Tricks of the Trade

Dave Porter, G4OYX

With the ever-increasing sophistication of technology, we now have receivers that can display accurately a frequency to tenths, or hundredths of Hertz, sometimes even better. On the VMARS nets we can identify those stations who are 'off frequency' and those who are *exactly* on 3615.000 kHz. In the early days of MF and LF in the UK, broadcast frequency stability and accuracy were not too important, as there were few stations on the air, essentially only for local coverage and they used exclusive frequencies, *i.e.*, not shared with other stations. With the advent of the BBC Regional Scheme, starting with Brookman's Park in 1929, where two high power channels were to be used at each site, the frequency stability of the drive source was still not too important and VFO control was employed. There were just enough channels available in Europe for the UK but, as the number of stations increased, shared channels became a fact of life. It was the Lucerne (LF/MF channel allocation) Plan of 1934 that concentrated the minds of the various broadcasting authorities in Europe that better frequency stability was required.

Tuning Forks

The BBC used a tuning fork as a means of generating a precise frequency at the Westerglen and Burghead stations in Scotland in 1936, as these shared the same 767 kHz channel. The forks were made by Muirhead and Co, and used Elinvar, a nickel, chrome, and steel alloy with a very low coefficient of expansion. The long term stability was about 2 parts in 1 million, i.e., 2 Hz. Previous designs of a mild steel fork drive used at Brookman's Park and Moorside Edge resulted in accuracies of 20 Hz.

With the increasing number of stations by the end of the 1930's, including the 100 kW sites at Start Point and Lisnagarvey, and the impending war, the BBC was fortunate that a technical solution was available, the quartz crystal. In 1937, the Washford and Penmon stations were chosen for a trial. Each station had a quartz bar of 50.25 kHz together with frequency multipliers of four doubling stages. By making adjustments each hour at Penmon, it was found that a synchronisation accuracy of 0.1 Hz on a carrier frequency of 804 kHz was achievable.

Wartime broadcasting

The quartz crystal drive unit came into its own at the start of wartime broadcasting, as there were to be two synchronised groups of 'Home Service' stations;

Group A, 668 kHz: Moorside Edge, Droitwich, Washford, and Brookman's Park.

Group B, 767 kHz: Westerglen, Burghead, Lisnagarvey, and Stagshaw.

These groups were used as a means of preventing the enemy navigating, *etc.*, using DF techniques on 'solo' stations. The success of the synchronising scheme was in no small part due to the excellence of the crystals provided by the Post Office Research Station at Dollis Hill. The BBC engineers received full co-operation from the PO engineers engaged in the production of the crystals, and they were invariably delivered in time to permit the BBC to keep to the target dates.

There was concern that the Irish, Athlone transmitter on 565 kHz, could be employed as a DF beacon and so the BBC installed crystal-controlled 'spoilers' at Clevedon, Penmon, and Redmoss on the same frequency with Radio Eireann programme to form a synchronised group. A similar exercise was conducted with the northern French stations until occupation. The crystal oscillator units employed at the Group A and B sites are not well documented, save to say they had a CPx nomenclature where x could be between 1 and 6.

The earliest crystal oscillator unit on which technical information is available is the CP17.E; this was first used in 1941. The only example the author ever saw was at Daventry in 1971 where it was the source for the 150 kW Third Programme service on 647 kHz. By 1977 it had been replaced by the COU-4, about which, more later!

It is interesting to note that the tuning fork equipment of the mid 30's occupied four 22" racks, 9' high and, at 1937 prices, it cost £3000, whereas the COU-4 occupied about 4.5" height of 22" wide rack and, at 1960 prices, it cost £150. The COU-4 had a frequency accuracy and stability some fifty times better than the tuning fork equipments.

The CP17.E was possibly of a higher accuracy than the COU-4, but it was found that extreme accuracy was not required. The author estimates that the CP17.E was priced at £1000-1500 in 1941.

