Tricks of the Trade

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We continue to celebrate the 50th anniversary of the arrival and expansion of the off-shore radio stations around the coast of the UK. The 50 kW Continental Electronics CE317B was described in the previous ToTT **[1]** amongst others. This transmitter was essentially a CE316 10 kW AM transmitter with a Doherty linear amplifier to raise the power to 50 kW. CE had incorporated its patented 'Weldon Grounded Grid' configuration to the carrier valve position to ensure better stability and efficiency.

Introduction

CE317C transmitters were first released by Continental Electronics in 1964/65 and quickly became accepted within the broadcast industry as a 'workhorse' transmitter. Many of these are still installed and working to this day around the world. The design was a convergence of the two types of earlier transmitter technology with a modern valve complement. A Doherty power amplifier was designed around a pair of the then new, high-power air-cooled RF tetrodes, Eimac 4CX35000C, with screen grid modulation applied directly to this final amplifier stage. A remarkably small number of valves was required to accomplish this design, with substantial cost savings in manufacture, operation and spares holding.

Circuitry

Audio amplification and modulation were simple and similar to the earlier lower powered transmitters, using the same 'series regulator' arrangement (**Figure 1**). The actual modulator valves were a pair of paralleled Eimac 3X3000As to ensure that an adequate amount of power was available to the PA screen grids. The two PA valves were both driven by the same RF drive source with a 90° phase advance network **[1]** and a common control grid bias of –600 V. However, to bias the valves to the correct condition for Doherty operation, the PAs were fed with different static bias voltages on the screen grids. The peaking valve was normally operated with –200 V on the screen grid to ensure it was not conducting at plain carrier, whilst the carrier valve was operated at +750 V on the screen grid to ensure it was operating in Class C. The anodes were connected to the combining point of the load through the 90° network as for the CE317B. Both valves were operated in conventional grounded cathode configuration, the earlier 'Weldon' grounded-grid arrangement having been dispensed with. Modulation was applied simultaneously to both screen grids. As the carrier valve was already operating in Class C, increasing its screen grid voltage with positive-going modulation had little effect. However, increasing the screen grid voltage of the peaking valve from the static –200 V towards the +2000 V which exited the modulator brought this valve into greater conduction thus delivering power to the (combined) output. Under negative modulation, the peaking valve is already cut-off whilst the lowering screen grid voltage on the carrier valve reduces the power delivered from this valve. Using 4CX35000C tetrodes with their attendant high gain for the output stage means that relatively low RF-drive is required, in fact only a few hundred watts. This drive was easily supplied by a single QY4-400 valve (itself preceded by a 6146 buffer and another 6146 in the crystal oscillator stage) to drive the PA stages, a contrast to the 5 kW required to drive the PA stage on the earlier CE317B using triodes in the output stage. A small dual-beam oscilloscope was built into the transmitter to aid with alignment and to set-up the operation of the PA stages.

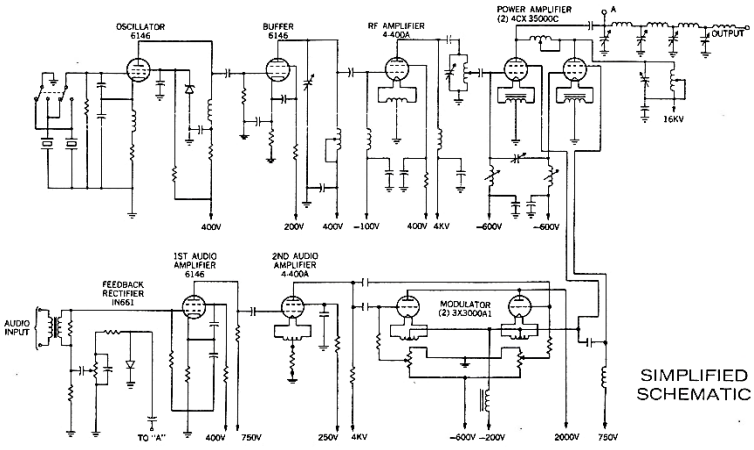

Figure 1. Schematic of CE317C 50 kW screen grid modulated Doherty transmitter (Continental Electronics sales brochure)

Valves and power supplies

CE317C transmitters were well-respected by transmitter engineers because they used simple circuitry (**Figure 1**), a small number of common valves and the power supply requirements were minimal. The line-up consisted of two 6146s in the low-power RF stages followed by the single 4-400 as the driver; then the two 4CX35000C output valves. In the modulator the first audio amplifier was another 6146 into a 4-400 and two 3X3000A1 triodes in the output. The power supply provided 16 kV for the final anode HT with 4 kV for all the 4-400s. 2 kV was required for the 3X3000A1 modulators. The 6146s had 400 V anode supplies derived from a 750 V rail and 200/250 V screen supplies from 400 V potential dividers. Bias was –600 V for the Doherty pair and potential dividers gave –200 V and –100 V for the 4-400 valves.

