When I Think Back...

by Neville Williams

From sparks and arcs to solid state - 3

In this third article looking at the development of techniques to allow direct transmission of speech and music via radio waves, we look at the so-called 'RF alternators' which found favour early this century. From here we look at early modulation systems, and finally the development of valve oscillators and transmitters.

Goldsmith also devotes a complete chapter to 'Alternators of Radio Frequency' – the design of which posed a state-of-the-art challenge to specialists in rotating electrical equipment.

As a measure of the basic problem, Goldsmith calculated that a 100,000-cycle alternator, with a 60cm diameter rotor spinning at 2500rpm, would require an impractical 48,000 poles and a pole pitch of 0.4mm!

Alternatively, if a designer opted for a rotational speed of 20,000rpm, 600 poles would be required with a pitch of 3.0mm – plus an ability to withstand enormous centrifugal force.

As an example of then-current technology, Goldsmith surveys three quite different alternator systems, each of which is capable of generating output currents to around 50,000Hz (cycles per second) or a wavelength of 6000m at power levels to 100kW or more.

Two of the systems involve frequency multiplication – one internal, the other external to the alternator – while the third relies on direct generation. In this present article, it is possible to outline the systems only in very broad terms. Readers wanting to study the technology in detail will have to refer to the original or other suitable texts.

The so-called 'Goldschmidt' alternator illustrated in Fig.6, relies on the fact that (and I quote) 'an oscillatory movement of frequency 'n' taking place on a system rotating with frequency 'n' is equivalent relative to fixed external points to an oscillation of half the amplitude or width and of double frequency'.

This is tantamount to frequency multiplication, which is 'internal' to the alternator.

To set up the required condition, the Goldschmidt alternator provides external means of resonating the rotor system, overall, at the fundamental frequency of the system, and the stator, overall, at twice that frequency.

The interaction of the harmonically related resonant modes, plus the original fixed and rotational fields, can be made to substantially cancel the 'n' and

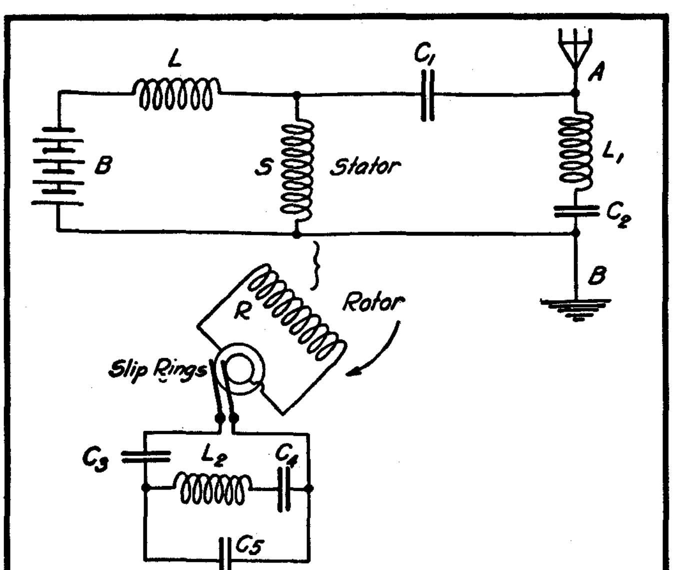


Fig.6: Illustrating the basic principle of a Goldschmidt alternator. By resonating the rotor at a frequency related to the rotational speed, the stator acquired an AC component resulting in an output at double or quadruple the natural figure.

