

Tricks of the Trade

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We continue to celebrate the 50th anniversary of the start of offshore commercial radio in the UK and are now in June 1965. By this time, the number of stations on the air was increasing steadily, taking advantage of the (lack of) laws at the time with regard to operations in International Waters. The first two stations, Caroline and Atlanta, had used 10 kW AM transmitters by Continental Electronics employing their patented version of screen grid modulation but, just prior to Christmas 1964, the US-inspired and -built station of Radio London on the former US minesweeper *USS Density* renamed *M/V Galaxy* was on the air with test transmissions on 266 m, 1124 kHz, running, at first, 17 kW. This 50 kW transmitter was an RCA BTA-50H and was the first of many in the offshore fleet to employ the 'Ampliphase' approach.

From 'outphasing' to 'Ampliphase'

The theory of what became known as 'Ampliphase' was proposed and developed in France by Henry Chireix in 1935 who called the technique 'outphasing'.

'Outphasing' was not taken up initially by RCA but by McClatchy Broadcasting in the late 1940s, first at KFBK, Sacramento, California (50 kW full-time) and at KOH, Reno, Nevada (5 kW day time/1 kW night time).

The result of the development work was later sold by McClatchy to RCA who turned it into a mass-produced product, first at the 50 kW level and, later, at the 10 kW and 5 kW levels. Unlike most other commercial designs (at the time) of AM broadcast transmitters, 'outphasing' units required neither modulation transformers nor modulation reactors thereby saving initial cost. A disadvantage was the requirement for more maintenance. Essentially, the 'outphasing' approach trades lower initial capital cost for higher operating cost while achieving a modest improvement in efficiency.

KFBK still maintains an RCA BTA-50H (the 'last gasp' of the 'Ampliphase' approach) as a standby transmitter but its main transmitter is a solid-state Harris unit, a prototype which later became the DX-50. KOH has long since scrapped its home-built 'outphasing' transmitter for conventional units.

'Ampliphase' proper

The marketing name 'Ampliphase' was adopted by RCA when they launched the BTA-50G transmitter using this bought-in technology in 1956. In 1960, the BTA-50H was introduced and, although similar to the 50G, it featured solid-state silicon rectifiers throughout, new 'lightweight' power amplifier (PA) valves and an improved modulator system. RCA also used the same technology to build 5 kW (BTA-5L), 10 kW (BTA-10J/L) and 100 kW (BTA-100B) transmitters for AM (MW) broadcast. In addition, a limited number of short wave 'Ampliphase' transmitters was produced (BHF-100A) though the design was significantly different from the standard MF broadcast units. A number of European manufacturers also built 'outphasing'-type systems, notably Marconi in the UK with a prototype 60 kW Third Programme transmitter at Daventry in 1949/50 and Thomson in France.

Amplitude from phase

The principle of 'Ampliphase' is to take a single frequency drive source, split it into two feeds, phase modulate each feed, amplify as required and add the two signals in a combining network. Amplitude modulation is achieved by the degree of addition or subtraction due to the phase difference between the two signals. RCA 'Ampliphase' transmitters were arranged such that, under zero modulation conditions, the quiescent phase difference between the two feeds was 135°. The two signals were modulated in equal but opposite directions by up to ±45° giving maximum and minimum phase differences of 180° and 90°. At a phase difference of 180°, the two waves cancel out in the high power combining network, hence this is the 100% peak negative modulation condition. At a phase difference of 90°, the two waves add to give 100% positive modulation.

Rigs you love to hate

In the trade, 'Ampliphase' transmitters quickly acquired the nickname of 'Amplifuzz' due to the quirky and complicated setting up procedure and the time-consuming maintenance for consistent performance. Consequently they became the transmitters engineers loved to hate and the reason why, in 1951, the Marconi prototype version at Daventry was removed and replaced by a pair of 100 kW air-cooled Class B-modulated transmitters. Marconi never did produce another such 'Ampliphase' transmitter.