Geoffrey G Gouriet

'Drive Section' was a part of the BBC Transmitter Department, which developed and arranged the manufacture of all TX drive units. Mr G.G. Gouriet was one of the engineers in DS. Sharp-eyed readers of the RSGB Handbook will have seen that he is credited with the design of the now classic VFO/crystal oscillator using a coil and series capacitor, or crystal and series capacitor across a series pair of high value capacitors. Clapp, in the USA, also developed the same circuit at the same time. Consequently the design is known as the Gouriet-

Clapp oscillator. It is this circuit arrangement that is used in both the CP17.E and the COU-4.

CP17.E Specification

The unit provided an RF output on frequencies between 150 and 1600 kHz with a short-term stability of ±2.5 x 10^{-8} over a period of 24 hours. The earlier units used PO 6B crystals, whilst the later units used PO W5 crystals. Below 600 kHz an additional divider unit was employed.

The RF power output was 6 W to a 100 Ω load, and a pair of Mullard AL60 pentodes (much loved by the BBC) were used as the output amplifier. The oscillator tube and the buffer were the much-BBC-used Mazda ACSP/3 high slope pentodes.

Drive Rooms and Ovens

The BBC Technical Instruction T2 for the CP17.E states that: ‘’The high stability of the equipment is ensured by the type of crystal used and its operation in a temperature controlled oven. During the operation of the thermal cycle, the maximum variation of inner oven temperature is about 0.01°C, for an ambient temperature change of 5°C’’.

On the high power stations, the drive equipment was contained within a special designated room. Here the ambient temperature was kept to within 5ºC. 22ºC was the ‘normal’ running temperature at both Daventry and Brookman’s Park whilst the author was based there. Washford was never so warm, whereas Westerglen and Droitwich (for the MF services) were at the temperature to which the control room staff set the room thermostat!

What’s in the oven?

In the CP17.E, just the PO crystal was in the oven. The series trimming variable capacitor was outside as were the high value (typically 300 pF and 2000 pF) mica capacitors from grid to cathode and cathode to earth, respectively. The crystal oven assembly is shown in figure 1.

To achieve the required stability, it must have been the great care taken with the insulation and construction of the oven and the unit, in general. Due to its size, 22” wide by 9’ high, it had a relatively high thermal mass and, as such, it took a while to ‘’heat through thoroughly’’ before full frequency stability resulted. Maybe the Drive Room temperature stabilisation helped as well.

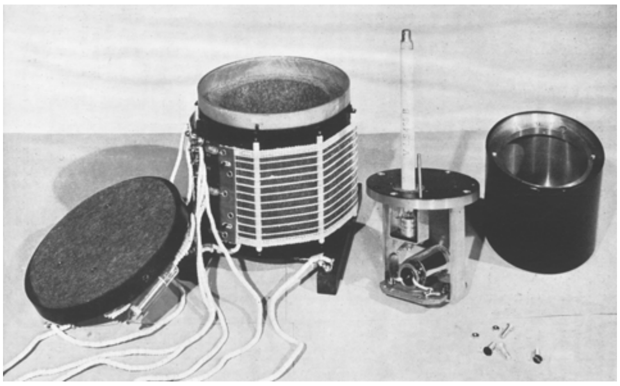

Figure 1. The CP17.E crystal oven assembly.

Control

The oven heating was by a selected AC voltage in the range of 100-170 V in 10 V steps. The heating elements were energised, and the cycle of on-off-on, *etc*., was checked, and the most even timings were selected by altering the tap. The oven temperature was 50ºC. A mercury thermometer, with in-built contact taps, was used to determine normal, over, and under temperature. Relays were switched by valves, rather like we would do now with logic gates, to control both the unit and operate the alarm for over and under temperature.

Alex Rothney and the COU-4

Unusually for a VMARS ToTT, I have taken the liberty to include content from an external source. In this case it is a contribution to ‘Prospero’ (the magazine for retired BBC Staff) from Alex Rothney. I reproduce excerpts from it here, as it is an insight into how DS worked!

It was entitled; ‘’COU-4 and how Drive Section went shopping in the interests of National Security’’

Alex Rothney writes: ‘’After serving as a MN Officer in WW2, I joined the BBC TX Dept in 1950 and was sent to Drive Section, which at the time consisted of two engineers and half a dozen wiremen. We were in the throes of preparing for the forthcoming frequency changes for the Copenhagen Plan.