The CE317C at sea and on land

Three CE 317Cs were used by the off-shore radio fleet. Two were fitted on board the M/V *Laissez Faire*, home of Swinging Radio England and Britain Radio in 1966 (these two eventually went to Transworld Radio in Swaziland where they apparently still operated well into the new Millennium) and one was installed on the M/V *Mi Amigo* for Radio Caroline when she was repaired in early 1966 following the Frinton-on-Sea beaching. The CE317C was a natural complement to the two CE316Bs already installed on the M/V *Mi Amigo* as well as the two CE316Cs installed on the Caroline North ship, M/V *Fredericia*. It is rumoured that a CE317C was also purchased for the northern ship but was never fitted, a story that has not been confirmed. The set which went on board the M/V *Mi Amigo* was not the one originally ordered by Caroline, however, as that transmitter was commandeered by the UK Government's 'Diplomatic Wireless Service' and used for broadcasting into Rhodesia from neighbouring Bechuanaland as the BBC Central Africa Relay Station (CARS). Ironically, this very same transmitter was later used in 1970 for jamming the broadcasts of Radio Northsea International from the M/V *Mebo 2*. Other early CE317Cs went to XETRA in Tijuana, Mexico, WRKO in Boston and KOMA in Oklahoma.

A major design flaw in the original high-voltage main HT supply transformer saw a number of these fail in service with spectacular and frightening results, but the unit was quickly redesigned by Continental and gave no further problems after that. The design was updated several times over the following 20+ years with solid-state low-power stages and these transmitters became the CE317C2 and CE317C3 making this family of transmitters one of the most long-lived and enduring models ever built.

The Marconi/MCSL B6034 variant

The design of the CE317C was also emulated under licence (or less formal agreement) by other manufacturers, such as Marconi and a very large number of their 1977 design B6034 transmitters were installed by the BBC as part of the November 1978 WARC frequency changes. The Marconi design was almost a carbon-copy with solid-state 150 W RF drive amplifiers to the carrier and peaking valves, though they used a 4CX1500B valve modulator driver assembly for flashover protection of the semiconductor voltage amplifier (beanstalk) stages to both the carrier and peaking valves. The BBC's use of these transmitters typically on 693, 810, 882, 909, 1053, 1089, 1215, 1341 and 1458 kHz at the Regional Stations *e.g*. Brookman's Park, Droitwich, Lisnagarvey and Moorside Edge often involved combining two or three 50 kW units to achieve 100 kW or 150 kW of power and then often duplexing these services with other high-power services into a common antenna. Many have since been taken out of service, being replaced by solid-state multi-module units for the 1053, 1089 and 1215 kHz services, although most on 693 and 909 kHz BBC Radio Five Live, except for Brookman's Park, are still B6034.

Other Doherty transmitter variants

The author knows of at least three other types of Doherty transmitter, a Marconi 10 kW unit type B6040 that was introduced by MCSL in the early 1980s, the 180–250 kW FCO/DWS/CED sets built at Crowborough during the 1970s and the 50 kW 'BBC Doherty' made in-house by the BBC in the mid-1970s.

The Marconi/MCSL B6040

The B6040 10 kW MF unit was all solid-state except for the two final output valves which were air-cooled EEV or Eimac 4CX15000A. It was configured as the earlier CE317B types where the control grids of both the carrier and peaking valves were fed with modulated RF from the modulated amplifier; the Doherty amplifier being operated as a linear. The quoted overall efficiency was 45% but this was compensated by an easy-to-maintain transmitter with long valve life because the valves were not being stressed to any great extent.

