Tricks of the Trade

Dave Porter, G4OYX

After the initial tests at Daventry on HF, starting in the early 1930's, it was found that to cope with the growing complexity of the BBC HF services, due to the many frequency changes, precision variable frequency drive units became essential. The main problems identified were of stability and resetting accuracy. After some commercial designs had been tried and eliminated (because of the above problems) the BBC was forced to develop its own equipment. There will be many in VMARS who have had similar considerations and consternations with VFOs, and the BBC's experience may be useful.

The Difficulties

In 1941, the first of these BBC units, based on an earlier Air Ministry unit, was trialled at the then brand new site of Rampisham (Wartime codename Over Seas Extension 3, OSE 3) in Dorset.

Results obtained indicated that the out-of-tolerance-working errors averaged 2.5%. Regrettably it was also found that the VFO needed constant attention and, because of the simple temperature control employed, frequency stability was an issue.

With the on-going rapid expansion of the HF services, and the building of Skelton (OSE 8 and 9, 1942) and proposed building of Woofferton (OSE 10, 1943) it was decided that, for the 50 (in total) Variable Frequency Oscillators needed for these sites, a re-design was required.

Regulations and Principles

The Cairo Radio Regulations in force at the time decreed that the carrier frequency stability on HF was to be better ± 50 parts per million.

The BBC wanted a design where frequent checking and re-adjustment was not required, and the complete drive should have an RF power output of at least 20 W. Also the repeatability of setting should be easily achievable.

A ''single oscillator'', producing a fundamental frequency between 700 kHz and 1400 kHz was proposed. A Harmonic Generator Multiplier, (HGM) was used to produce the actual sender carrier frequency. The HGM produced RF between 2.8 and 22.4 MHz. If a sender was to cover above 22.4 MHz, then a doubler unit within the TX would be employed, and an HGM output of between 11.2 and 15.0 MHz would be sent.

The repeatability requirement was fulfilled by using a suitable control dial (actually a National gearbox and dial as on the HRO) and, by sub-dividing the overall oscillator coverage into four ranges, it was found possible to select the correct VFO MF channel from the indicated setting. For precise tuning then a beat monitor unit was employed about which more later.

The long-term stability was ensured by using the correct choice of components for the frequency determining network and the temperature around these networks was maintained to within close limits.

The 20 W output power was provided by a pair of the then newly-developed 807 beam-tetrodes, operating as a tuned PA class C stage. The tuning inductors on turrets were switched by a cog and chain system.

The VFO-4 in detail (figure 5)

Despite being billed as a ''single oscillator'' stage there were in fact, three stages. The actual Gouriet-Clapp, GC, Oscillator was followed by a limiter, ACSP/3 and finally a separator, ACSP/3 or as we would call it now a buffer.

The GC oscillator was comprised of two paralled ACSP/3 pentodes, operating as tetrodes and having a high gm. This configuration enabled larger values of shunt capacitance to be used reducing the impedance between grid and cathode, and cathode and earth, thus allowing physically longer connections between the tuned circuits and the valves themselves.

The limiter stage permitted the voltage on the grids of the GC oscillator valves to be low and ensured frequency stability with supply voltage changes, and a reduction in harmonic generation. This fact was important as a wide-band buffer stage followed. The use of the limiter also meant that rectified DC could be produced to bias the oscillator stage so that a constant output level was produced over a wide range of frequencies. The osc output was 1.0 ± 0.2V into 100 Ohms over the entire range 0.7 to 1.4 MHz.

The four switchable sub-freq ranges were; Range 1: 695 – 850 kHz, Range 2: 830 – 1000 kHz, Range 3: 980 – 1215 kHz and Range 4: 1175 – 1415 kHz.

The Capacitors and Inductances

So that the VMARS reader can glean the most information on ''VFO-building'' this following section is detailed.

Each tuned circuit range had a negative overall temp coefficient of frequency of 30 parts per million per degree Celsius. This comparatively low value was obtained after a series of tests to determine the best combination of components and materials, rather than by concentrating on special construction or temperature compensating capacitors.

The inductances were wound with Lltz wire on formers with carbonyl-iron dust cores.

The L value for each range was chosen to maintain the optimum number of turns, which were scramble-wound and were given no fixing treatment. This lack of fixing was found to give superior long-term freq stability.