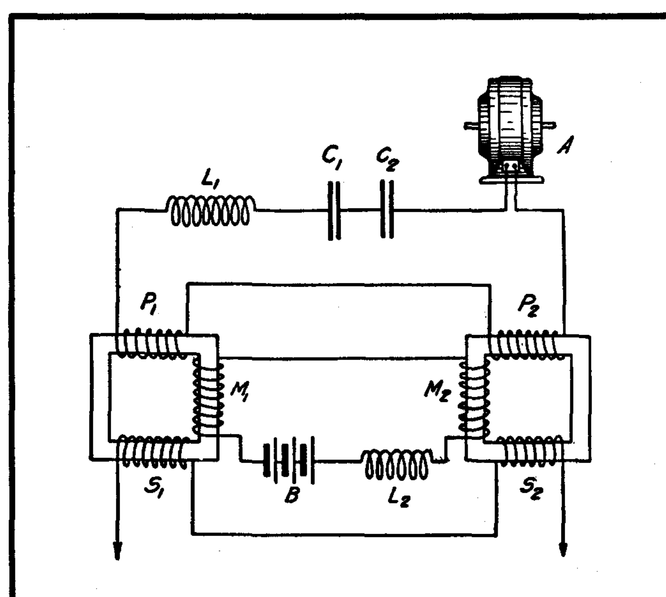


Fig.7: A system favoured by Telefunken to double or triple the frequency from an RF alternator. Transformers with saturated cores suppressed the respective half cycles of the input waveform.

'2n' components, yielding a resultant '4n' current in the stator at four times the fundamental alternator frequency. By design, that segment of the total stator system involving the antenna can be resonant at the quadrupled frequency, which therefore becomes the dominant output signal.

Inductor L prevents the RF energy from being diverted into the DC source, but special care was necessary in what were quite bulky motor/alternator installations to ensure that busbars to the pre-settable external resonating components did not compromise the wanted signal by stray L/C leakage effects.

