Tricks of the Trade

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Readers will recall last time **[1]** that we had arrived at the point by the early 1970's where valve technology, that enabled RF carrier powers up to 500 kW on HF and 600 kW on MF with just a single PA valve for broadcast use, had been developed. The valves and their manufacture were described by Dr Peter Foreman in Issue 39 of *Signal* **[1]**. In the previous issue of *Signal* **[2]** Ewan Fenn G3RTF wrote that manufacturers began to progress pulse width modulation (PWM) and pulse duration modulation (PDM) systems using the modulator valve as a switching device rather than operating over the linear part of the characteristic. The techniques were first advanced in Germany and in the United States and Chief Engineer, Hilmer Swanson of the Harris-Gates Radio Company of Quincey, Illinois was one of the major players and patent holders. The first PDM product from the Harris-Gates Company was a 100 kW MF transmitter, the VP-100, followed by a 100 kW HF unit, the SW-100A. Four examples of these HF units were installed by the UK FCO/DWS at Masirah, Oman as the British Eastern Relay Station, BERS, in 1978 and were scrapped in 2002.

The Harris-Gates PDM system

The Harris-Gates PDM system was described in an engineering document **[3]** by Hilmer Swanson within the sales brochures for the VP-100 and SW-100A transmitters. Much of the following is from notes taken from that document.

Transmitters employing PDM are essentially high-level plate-modulated units that use a novel type of audio modulation technique to generate the plate modulation. In the PDM system, the modulator operates in a manner similar to a switch, having two conditions: ON or OFF.

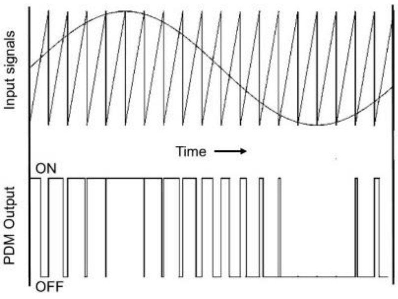

Figure 1. Principle of PDM generation. The audio signal is depicted as the sinewave. Adapted from [4]

Audio information is contained in the duration of the ON pulse; hence the patented name of PDM. The amplitude of the audio signal is determined by the percentage of the time the modulator valve is conducting; that is the 'duty cycle'. A square wave of approximately 70 kHz is pulse-width-modulated by the audio signal. The amplitude of the audio signal causes the symmetry of the 70 kHz wave to vary (**Figure 1**). For instance, a large positive signal will cause the wave to be ON for most of its cycle and, for a large negative signal, OFF for most of the time. Thus, the frequency of the audio determines the frequency with which the symmetry of the rectangular waves varies.

No new modulation process is employed in PDM; it is still high-level plate modulation of a Class C RF amplifier. The difference between PDM and 'conventional' (at that time) methods of generating high-level plate modulation is simply the manner in which the audio signal is translated and applied in series with RF amplifier plate supply.

The audio information is superimposed on the 70 kHz pulse train at low level, amplified by a series of solid-state amplifiers and a valve to a level sufficient to modulate the final amplifier (**Figure 2**). The 70 kHz component is filtered out to leave the amplified audio and a DC component that is the modulated plate voltage for the PA. This approach eliminates the need for a modulation transformer, reactor and blocking capacitor. Continuous 100% modulation capability over a wide frequency range is inherent with PDM and provides excellent fidelity with all audio waveforms with no compromise of cost or complexity. Automatic carrier control and power change are easily accomplished along with fast-acting crowbar protection by opening the high voltage DC supply to the PA/modulator valves in the event of valve flash arcs.

The PA plate voltage is determined by the duty cycle of the PDM, *e.g.* if the duty cycle is 10% then the PA voltage is 10% of the HV PSU voltage while, at plain carrier, the duty cycle is 50% and so the PA voltage sits at 50% of the 29 kV HV supply for MF and *c*. 23 kV for HF.

Theory of operation

A PDM pulse train has a constant repetition rate or frequency but has variable width pulses, their width being a function of audio amplitude (**Figure 1**). The output of a 70 kHz oscillator is clipped to form a square wave and integrated (B) to form a ramp/sawtooth voltage (**Figure 2**). This voltage is summed with the audio signal (A) at the input of a Schmitt trigger threshold amplifier (C). The output is a modulated rectangular pulse train (D) with a 70 kHz repetition rate modulated in accordance with the input audio. These pulses are amplified by the driver and modulator stages and applied to the RF PA cathode through a low pass filter that removes the 70 kHz and its sidebands, thereby recovering the original audio. The modulator valve acts like a variable resistor whose resistance varies with the amplitude and frequency of the programme audio. Connected in series with the RF PA it enables AM by simple series modulation.

