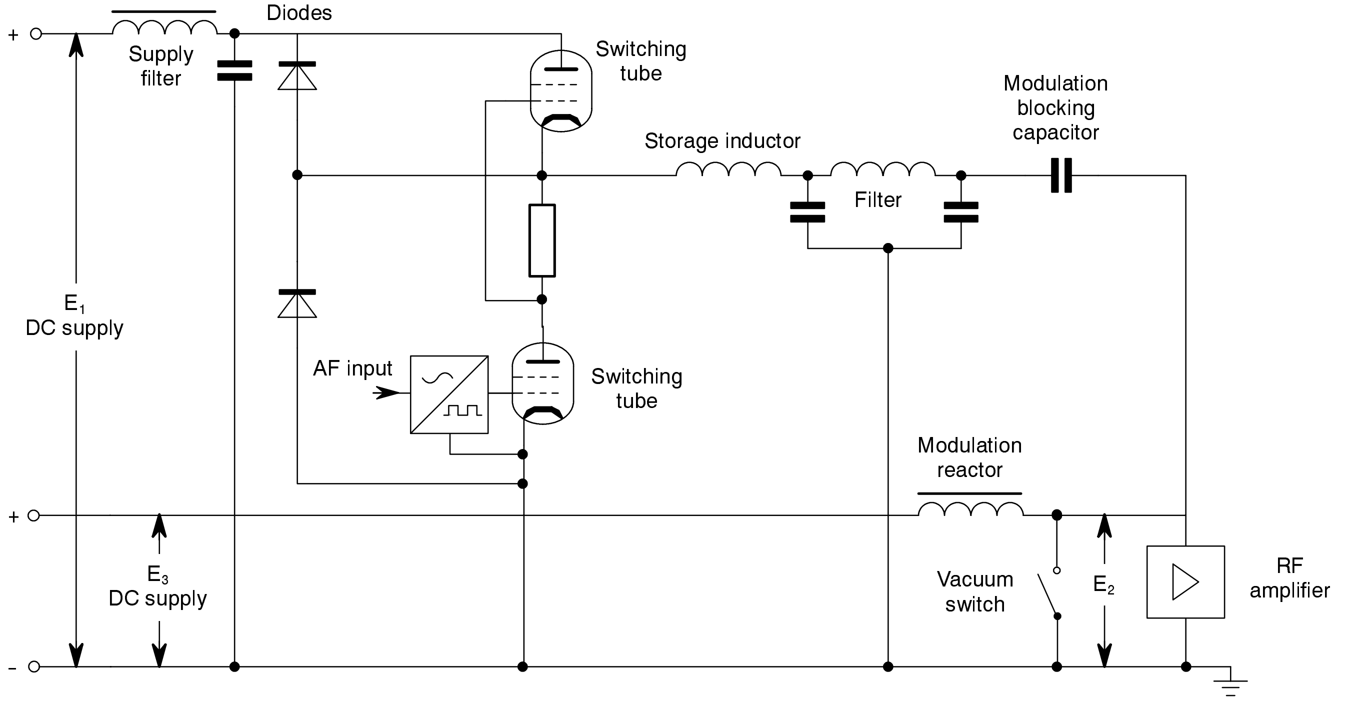


Figure 15
Basic circuit diagram of the Pulsam system.

8.3. *The Advanced Pulsam modulator*

The Advanced Pulsam modulator is a variation on the classic series modulator. The valve is mounted on a low-capacity box which houses the power FETs. These are used to drive the control grid and the screen grid with constant current feeds, and a third electronic switch provides the PWM drive to the control grid. At the carrier, the valve is driven with a mark-to-space ratio of approximately 50:50 and, consequently, the DC potential is half that of the HT supply voltage.

With increased modulation, the on period becomes longer and the off period is shorter. Conversely, in the trough of modulation, the duty cycle becomes reversed. The cathode of the valve is at high potential with respect to ground and therefore requires a highly-insulated filament transformer. This is constructed on a similar principle to the toroidal transformer on mast lighting, to reduce its capacity to a minimum, and has to pass about 10 kW of filament power.

A similar construction is used for the bias and screen transformer. Control signals are fed to the valve, and monitoring signals are sent back by means of fibre-optic cables, which provide very good electrical isolation and high noise immunity.

The series modulator, with its ability to control the DC voltage to the RF amplifier, opens up the possibility for further energy-saving modes of operation.

9. *Energy-saving modulation systems*

There are two standard modes to save energy, both relying on controlled-carrier operation:

9.1. *Dynamic Amplitude Modulation (DAM)*

This method reduces the carrier power at low modulation levels. In the case of a 500 kW transmitter, the carrier power at zero modulation is typically reduced to 180 kW. Up to modulation levels of say 90 %, the carrier level is still reduced. However, further increases in the modulation level increase the carrier power up to the point where, at full modulation, it is back to 500 kW.

Depending on the programme material, power savings of 40% are achievable with DAM. The drawback with this system occurs at the fringe of the reception area, or in areas of interference. As the carrier is reduced under low-modulation conditions, the AGC of the receiver increases its gain and reduces the received signal-to-noise ratio. This can be most annoying to the listener.

9.2. Amplitude Modulation Companding (AMC)

This system, devised by the BBC, is almost the reverse operation of DAM. Here, under conditions of low modulation, the carrier power is at a maximum and, in fact, may even be enhanced above the normal carrier level. When modulation is applied, the carrier is reduced until, at a level corresponding to 100 % modulation, it may be 6 dB down on its original level.