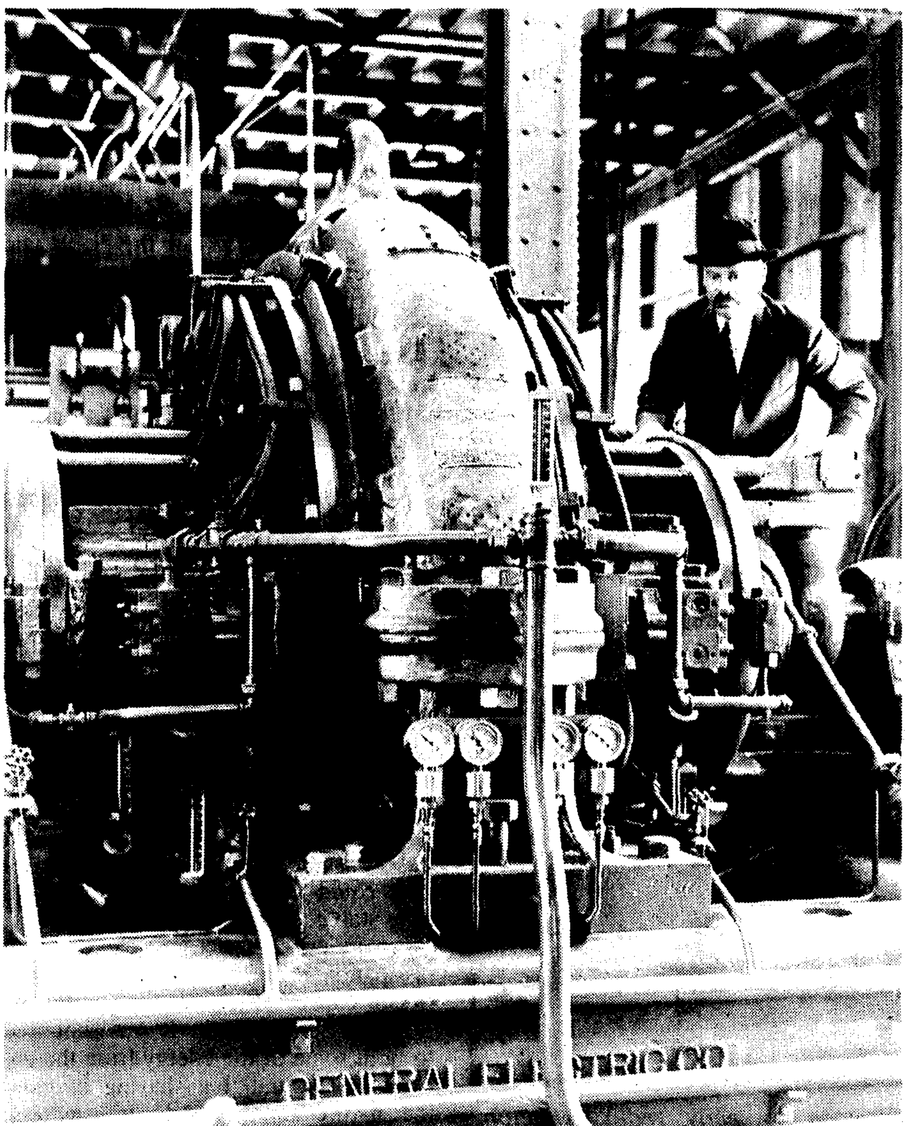
External multiplier

Fig.7, also from the Goldsmith book, shows a system favoured by Telefunken, which involves an inductor type alternator A and a pair of saturable transformers operating as a frequency multiplier. L1, C1 and C2 serve to bring the total input circuit to resonance at the fundamental alternator frequency.

In operation, the transformer cores are brought close to saturation by a current from DC supply B though the respective windings M1 and M2. Inductor L2 passes the direct current but inhibits alternating current from circulating around the DC loop.

Because of core saturation, the respective transformers can each transfer only one half-cycle of the input frequency, the other half being effectively suppressed. The windings are so arranged, however, that they operate out of phase, such that windings on transformer 2 preserve and invert the half-cycles suppressed by transformer 1.

In the simplest situation, the half-cycles interleave to provide a waveform which is predominantly a second harmonic of the original input – or double the frequency. Goldsmith says, however, that, by reversing the phase of one secondary, the output waveform becomes preminantly a third harmonic, so that the system can be set up fairly readily to operate either as a doubler or tripler, feeding a suitably resonant aerial system.



GE pioneer Dr Ernst Alexanderson pictured in 1922 with one of his high speed 'RF' alternators. They were typically fitted with 600 or 800 poles!

Alexanderson/GE system

The third type of RF alternator was researched in part by the National Electric Signalling Co, working in conjunction with R.A. Fessenden. At his suggestion, it was taken up by E.F.W. Alexanderson of GE, who produced a practical design in 1908, rated to deliver a direct signal of 100kHz at a power level of around 2kW.

The Alexanderson alternator was also of the inductor type, typically using a 300 to 600-slot field and a spinning disc of chrome nickel steel, which was thick at the hub and thin at the periphery to equalise the radial tension on the metal throughout the whole unit.

Radial slots were milled through the outer extreme of the disc and subsequently filled with phosphor bronze, firmly rivetted into the slots, then ground and polished to cope with air drag and a centifugal force of 37kg on each each individual filler at a typical operating speed of 20,000rpm.

For efficient operation, the Alexandersen alternator called for the utmost precision, with the outer edge of the disc spinning at a peripheral speed of about 20km/minute in a stator gap adjusted down to a clearance on each side of about 0.4mm.

Driven by a DC motor with a belt and/or gear train, or directly by a steam turbine, Alexandersen alternators were normally provided with pressure-fed lubrication and protected by an automatic cut-out sensitive to oil flow.

Goldsmith pictures a 50kW, 50kHz Alexanderson/GE installation that had been operating with a high degree of reliability up to the time his book was published. He notes that Alexanderson alternators were, of necessity, low impedance devices, requiring a step-up matching transformer to couple them to the antenna system.

At the time of publication the highest known frequency that had been achieved directly by a rotating machine was produced by an 800-slot Alexanderson alternator: namely 200kHz or 1500 metres. Obviously enough, while the signal may have been well suited for speech modulation, the technology was limited to the low end of the radio frequency spectrum.