The FCO/DWS/CED 180–250 kW Doherty

The FCO/DWS/CED MF units were built in-house at Crowborough (Aspidistra) in the 1970s and used all over the world at FCO sites including Crowborough (later Orfordness) and Cyprus for BBC External Service relay. They were designed to be of suitable size to be deployed rapidly *via* a RAF Hercules transport plane if required. Other than the main HT transformer, there were no particularly heavy iron-cored components. At Orfordness two variations were installed, namely a pair of transmitters, ORF2A and ORF2B (**Figure 2**) from the late 1970s, that were the later 250 kW versions. These carried the main 1296 kHz 500 kW service. There was also ORF3, an earlier 180 kW unit that was originally in service at Crowborough. ORF3 was the reserve transmitter for the 600 kW ORF1 AEG service on 648 kHz. Much of the low-power AF and RF circuitry was solid-state and designed and supplied by a company local to Crowborough, HCD Research Ltd. at Burgess Hill, Sussex. Valves were used to amplify the power up to the final stages which were a pair of EEV CY1172 steam-cooled tetrodes. At the time of writing it has not been possible to ascertain as to whether the modulation was effected prior to the final carrier and peaking stages with the Doherty amplifier operating as a straight linear, as in the CE317B, or whether screen grid modulation was effected directly on the output valves as in the CE317C/B6034 or even as the BBC Doherty (see below), in which both RF and AF were applied to the Doherty amplifier control grids. Further research is in-hand to clarify this important aspect.

Figure 2. ORF2A and ORF2B with Doug Nicholls the ferryman in the shot

ORF3 was, in fact, the original Aspidistra prototype unit and, during development, it was found that, with an

improved driver valve to the carrier and the peaking valves, an increase of power from 180 kW to 250 kW was possible.

The BBC Doherty transmitter

Prior to purchasing the Marconi transmitters, the BBC home-built a small number of 50 kW Doherty sets in the early 1970s, using an in-house design. They were originally used at Burghead, Lisnagarvey, Stagshaw and Start Point to allow their 100 kW pre-War units to be scrapped. To achieve the same 100 kW output at each site, another BBC-built 50 kW transmitter with Class B modulation was installed and the Class B and Doherty transmitters were paralleled in a Bridged-Tee combiner. To save costs, many of the iron-cored components in this Class B transmitter were original spares from the 100 kW STC pre-War transmitter. Air-cooled, rather than water or steam-cooled, valves were used throughout to enable the sites to run unattended.