Although, for broadcast use, the technique became obsolete in the 1970s, 'outphasing' has undergone somewhat of a renaissance in recent years, particularly for microwave transmitters. It is used as an efficient and accurate means of producing phase/amplitude (QUAM) modulated wideband carriers required by the digital communications systems of today.

Figure 1 shows a block diagram of the RCA BTA-50H transmitter. The frequency source is a crystal oscillator (at the operating frequency) based on an 807. This oscillator module was common to many other RCA BTA series transmitters from the 1940s through to the 1960s.

Whereas much of the following description refers to the BTA-50H, the same modulator chassis was used in the 50G/50H1 and 100B AM broadcast transmitters.

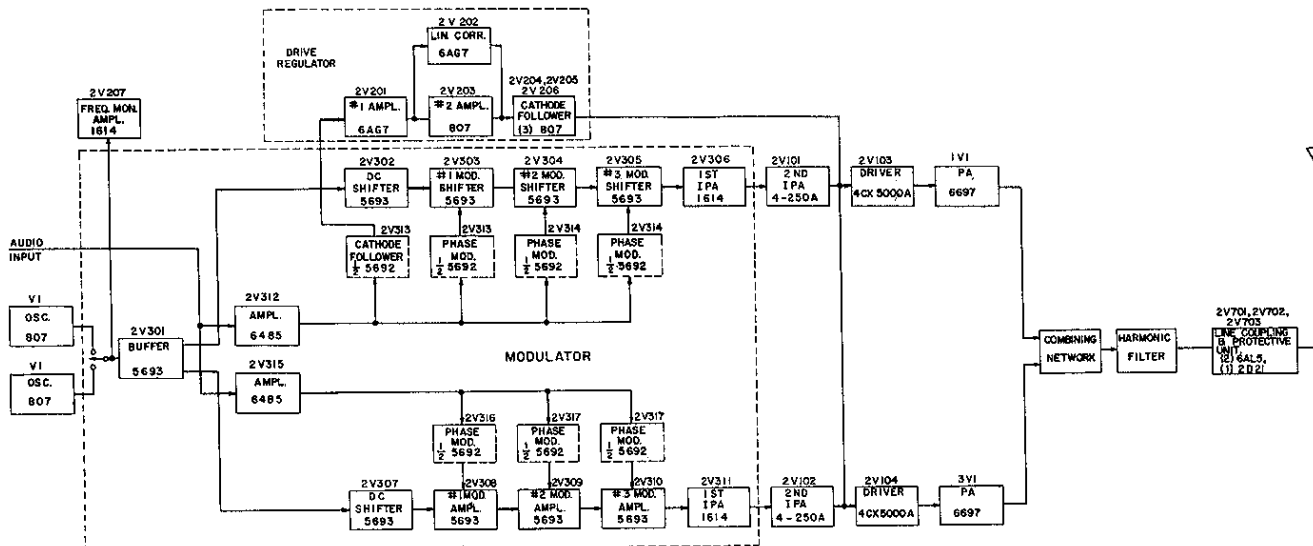


Figure 1. Block diagram of the RCA BTA-50H transmitter reproduced from the handbook

The ‘Ampliphase’ exciter

The first part of the Ampliphase process is delivered by a 5693 pentode which drives a transformer load, producing bi-phase RF outputs, 180° apart. These outputs are then fed to two identical modulation chains, each comprising four cascaded 5693 ‘modulation shifter’ amplifiers and a 5692 ‘phase modulator’ triode. The first stage is ‘DC modulated’ by a variable resistance (no triode in this stage) which is used to set the quiescent phase difference at 135°, determining the transmitter’s unmodulated RF output power. The three subsequent stages have audio fed to the grids of the triodes. The anode load of each pentode amplifier is effectively a tuned circuit comprising a parallel L/C network with a series component formed by the anode/cathode conductance of the triode. As audio is applied to the grid of the triode, its conductance thus varies and produces the effect of a variable resistance in the L/C resonator, giving rise to an instantaneous phase change which corresponds to the applied audio. Cascaded stages are used to ensure linearity of modulation since a single stage could not provide sufficient phase change in a linear mode. Equal but opposite modulation is achieved by feeding the two chains with anti-phase audio derived from dual windings on the audio input isolating transformer. As the total phase change required is ±90°, one chain must reach +45° while the other reaches -45°. Hence three stages of active phase change are required to produce the 45° from just 15° of modulation at each stage.