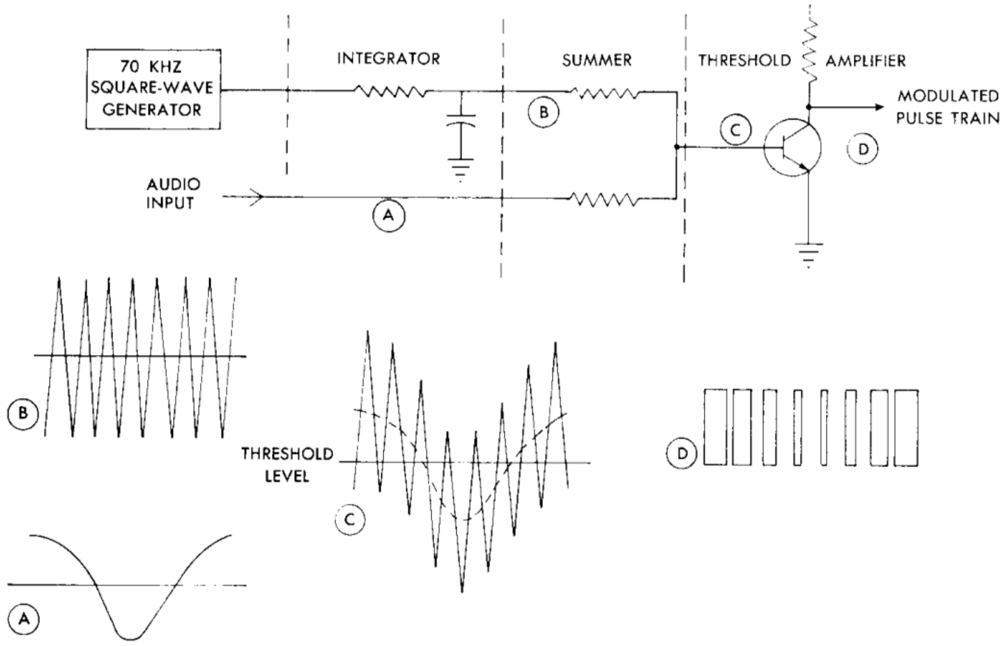

Figure 2. Generating the PDM in practice [3]

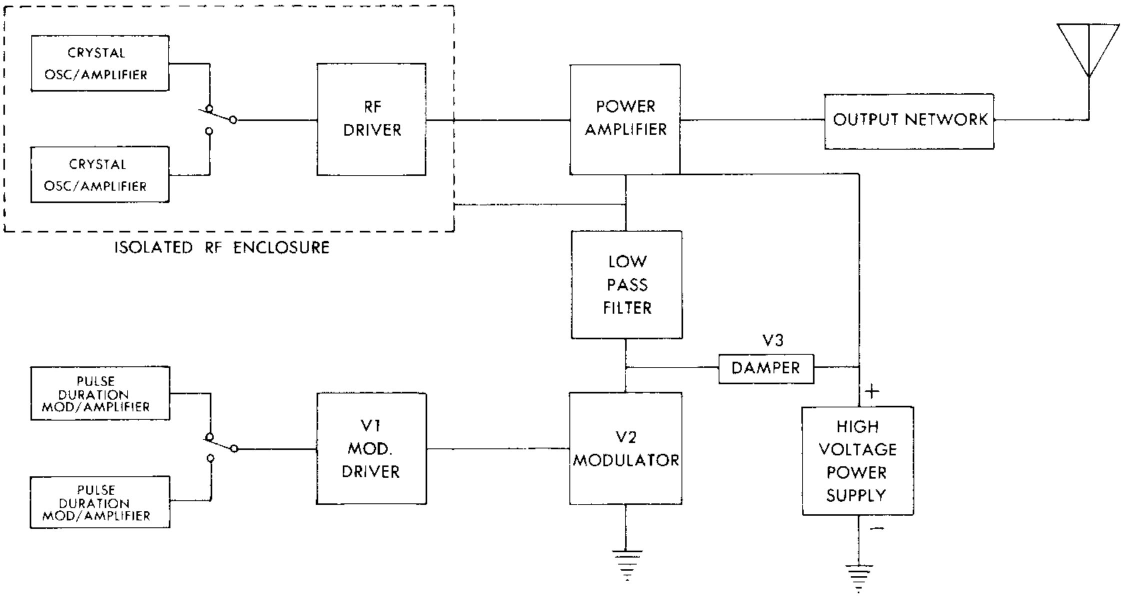

Figure 3. Block diagram of the VP-100 transmitter [3]

The pulse duration modulator

The modulator valve V2 (**Figure 3**) is connected through a low-pass filter to the cathode of the PA along with a damper diode V3. The other side of V3 is connected to the HV supply and conducts alternately with the modulator at a 70 kHz rate. V3 conducts when the modulator does not and provides a discharge path for the energy stored in the inductors in the low-pass filter. This function is necessary in the interests of efficiency and low distortion.

Lack of transient peak voltages

The peak voltages appearing on the RF PA are the same as those on any regular plate-modulated Class C amplifier; however, the absence of a modulator reactor greatly reduces the magnitude of the peak voltage that can occur compared to that in regular plate modulator units.