Significantly, perhaps, the *Admiralty Handbook* makes only passing reference to RF alternators. It concedes that they produced a very pure wave, were easy to key, well suited for telephony and for high power working. Against that, the first cost was high, they required expert supervision and maintenance, they were suitable only for low frequencies, and frequency changing was more of a problem than with other systems. The Royal Navy simply did not use them.

Speech modulation

If the generation of stable continuous radio waves posed a problem for the pioneers of radio telephony, so also did the task of modulating those same RF carriers with speech and/or music waveforms. Radio valves had been invented, but their routine use as oscillators, amplifiers and modulators was still somewhere in the future.

If a transmitter had to be modulated with speech, it had to be achieved more or less directly with a microphone – with or without the dubious assistance of a magnetic relay.

What's more, with the type of transmitting equipment discussed thus far, there was little option but to connect the microphone into the arc, alternator or aerial circuit in such a way that it would vary the efficiency of the circuit and therefore the instantaneous amplitude of the RF output.

While Fig.8 indicates some of the circuit options available, it also suggests that the levels of current and/or voltage involved in the majority of circuit situations might be much higher than could be tolerated by ordinary microphones.

According to Goldsmith, carbon microphones of the period had a resistance of 50 to 100 ohms and an effective dissipation rating of about 2 watts. This implied a maximum permissible voltage of around 10 and current in the range 0.1 to 0.2A. Excessive current could typically cause an objectionable 'frying' noise, heat damage to the granules and a tendency for them to 'pack' or 'cake' and lose sensitivity.

The resulting incompatibility prompted would-be solutions that ranged from ingenious to bizarre!