I can now reveal some secret history! In the name of defence of the realm it had been decided that the main MF stations had to be equipped with an emergency frequency. DS were instructed to produce twelve new drives but no other department could be involved and the drive had to fit a spare 4.5” slot on an existing CP17.E bay.

There were two immediate problems; all existing ovens were roughly a 9” cube and the epicyclic tuning dial diameter was larger than 4.5”.

(The author suggests it was an HRO dial on the CP17.E, if he remembers correctly).

We had some suitable heating mats and contact thermometers in the stores at DS, but a trip to Lasky’s of Lisle Street was required as they had some ‘surplus’ Muirhead epicyclic drives.

I had the task of designing the COU-4. The oscillator circuitry was similar to the CP17.E. The oven control and alarm systems were greatly simplified, but it resulted in loss of accuracy of oven control over that achieved by the CP17.E. However, the latest crystals were less affected by operating temperature anyway.

These modifications resulted in a much smaller oven assembly which could be mounted in the 4.5” space. By using both sides of hinged panels, front and back, all the electronics could be swung out for maintenance. Production was soon under way. All the work was done in our own workshops. We then received an order for another thirty! We had enough oven spares, but no more surplus epicyclic drives, so they had to be purchased directly from the manufacturer.

Soon after that, I was seconded to Tanganyika. Some years later when I returned to the BBC, I found the production of COU-4 was now in the hands of Planning and Installation Department, and they were being fitted to all the low power DF sites. Secrecy was no more, indeed a Technical Instruction, T3, describing the COU-4 had appeared, but Drive Section had vanished!''

The 1950 Copenhagen Plan

Now that we have covered the need for, and the reason why, frequency stability and accuracy was required, we will examine the COU-4 in depth and see why it was such a successful unit. It had been developed for the start of the Copenhagen Plan on 15th March 1950 and lasting until the start of the Geneva Plan on 23rd November 1978.

Synchronised working was the order of the day in 1950 with a large network of high power stations on 1214 kHz for the Light Programme as well as country-wide groups such as 809 kHz for the Scottish Home Service and 881 kHz for the Welsh Home Service. By the mid-50's the need for another group, 1546 kHz, for the Third Programme fillers was established.

Now that the Home Service and Light Programme stations were sharing frequencies with high power sites in Europe, for example Moorside Edge 692 kHz with Wachenbrunn in Germany, accurate and stable drives were mandatory to prevent degradation of service caused by heterodynes.

In addition, with the start of the Cold War, there was the deployment of Deferred Facility sites for Civil Defence, emergency local MF service, often using pairs of BBC/RCA ET-4336 transmitters.

The COU-4

This unit, in its three variants 4, 4A, and 4B, became the standard workhorse for an MF drive. The 4A was used at some HF sites as a drive for further multiplication to HF, whilst the 4B was the final and definitive version.

All were housed in a 22" rack chassis. Early examples used EF50 valves for the oscillator and buffer stages, with EF55 in the output. Later on, EF91s were used in place of the EF50s, and EL84 in place of the EF55. The HT rectifier was, at first, the Mazda UU6 and, later, the EZ81.

The circuit of the COU-4B is shown as figure 2 (please see end of article).

Leaving aside the oven assembly for a moment, it can be seen that V1 is a Gouriet/Clapp oscillator followed by V2, a class A limiter stage in a conventional aperiodic amplifying circuit. The limiting is provided through an extra output coupling to feed a diode, MR1, which produces bias for V1. The derived bias for V1 is adequately decoupled and filtered as V1 is devoid of any other means of bias. The EL84 output stage is quite conventional and operates in class A. A very neat wideband output transformer is provided with inductive loading inbuilt by L5 (400 µH).

The balanced 100 Ω output was able to power a single TX, with a special BBC-designed input transformer, or be coupled to a splitter transformer to provide two outputs of up to 2.5 W, each to drive a pair of transmitters. This arrangement was much used on the ET-4336 DF sites.