Valves in use

For the SW-100A, the RF PA and the modulator valves were 4CV100,000 vapour-cooled tetrodes with 4CX1500As as RF and modulator drivers. The diode was an F-1099. For the later SW-100B it is as above with the F-1099 replaced by a 2CX10,000F.

Design challenges

Most of the above information came from the Harris-Gates sales leaflet and so was biased towards the advantages of low-cost ownership and spares holding. While this was the case, no doubt there were areas where operation and reliability could be challenging. With the modulator grounded in a basic series system, it stands to reason that the 100 kW RF PA section was effectively above ground, indicated in the block diagram where the words “Isolated

RF Enclosure” are printed detailing the earthy driver stages.

This is not a good idea for an RF design as adequate decoupling is required to the actual ‘earthy’ chassis and, with an HV rail, the component specifications for both current and voltage are enhanced over what conventionally would have been an earthed RF unit . Ewan G3RTF alluded to this in his article **[2]** and his remarks are reproduced here for completeness:

All PWM systems must be designed to take account of the effects of stray capacitance on the switching valve as this will result in power loss and distortion of the audio signal in series PWM systems. One way of avoiding this is to have the cathode of the modulator tube 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 tube and its associated components must be in close proximity to the RF amplifier which becomes more difficult at high power due to their physical size (See also Figure 3 in the same article).

Returning again to the Harris-Gates sales brochure **[3]**, a section dealt with the “Salient Features of PDM” and is reproduced below:

Reliability: the most troublesome components in an AM transmitter, the modulation transformer and reactor, have been eliminated in the PDM design. Because the modulator stages operate in a highly reliable saturated switching mode, small changes in component characteristics have negligible effect on the modulator performance. Tube and transistor linearity has almost no effect on the modulator performance. Tube life under this mode of operation will be increased greatly.

Ease of Maintenance: because of the reduced cost of the components and the inherent low failure rate of the saturated switching mode, circuit maintenance costs are lower.

Operating Economy: with an overall efficiency of 65% normally achieved and a lesser number of tubes, the operating cost is greatly reduced from that of a conventional Class B modulated transmitter.

Operating Convenience: power output can be adjusted to almost any power level between zero and the rated output and automatically maintained at the level.

Table 1 was the final selling point

The author, having over 40 years’ experience with high power AM transmitters, would dispute the above claims of unreliable modulation transformers and reactors, having never witnessed such a failure and only ever hearing of one at Brookmans Park with a WWII modulation transformer on the 140 kW STC 877 kHz (later 908 kHz) transmitter. Fellow VMARS Member Glyn Jones G4AIJ reports a similar failure in another 100 kW STC MF transmitter at Stagshaw. Provided the transformer oil was checked for acidity or degradation every five years or so and then changed if required, they were fine. However, main HV transformers sometimes did fail and, anyway, the Harris Gates PDM transmitter would have one with a significantly high secondary voltage to produce the 23/29 kV HV.

AEG-Telefunken

At the beginning of this ToTT, reference was made to a German PWM development at about the same time and it is worth adding the following few words from Ewan G3RTF **[2]** about the AEG-TFK ‘Pantel System’. *Here the Final RF Amplifier has its cathode at chassis potential, which removes any restriction on its use at high power. The effects of stray capacitance are minimised in a novel arrangement which locates the unwanted effects inside the filter. A 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 more involved in the Pantel arrangement requiring a tightly-coupled winding on the storage inductor. Fibre optics are employed to connect to the switching tube grids for isolation purposes* (See Figure 4 in *Signal* Issue 38 page 26).

Time-line

Much of the development described above was conducted late 1960s and early 1970s and represented a small step in improving the overall efficiency of the modulation system for high power AM transmitters. It was, however, the Oil Crisis of 1973 that concentrated the transmitter manufacturers’ minds as to how to effect further energy-saving initiatives. These will be explored next time.

References

1. D Porter G4OYX. Tricks of the Trade. *Signal* 2016, **39** (May), 29–31.
2. D Porter G4OYX and E Fenn G3RTF. Tricks of the Trade. *Signal* 2016, **38** (February), 24–28.
3. H. Swanson. The pulse duration modulator: a new method of high level modulation in medium and short wave broadcast transmitters. *Gates Engineering Report,* July 1971.
4. Credit: By Pwm.png: CyrilBderivative work: Krishnavedala (talk) - Pwm.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15335773.

	Harris-Gates PDM design	Conventional AM
Efficiency	Limited by tube pulse characteristics It is independent of distortion Overall efficiency of 60–70%	Limited by linear operating conditions Compromise with distortion Overall efficiency of 40–50%
Economy	Two power tubes Low-cost 70 kHz inductors	Three power tubes Expensive modulation transformer and reactor
Performance	Response limited by power supply and switching rate Distortion independent of tube linearity High performance at high power levels Carrier shift almost zero	Response limited by iron-cored components Distortion dependent on linear operation Performance compromise at high power and modulation Carrier shift usually 3–5%

Table 1. A comparison of the Harris-Gates PDM design with a conventional AM modulator [3]