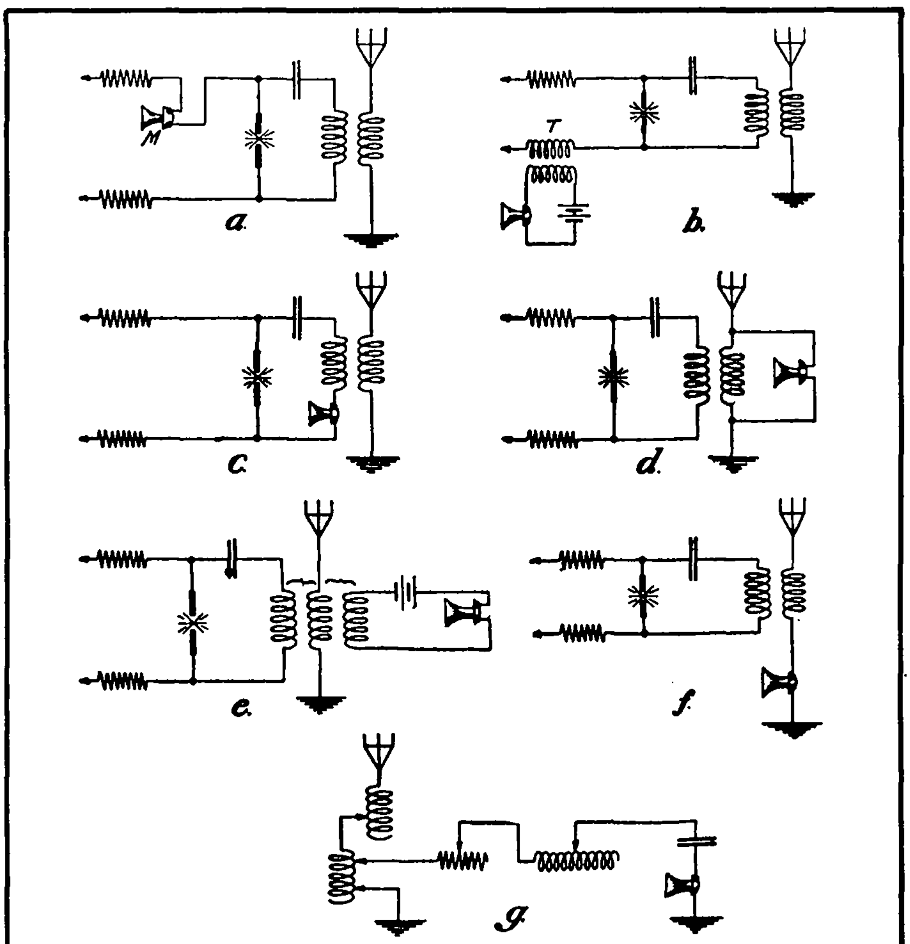


Fig.8: Carbon microphones were connected to early radio telephony transmitters in a variety of ways. Their broad effect was to cause an initial loss of efficiency, which was then varied up and down with instantaneous changes in microphone resistance.

Believe it or not

According to Goldsmith, Dr Lee de Forest resorted to attaching a buzzer to one of his microphones so that the operator could 'de-cake' it from time to time by pressing a button.

A certain Lieutenant Ditcham opted for four pairs of series-connected microphones, mounted on a rotatable table-top stand. Every two minutes he would click the stand around to bring two new microphones into circuit, leaving the others to cool down!

J.B.Marzi, an Italian designer hit upon the idea of a moving stream of carbon granules, so finely divided that they would flow like a liquid and carry away their own heat. Loaded into a reservoir at the top of a table-top microphone assembly, the granules would gravitate steadily through the diaphragm chamber into a container underneath, to be be emptied back into the reservoir as necessary.

More conventionally, microphones were cooled by integral fans, by oil thermo-cycled through an attached reservoir, or provided with water jackets connected to an external supply.

Some microphones were designed around carborundum powder with asbestos spacing washers – more durable than normal carbon granules, but electrically less convenient than a carbon and felt design.

'Hydraulic' microphones, devised by Chambers, Vannui, Majorana and others, dispensed with granules altogether, exposing columns or globules of slightly acidic water or other conductive liquids to sound waves and taking advantage of variations in their instantaneous resistance. From all appearances, they could hardly have been mechanically stable.

Fessenden sought to dodge the heat dissipation problem altogether, by wiring a *capacitive* microphone into the resonant aerial circuit. It was supposed to 'spill some of the energy from the antenna to ground' but, having in mind the nature of the early transmitters, there was every chance that it would modulate the frequency as well as the amplitude of the radiated carrier!

Back to the granular types, an accepted way of achieving high dissipation was by operating several microphones in parallel.

A noteworthy design by Egner and Holmstron of Stockholm contained 16 low resistance high-current cartridges arranged in groups of four, to share four separate diaphragms. All 16 were mounted in a rectangular metal housing with external cooling flanges and filled with a non-conductive cooling oil. Provision was also made to periodically displace the air in the microphone chambers with hydrogen or a gas containing hydrogen. Terminals at the rear allowed the microphones to be connected in series and/or parallel to provide a choice of resistance and current rating.

Fig.9 shows an alternative method of achieving a similar end result, with acoustic tubes branching from a single mouthpiece feeding multiple cartridges. Using only three microphones, the one illustrated in Fig.9 would be appropriate only for a low-power or short-range transmitter. More typically, a Berliner/-Poulsen ship radiophone installation pictured by Goldsmith uses six cartridges, while a Lorenz multiple microphone uses no less than 25 Berliner cartridges fed by tubes from a common speaking trumpet!

The valve era

With the adoption of valve-based technology, transmitter design became much more elegant and purposeful.