Comprehensive metering was provided to check the anode current of all the valve stages as well as the HT voltage. Lamp indication was available to show the oven-heating on/off cycle, and an over-temperature alarm with the option of connection to an external bell! These facilities were as in the CP17.E, using a tapped mercury thermometer to operate the PO 2000 relay switching to maintain the temperature at 45°C, and to signal over and under temperature.

The power supply delivered 300 V DC from a Partridge mains transformer and the UU6 or EZ81. Unusually, the transformer was a point of failure due to overheating and modified ones were supplied and fitted over the years.

The COU-4 oven

This was the heart of the design and the developments by Drive Section made for the success of this unit. Compared to the CP17.E, not just the crystal but all the frequency sensitive components were contained in the box within the oven.

The box was isolated from earth to avoid the stray capacitance from the high potential side of the fundamental frequency PO W5 crystal. This would have prevented reliable oscillation over the full range of frequency-adjusting capacitance, without having to alter physically the fixed mica components within.

The box was made of 14 SWG sheet copper, nickel-plated on the inside, and blackened on the outside. There was a front surround of thermal insulation and a blackened steel outer box with the barreter-controlled heating elements.

Thought was given to the eventuality of two units being mounted one above the other on a bay, as the upper one would be warmed by the lower, consequently the upper had an Osram Type 161, 160 mA barreter and the lower a Type 302, of 300 mA rating. Replacement barreters became hard to source, and paper capacitors were used as series droppers, 4 µF being typical.

The trump card was the four-way grooved 6.35 mm paxolin rod that connected the innards of the box *via* 30 SWG enamelled copper wires to the outside world. This was both electrically and thermally stable. Colour coded tags were provided to a screened connection tag-block.

Bandspread options

A Muirhead 30:1 reduction drive (as on the Admiralty RF26 unit) was used on the 100 pF variable capacitor. For frequencies above 1 MHz, bandspread was employed on the trimming capacitor within the oven to make fine frequency trimming easier. Figures 3 and 4 show the variations of circuitry. A test point 'T' was provided so that the crystal excitation voltage could be measured using a valve voltmeter.

Using the COU-4

The frequencies of the drives were checked daily on the manned high power sites by comparison to Droitwich LW, 200 kHz. A FCE-1 (Frequency Checking Equipment-1) was used to display on a 3" CRT, a triangular dotted display which was stationary when the frequency was XXXX.000. The convention was to make the dots move very, very, slowly clockwise so that all stations on all frequencies had an identical, very small positive error. Weekly, the meter readings and timing cycles of the units were checked and recorded in a special, custom log book.

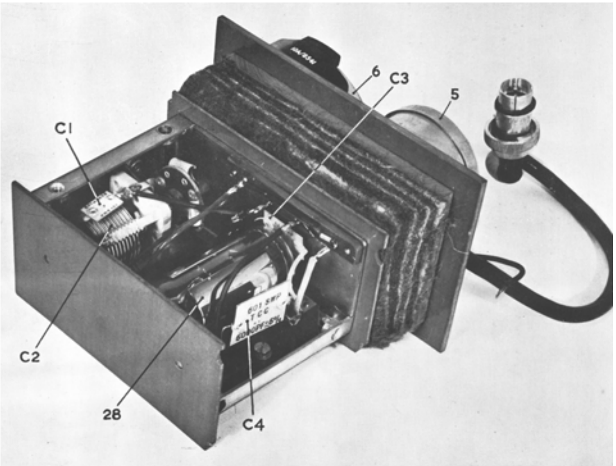

Figure 3. Typical COU-4 construction: assembly inside the constant temperature chamber. '28' is a W5 crystal by the PO.