The coil assemblies were pre-aged for a month before use, using thermal cycles similar to those in the actual VFO-4 oven. This treatment was found to reduce the service ageing period markedly and thus the need for re-calibration after only a short time in service.

The use of dust cores made the inductances compact and a higher value of Q was obtained over that which would have resulted if a physically larger air-cored coil had been used in the restricted space of a screened oven.

The adjustment of the tuned circuits was by four small variable capacitors, with their rotors on a common shaft. The shape of the plates chosen resulted in a good approximation to a ‘straight-line’ oscillator frequency.

The driving shaft was, as in the COU-4, made of SRBP to minimise thermal effects. The complete tuned circuit assembly was mounted on a heavy plate bolted to the base-plate of the inner oven.

The Mechanical Aspects including the National drive

Reduction gearing of 20:1 was employed to drive the rotors of the variable capacitors. Ten revolutions of the shaft moved the rotors through 180º. An 8-inch diameter dial, graduated on its periphery into 500 divisions, was used in conjunction with a 4.5 inch counter-type dial. The smallest graduations of the outer dial represented 1/50,000 of the available capacitance in each range and as the outer dial could be set by estimation to quarter divisions, a reading discrimination of 10 Hz at 1 MHz was possible, with even better discrimination after the acquisition of operating skill.

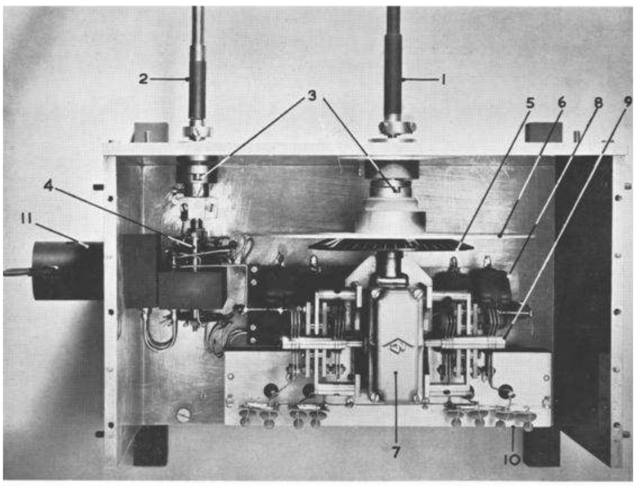


Figure 1. VFO-4 LC assembly showing the National drive labelled ‘7’ which is attached to the familiar looking HRO dial labelled ‘6’.The main frequency control shaft is labelled ‘1’.

The Ovens

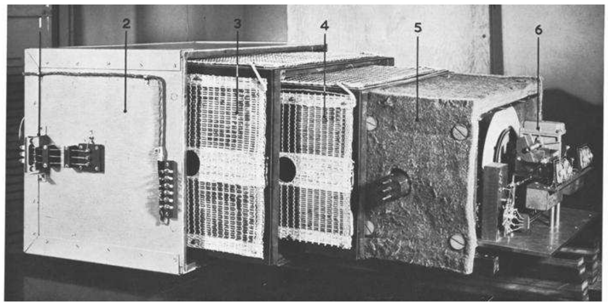


Figure 2. The VFO-4 constant temperature oven assembly with containers partially withdrawn

Key to figure 2: bracket carrying LC assembly connector; 2: outer wooden box; 3: outer oven assembly, 4: inner oven assembly, 5: constant temperature chamber, 6: LC assembly

The specification was for a variation in temperature around the tuned circuits of ± 0.01ºC for an ambient change of 5ºC. The inner oven temperature should ideally have been at a value considerably higher than ambient but, with the war-time restraints on components, a compromise of 40ºC was adopted for the inner oven with 35ºC for the outer oven and a maximum of 24ºC for the ambient. That ‘’warmish’’ 24ºC figure may or may not have been too pleasant for the Drive Room staff who had to retune these units throughout the 24 hours.

As on the CP-17E and (much later) COU-4 crystal oscillators, mercury thermometers with in-built contact taps were used to control the oven heating cycles and monitor the oven temperatures.

The Harmonic Generator Multiplier

The HGM enabled multiplication of the VFO output frequency to; x4, x8, or x16 (see figure 4-on next page).