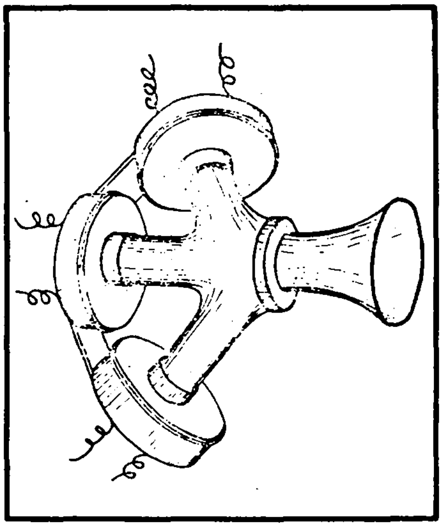


Fig.9: An effective if cumbersome way of providing a high current microphone, as illustrated in Gernback's Wireless Telephone – published in 1911.

Fig.10 shows a typical, relatively simple circuit published by the A.W. Valve Co in the mid 1930's, in a booklet entitled *Radiotron Circuits for Experimenters*. It should serve to illustrate the thinking behind valve transmitter design.

The first stage (top left) is an oscillator, designed to generate the basic signal. This is amplified and/or processed in the following stages and ultimately radiated at a precise frequency specified by the administrative authority or, in the case of experimenters, within strictly defined frequency bands.

In the early 1920s, the basic oscillator frequency was commonly determined by a ruggedly assembled tuned circuit, which the operator was required to adjust with the aid of an approved wavemeter.

(In 1923, to assist experimenters in the Sydney area, pioneer experimenter Charles Maclurcan (2CM) was authorised to measure the frequency of other experimental stations, on request, on behalf of the State Radio Inspector, Mr W.T.S. Crawford; this was to a potential accuracy of about 1.0%).

In later years, the tuneable L/C circuit was commonly replaced by a quartz crystal, as depicted in Fig.10, which oscillated in piezo-electric mode at the particular frequency for which it had been ground. Far more stable than a conventional tuned circuit, it became possible to generate a 'rock-steady' signal within 0.005% or better of the specified frequency.

Oscillator stages were normally operated at a modest power level, to limit valve heating and mechanical stress on the vibrating crystal. Depending on the tuning of the anode circuit, the oscillator could deliver an output signal at the same frequency as the crystal or, in 'doubler' mode, at twice the crystal frequency.

The second stage in Fig.10 is a 'buffer' amplifier, so called because it serves to isolate the oscillator from the RF output stage, which feeds the antenna. The dynamic operating conditions of