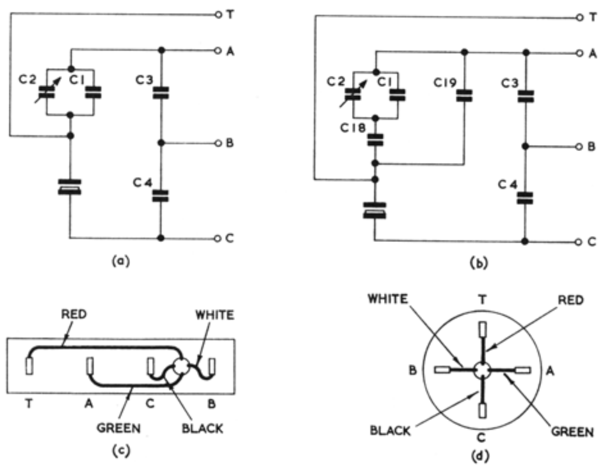

Figure 4. Inner-oven circuits: (a) basic and (b) bandspread, and tag blocks in (c) inner-oven, and (d) junction box on front panel of oven.

The stability of these drives was such that they were accurate to one–fifth of a cycle, that is, 200 milli-Hertz over 24 hours. This level of stability easily afforded efficient, inter-station synchronised working.

What happens if the frequency is wrong'? Tests carried out in the mid 70's showed that, on inter-station synchronised transmissions, if the frequency error was >1 Hz, then the effective service area was reduced by 10dB. For example, a 50 kW station's coverage would be reduced to that of a 5 kW site if the frequency was in such error due to the groaning heterodyne.

The present limits for inter-station working are still 200 milli-Hertz but, for local radio, then ±10Hz is allowed. Personally the author would recommend the tighter limit as if a low power station is sharing a channel with a high power group for example, Sunshine 855 kHz 150 W output versus Spain's 550-odd kW sync group, he would prefer to be 'dead-on' with them! If not, one enters into the '10dB coverage loss' situation.

Radio One on 247m…. the mush!

Many folks of the author's age will remember the start of this service on what was the former Light Programme 'filler' frequency. In Nottinghamshire, the disappointment of the coverage was very evident, as even in daytime the signal faded in and out all the time. The reason for this took the BBC many years to resolve, only partially. By way of explanation, prior to Radio 1, Brookman's Park in Hertfordshire carried the 50 kW Light Programme for London, and Moorside Edge the same power for the industrial heartlands of Yorkshire and Lancashire with a directional antenna. In the Midlands and the South West, the Light Programme was excellent from Droitwich, 200 kHz. After Radios1 and 2 were introduced, Washford, 60 kW and Droitwich, 30 kW were switched on. In Nottinghamshire we were now receiving Brookman's, Droitwich, and Moorside, with maybe a hint of Washford. Even with a ferrite rod, it was hard to DF any of the trio to get one. The BBC knew the drives were OK as they were all set daily and accurate. It wasn't until 1974 that Research Department sussed it. The fix was to delay the audio feed to Brookman's so that it matched the time taken to travel to Droitwich. Unwittingly, the fix was good in Nottinghamshire but actually it was intended for Luton where the QRM was equally as bad. Maybe the population of Luton contained the complaining son or daughter of a BBC Radio1 producer?

Prior to programme, an asymmetric tone was fed from London to determine that the modulation was 'the right way up', and the timings could be checked with a remote check receiver located in the Luton area. The author was at Washford at the time so was involved in the tests as they had to 'steer' the 60 kW there off-channel a good few milli-Hertz so that RD staff could measure in the Luton area just Brookman's and Droitwich.

The final solution for this mush-area problem was to move the popular Radio1 service to 1053 and 1089 kHz after 23rd November 1978, using alternate transmitters up the country, and to use 1215 kHz for the Radio 3 service that did not have such a large audience.

Next time in ToTT we will look at the use of VFOs in the BBC to generate the drive frequencies for high power 250 kW HF transmitters.

Acknowledgements

The author is indebted to:

Martin Ellen, Webmaster of the bbceng.info website for obtaining permission for long-obsolete BBC copyrighted diagrams and data to be used for general education and private study. It is with his help that the author has been able to use the extracts from BBC Technical Instructions first published in 1953.

Alex Rothney, for his permission to reproduce his letter published in the November 2005 issue of the BBC Prospero magazine.

John F Phillips, retired Assistant Engineer-in-Charge, Droitwich, who kept copies of the BBC Technical Instructions and was able to lend them to the author.