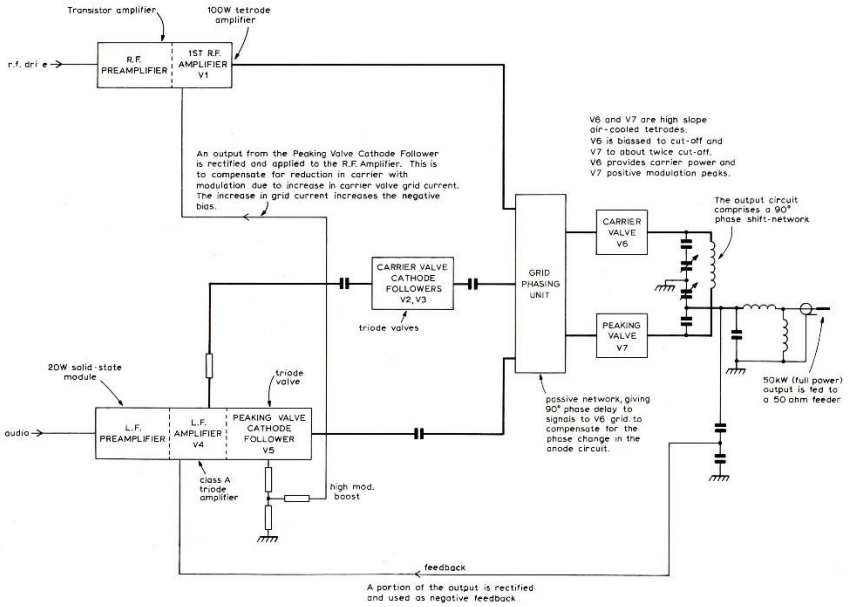

Figure 3. BBC Doherty: signal path block diagram

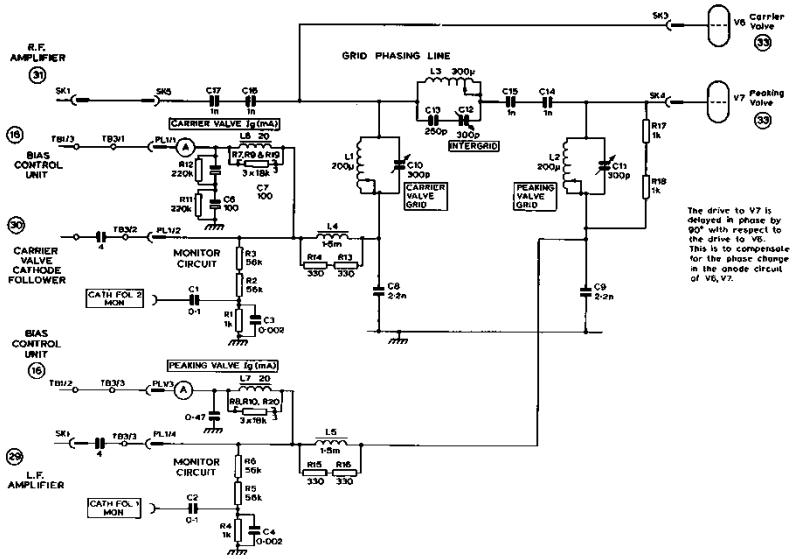

Figure 4. BBC-Doherty grid phasing circuit showing drive complexities

The BBC Doherty (sometimes called 'Willis Doherty' after the BBC Head Office Engineer J Henry Willis, 'JHW', who designed, built and commissioned them) appears to have no model number and, rather than using screen grid modulation (to avoid infringing any CE patents), had to employ very elaborate circuitry (**Figure 3**). Effectively, the Doherty stage was configured as it would have been with triode valve circuitry, simply mixing RF drive and AF drive at the control grids of the two STC/ITT 4JC301J PA tetrodes. Keeping the RF out of the AF feed and *vice-versa* was not easy, requiring the use of a considerable amount of extra components.

This added complexity (**Figure 4**) compromised the linearity of the system and some pre-distortion of the audio was required as well as 'High-Mod-Boost' to maintain linear modulation levels. A substantial amount of RF-derived AF negative feedback was employed (**Figures 5 and 6)**.

It was imperative that the RF output-derived AF-negative feedback rectifier was functioning because a significantly distorted output would result if it was not. The author (DP) can testify to this fact with the above feedback rectifier fault on the BBC Radio London 50 kW 1457 kHz service at Brookman's Park in 1977. The fifth site with a BBC MF Doherty was Droitwich carrying Radio 1 after 1976 at 30 kW; prior to that from 1967, a modified ex-Ottringham wartime 150 kW transmitter had been used running at much reduced power. That said, it was a good place to finally finish off all the low emission M-OV valves from the 200 kHz and the 1088 kHz, later 1052 kHz, ex-Ottringham 150 kW/ 200 kW transmitters.

The BBC-Dohertys were not particularly efficient, consuming more power at 45% modulation than the CE317C did at 100%; the BBC declined to provide a figure for 100% output. Most of these transmitters were taken out of service in November 1978, although a final pair was commissioned and JHW came out of retirement to build them for the 200 kHz (later 198 kHz) LF services from Westerglen and Burghead; but even these transmitters were eventually replaced by MWT/MCSL Doherty units in the mid-1980s.

Some ToTT of J Henry Willis

The author (DP) had the pleasure of working with JHW at Brookman's Park in 1977 as it was there that these LF units were being built. Henry was very much a practical hands-on engineer and would often be tasked with using what he could find already in stores to effect a solution. The concept of using an audio transformer *in reverse* was first seen by the author (DP) on the Doherty where Henry had used an RS Components EL84/EL84 push-pull output transformer to couple from a Henry's Radio 20 W solid-state amplifier at 4 Ω to get a 9 kΩ feed to the input of the first AF amplifier in his transmitter. This arrangement is now a favourite personal choice for modulation transformer use with MOSFET

amplifiers. Another ‘classic’ he used in an earlier 20 kW MF transmitter modification was an ECC81 with both halves in parallel to operate a high impedance relay in the anode circuit by warming up the valve’s indirectly heated cathode from pulses of current as the transmitter overload relays operated. After three shots the cathode was sufficiently hot that the ECC81 conducted, the relay operated and locked out the transmitter. Only when it had cooled down could a re-powering attempt be made.

In closing this ToTT, mention must be made of the time a high power 909 kHz rejector was required and the author had sourced a suitably-sized inductor but was in search of a large ceramic capacitor or two to add in parallel for resonance. Henry was approached and said “There’s a 2000 pF 15 kV one here and with that coil 909 kHz resonance will be one and a half turns from the end”… and it was.

Next time we will get to the arch US rival to the CE317C from the Radio Corporation of America.