Exciter output amplification

The two outputs of the modulation chains are amplified by separate conventional cascaded Class C RF stages (QY4-250 tetrodes at 1 kV anode voltage and 4CX5000C tetrodes at 5 kV anode voltage), culminating in PA stages based on ‘lightweight’ air-cooled RCA 6697 triodes operating at 15 kV anode voltage (Figure 2). These 6697s are tuned with a conventional tank circuit and it is the outputs of these two tank circuits which are combined to generate the modulated carrier. PA tuning is complicated due to two phase shifted signals coming together. One PA will see the leading phase of the other PA in the combining point as a capacitive load, while the second PA will see the lagging load as being inductive. The tank circuit must also

be arranged such that it presents a 90° (λ/4) phase shift between the PA anode and the combining point. After the combining point, conventional Tee/π filters and harmonic traps are used to match into the load.

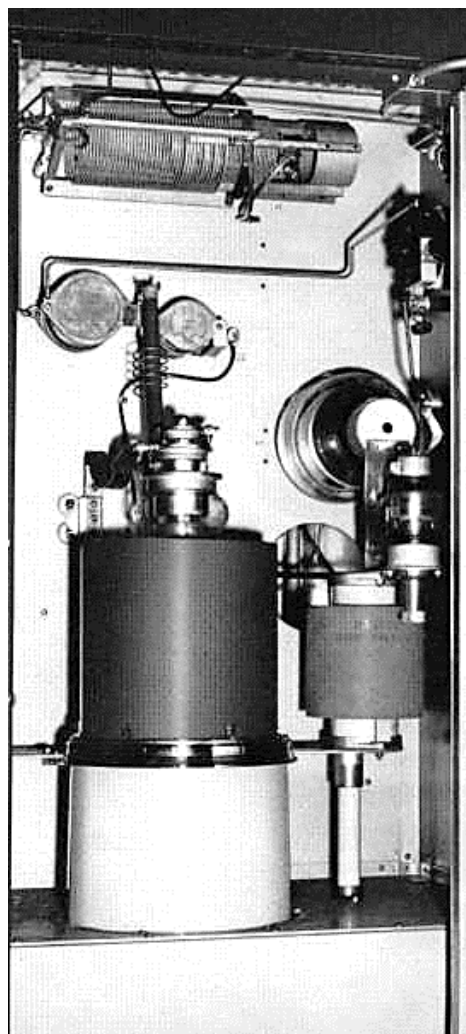


Figure 2. Close-up of one of the PA stages of the BTA-50H showing the 6697 valve

Linearity problems and correction

One drawback of the process described above is that, although the audio-to-phase modulation process is linear, the process of combining the two resulting RF waveforms is not. It is actually a co-sinusoidal function of the phase difference which can be thought of as follows: if we equate the zero to 100% modulation index input to be 0–90° phase change then, at 50% input, we have a phase difference of 45°. However, the amplitude of a sinewave at 45° is in fact 0.707 of its peak value. Thus, at 50% input we have 70.7% output. Accordingly at 33.3% (30°) input we have 50% output and, at 66.6% (60°) input, 86.6% output. Hence, there is a resulting compression of positive modulation and non-linear modulation (**Figure 3**). In reality, the phase addition is a function of half the phase angle, so the input level for 100% modulation increases the carrier to 185% of the nominal level.