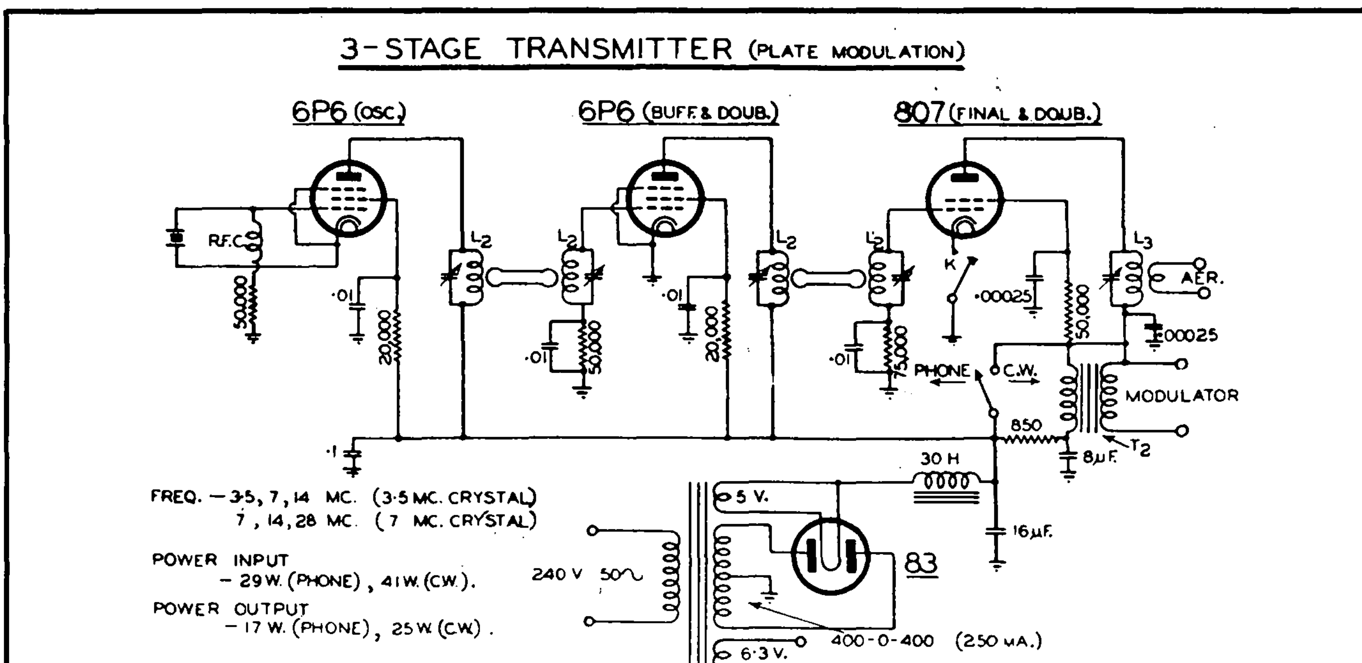


Fig.10: A typical valve type transmitter used by amateur operators from the late 1930s. Broadcast transmitters used similar basic principles, but at a far higher power level.

this last stage vary greatly when it is being keyed or modulated, and this is prevented by the buffer stage from prejudicing in any way stable operation of the oscillator.

Note that the buffer also can operate as a straight amplifier or in doubler mode such that, with a 3.5MHz crystal, the transmitter could operate at the original frequency in the 3.5MHz (amateur) band or at double or quadruple the frequency in the 7MHz or 14MHz bands.

The final stage used an 807 beam power tetrode, capable of being keyed for CW Morse code transmissions or, at the throw of a switch, modulated with voice or music signals. Rated maximum power output from the 807 was 50W for telegraphy and 42.5W for telephony.

More flexible design

With this type of transmitter, the aerial system plays no part in determining the exact frequency of the generated signal and it can be designed quite independently to meet the operator's requirements. It may conceivably be a large installation or something confined by available space. It may be a single-band or multi-band design, directional or non-directional; the radiation pattern will be affected but not the transmission frequency.

Similarly, there would be no awkward limitations on the choice of microphone or the depth and linearity of modulation.

The 'modulator' on which this depends is an audio power amplifier, essentially little different to a domestic music or public address system, except that it must be capable of delivering the requisite power to the transmitter through a suitably designed modulation transformer T2.

With Fig.10, using plate modulation of the final stage, and a plate power input of about 60W, the required modulation power would be about 30W RMS – a fairly routine figure for an audio system. The audio input signal – speech or music – could be derived from any ordinary input source or any available microphone, requiring only the provision of a suitable preamplifier.

It is only a matter of audio switching, or mixing, to feed into a modulator signal from a phone line of from a keyed audio tone generator to use such a transmitter with remote audio input or for modulated CW tone transmissions.

In the case of high-powered transmitters, where the amount of audio power might pose a problem, the designer has the option of modulating an earlier stage or modulating one or other of the grids instead of the output plate circuit. Forced air and water cooling is frequently used in high power transmitter stages, to cope with heat which cannot be dissipated by ordinary ventilation.

(For an historical survey of valve transmitters, large and small, the reader is referred to *Australian Radio – The Technical Story 1923-83* by Winston T. Muscio, 1984, Kangaroo Press, Kenthurst, NSW).

Thermionic valves are still used in the output stages of high-powered transmitters but solid-state devices have taken over, especially in the preliminary lower-powered stages. They are more compact and economical and, as in other electronic equipment, facilitate more elaborate circuit design. Instead of relying on tuneable circuits or simple crystals, for example, digital logic circuitry makes it possible to select precise channels by simply punching in the required frequency on a keyboard.

But I'm no longer thinking back. I've caught up with the present!