At the receiver, this has a beneficial effect. At low modulation levels, the large carrier reduces the noise at the receiver. Conversely, when the modulation is high and the carrier is reduced, the noise in the receiver will be swamped by the demodulated signal. Energy savings of up to 50 % have been reported when using the AMC system.

10. Single-sideband broadcasting

Modern HF transmitters are required to have the capability for single-sideband (SSB) operation. The carrier suppression must be adjustable over the life of the transmitter, as increasingly more receivers designed for SSB reception become available to the domestic audience. Initially, operation with only 6dB of carrier reduction is proposed. This will allow a compatible signal to be received with a conventional double-sideband receiver.

As cheaper SSB receivers become commonplace, the carrier level may be reduced further. The purpose of this is to reduce the occupied bandwidth and to save power.

The conventional way to produce an SSB transmission has been to generate the SSB signal in the drive circuit, and to amplify it to the required power level by means of linear power amplifiers. These, of course, are not very efficient but they are acceptable at powers of only a few tens of kilowatts, as used in communication transmitters.

With broadcast transmitters, the required peak envelope power may be in excess of 1 MW and, obviously, a more efficient solution is required.

A method originally proposed by Kahn is in widespread use; it does not require the high-power amplifier to be linear and, consequently, it can use the efficient class-C operation. It also requires a DC-coupled modulator, i.e. a series modulator.

The SSB signal is generated in a low-power drive in the normal way. It is then demodulated to retrieve the envelope signal which is fed to the high-power modulator. The SSB signal is then hard limited to remove any amplitude information; the remaining signal, which contains the original phase modulation, is amplified and used to drive the class-C output stage. The amplitude signal and the phase-modulated signal then combine at the anode of the output stage to produce a high-efficiency SSB signal.

11. Solid-state modulators for HF broadcasting

The efficiency of thermionic-valve modulators had been improved to the point where anode-conversion efficiencies in excess of 90 % were commonplace. There was, at this time, little room for improvement as the power dissipated in the filament and the grids was now very significant. The only way forward was with semi-conductors.

11.1. Insulated-gate bi-polar transistors (IGBTs)

Bi-polar transistors – capable of switching many amperes at comparatively high voltages – had already been developed for motor control. These devices were manufactured with the drive circuitry built into the package, to produce insulated-gate bi-polar transistors. Devices of this type are now available to switch several hundred amperes and are capable of blocking 1000 volts or more.

IGBTs are much more suitable than thyristors for switching purposes as they can be turned off quite simply, rather than having to be commutated off by reversing the current.

11.2. The Pulse Step Modulator system

The Brown Boveri Co. in Switzerland has produced the Pulse Step Modulator (PSM) system [7] which, basically, consists of a quantity of lower-voltage power supplies connected in series. The output of each power supply incorporates an IGBT switch, shunted by a diode. These IGBTs can be switched on individually and instantaneously to provide the optimum voltage requirements at any given instance during transmission of a modulated carrier. The shunt diode allows current to pass through the module if its IGBT is switched off, so that the module offers a low impedance when it is not contributing any voltage to the series chain. The system can be likened to a very large D-to-A converter.

Overall efficiencies of 96 – 97 %, including the transformer loss, are now claimed for the PSM system and it would appear that the high-power modulator has reached near perfection!

The additional advantage of a multi-module solid-state modulator is that it will continue to work with several failed modules, either by reducing the carrier power or by limiting the modulation peaks to below 100 % in the positive direction. The removal of the modulator valve now makes single-valve high-power HF transmitters a reality.

12. Solid-state power-blocks for MF broadcasting

At MF, high-power transmitters are now available which use all-solid-state devices. A typical example is the Harris DX series [8], where solid-state power blocks are combined up to the total output power which is required. The digital AM system uses a 12-bit ADC, a digital modulation encoder, and a power-multiplying DAC which recreates an AM signal from the processed digital information. A typical arrangement, using a 12-bit ADC, utilises the 7 most-significant bits to turn on modules of the same size; the 5 least-significant bits are used to control the binary-weighted amplifiers, thus giving 12-bit resolution.

There is no theoretical limit to the power that can be obtained by combining suitable power blocks – only one of economics. Obviously, to double the power of a transmitter which uses modular construction, it is necessary to double the hardware (unlike in the case of valve transmitters). Modular construction does, however, offer the benefits of graceful failure and the elimination of the replacement costs and the catastrophic inconvenience which occurs when a large valve fails. High efficiency and good audio performance are claimed for this solid-state system.

13. HF transmitter control systems

In the early days, transmitters were adequately controlled by rheostats, knife switches and a few relays. Today their control systems use the latest micro-processor and computer systems. Not only have the energy costs risen with time, but also the labour costs. Not so many years ago, high-power HF transmitting stations were manned around the clock with both operational and maintenance personnel.

Today, HF transmitters change their frequency completely automatically, with frequency-follow auto-tuning systems. It is only necessary for the exciter frequency to be changed; the transmitter tunes automatically to the new frequency and loads itself to the correct conditions, making due allowance for the antenna VSWR. Equipment is required to change frequency ten or more times daily and accomplishes each change, typically, in less than ten seconds.

On large HF transmitting stations, computers now operate not only the transmitters but the complete system. By means of a matrix of feeder switches, any transmitter can be routed to any antenna, which may well have the ability to be slewed in azimuth and/or elevation. Programme material is also routed to the appropriate transmitter along with the required-frequency-change command. Via VDU screens and keyboards in the control rooms, the status of all equipment can be monitored, with printouts of any irregularities. Some stations are already operating completely unmanned during part of the 24-hour cycle.

At a large HF station, it is most impressive to see ten 500 kW transmitters change frequency simultaneously – without an operator in sight!

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