Reference

1. D Porter G4OYX and A Beech G1BXG. Tricks of the Trade. *Signal* 2014, **33** (November), 17–20.

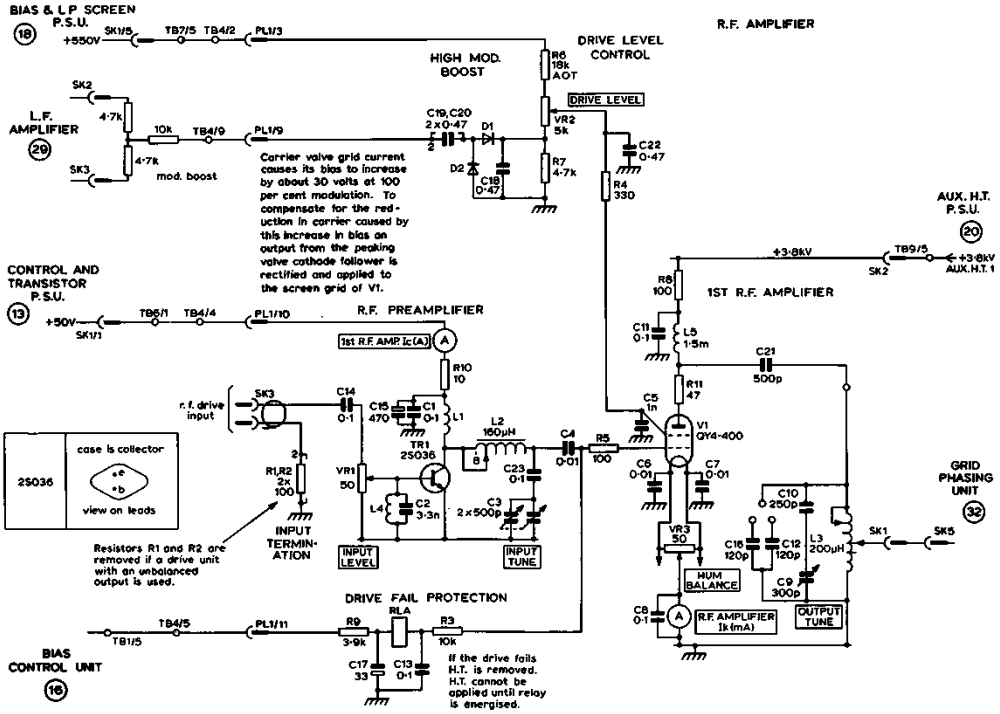

Figure 5. BBC Doherty low power RF amplifier stages showing ‘High Mod Boost’

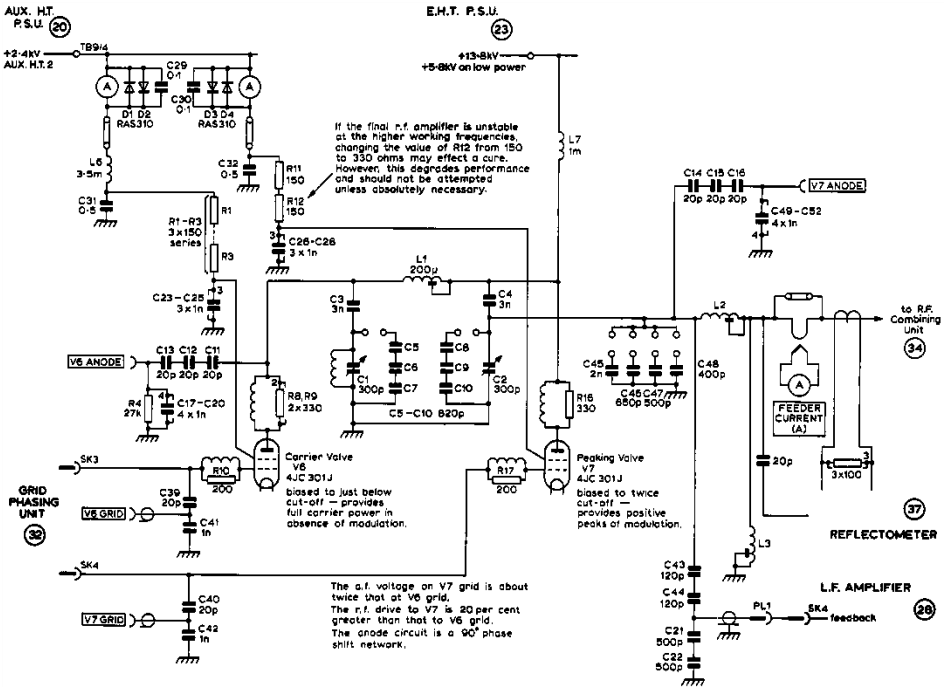

Figure 6. BBC Doherty final RF amplifier stage