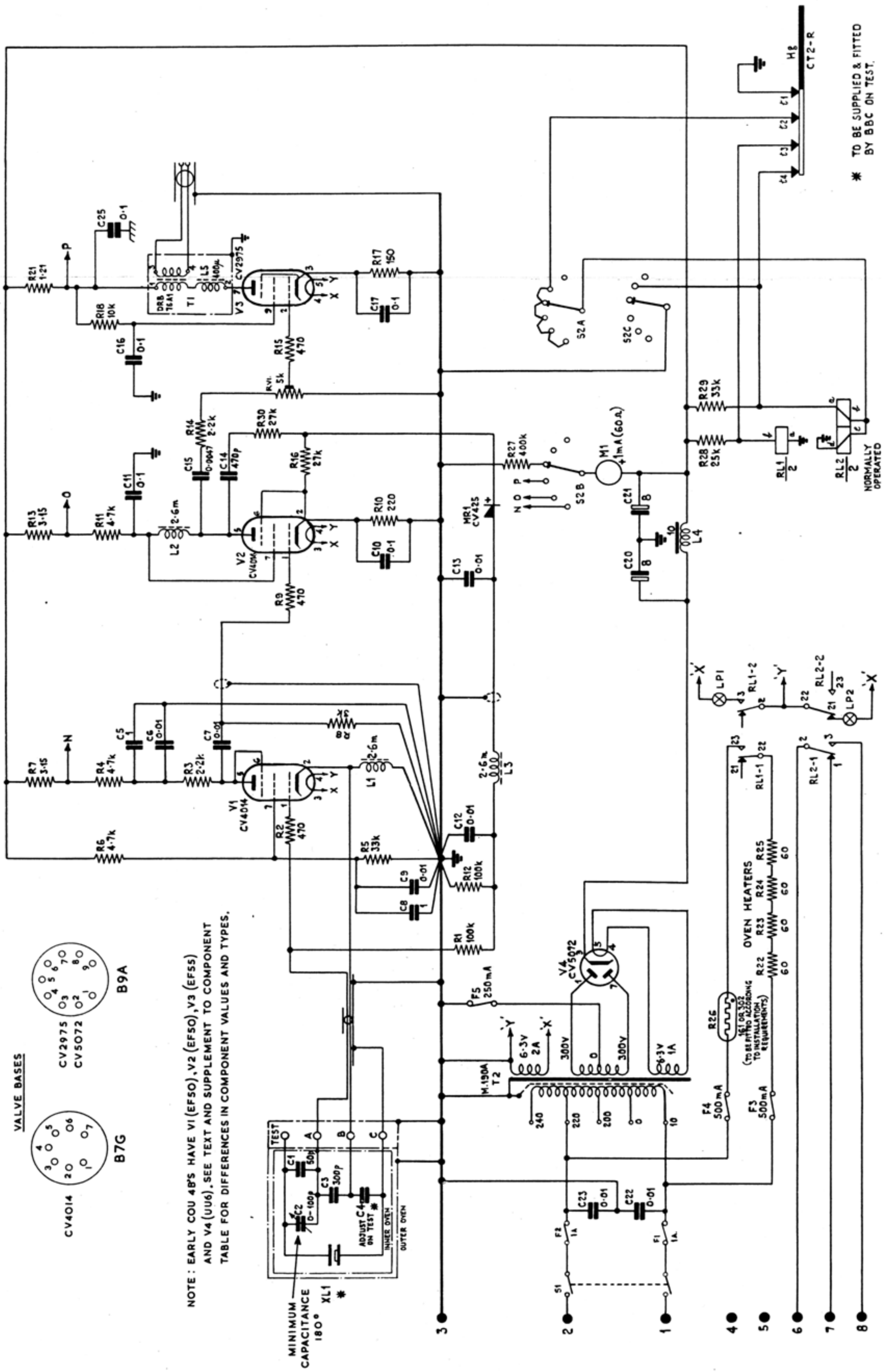

Figure 2. Circuit diagram of the COU-4B crystal oscillator unit.