To counteract this dependency and improve the modulation efficiency, audio modulation is processed by the 'linearity corrector' in the drive regulator unit (**Figures 1 and 4**) and the dynamic result is superimposed on the bias of the driver stages to the PAs.

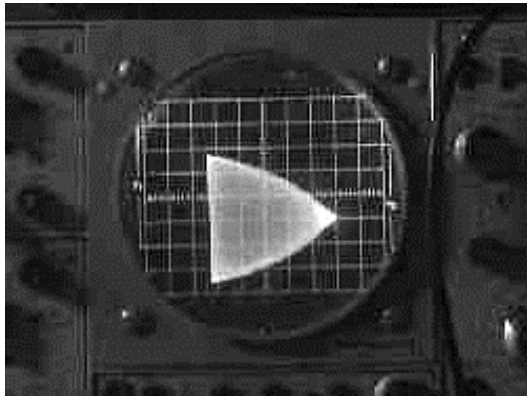


Figure 3. Trapezoid modulation display without linearity correction

Drive regulator chassis and negative feedback



Figure 4. The drive regulator chassis containing two 6AG7s and four 807s

Under high positive modulation, the bias voltage is reduced, allowing greater anode conduction and higher power. Under negative trough modulation, the driver bias is increased to reduce the drive to the PA stages preventing the two stages producing 25 kW of energy only to be cancelled out in the combiner. Reducing the drive level has the added benefit of compensating for inequalities of the power output of the two stages as well

as reducing overall power consumption. These features are combined with a negative feedback network, to enhance the transmitter stability and distortion, within the drive regulator chassis (**Figure 4**).

Another slant on the theory

An alternative way of understanding the PA combining and drive regulator process is to consider the output as being 'load impedance modulation'. The transmitter tank circuits normally produce a phase change of 90° ($\lambda/4$) between input and output. At the point of 100% negative modulation, the two opposing waves cancel out in the common load, looking like a short circuit which is reflected through the $\lambda/4$ tank as an open circuit in the anode circuit (thus no power is actually supplied to the load). As the two waves come closer together in phase, the perceived impedance of the load increases, which again is reflected through the tank circuit to the anodes. A constantly varying load is, therefore, seen by the PA anodes and the drive regulator must adjust the bias under modulation conditions to keep the anode voltage/current characteristics suited to the apparent impedance and amount of power required by the load.

So Mr Chireix or Mr Doherty?

The pros and cons of 'Ampliphase' are varied. It can achieve excellent modulation fidelity and high transmitter efficiency compared to a regular anode modulated transmitter (for example in a 50 kW unit there is no need for a 25 kW audio amplifier and modulation transformer) but the line-up does require two identical RF PA stages and a matched combining network. It can be problematical to set up and maintain identical performance for the two modulation chains. Any mismatch in the phase shift or level between the two chains results in non-linear phase shift of the final carrier with transmitted audio distortion ('Amplifuzz') after combining. It is also necessary to maintain all the tuned stages within the transmitters with as broad a bandwidth as possible to prevent any additional inadvertent phase distortion which would result in sideband splatter on the final output.

Conclusion

In addition to the drive regulator unit with dynamic monitoring and feedback correction of the linearity, the operation of the 'Ampliphase' transmitter depends critically on all the high power quarter wave networks and, in the exciter, the low power valved phase change networks. Compare now this complexity with the circuit of the Continental 50 kW CE317C; there was just the pair of fixed tuned quarter wave networks and the simple screen grid modulation of the final valves. The CE317C had, in effect, the impedance modulation of the 'Ampliphase' without the need for the active generation, monitoring and correction of the RCA exciter.

Granted, the CE317C did not appear in that final form until 1964 but, for transmitter engineers, it must have been a godsend to operate and maintain over the RCA equivalent.

Next time we will look at a late development to the 'Ampliphase' system and then examine which of the UK offshore stations had which RCA unit.

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