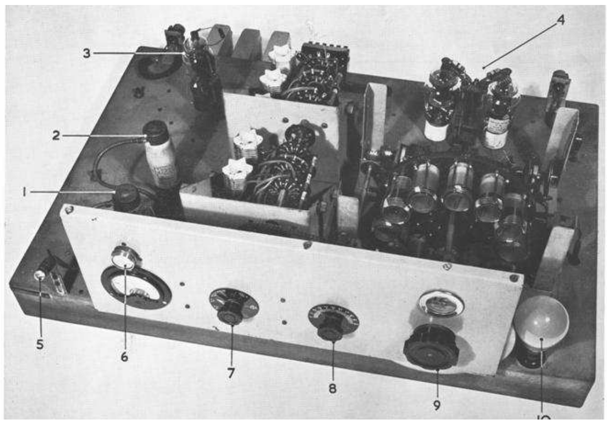


Figure 3. The Harmonic Generator Multiplier- note the two 807s labelled ‘4’.

Two ACSP/3 pentodes were used, the first as an aperiodic amplifier and the second, biased to beyond cut-off, to produce an output rich in second and fourth harmonics as well as the fundamental. A selectable tuning unit followed, and the chosen frequency was amplified by the first power stage, a Mullard AL60 pentode into a second selectable tuner unit, and out to drive the paralled pair of 807 valves. A final tuning unit effectively cleaned up the carrier frequency to the 20 W level.

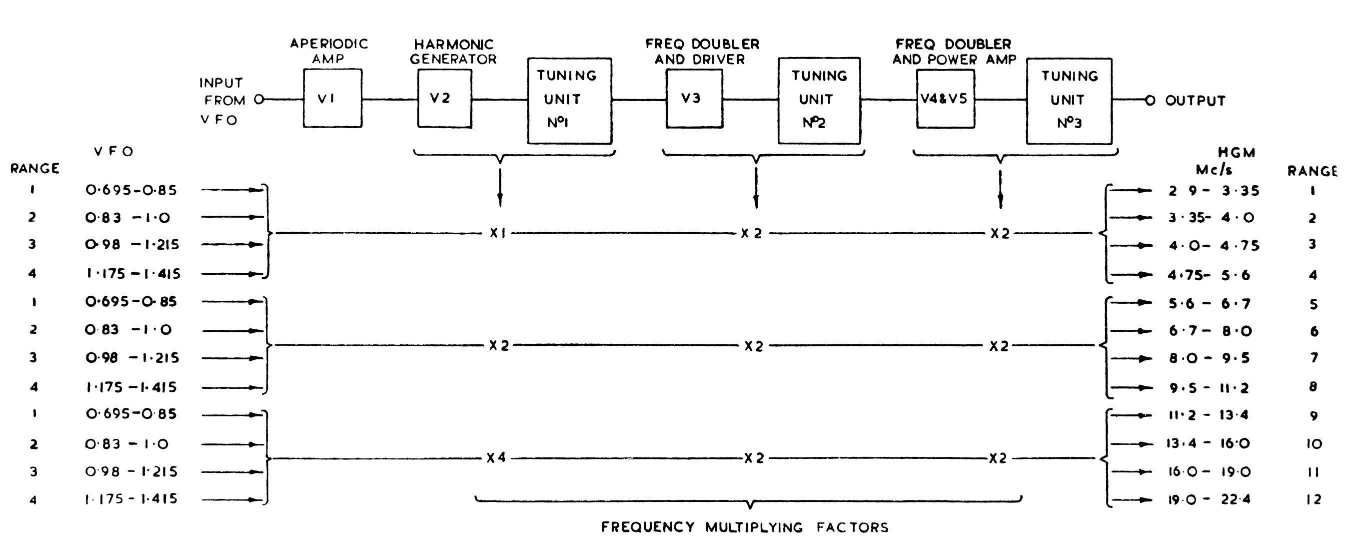


Figure 4. Block diagram of the Harmonic-generator Multiplier to show how the different frequencies are related and generated

The Frequency Monitor Type FRM-4

This unit provided a range of accurate 5 kHz markers from 2.8 to 22.4 MHz, derived from a precision 100 kHz crystal unit. In this way the carrier frequency generated by the VFO and HGM combination could be audibly compared with the one of the standard precision 5 kHz markers, and the VFO adjusted until zero-beat was obtained. It's interesting to note that at, say, 21 MHz an error of 3 Hz is equivalent to an accuracy of about 14 parts per 100 million, so good accuracy ensued and the Cairo Regulations were satisfied.

The Beat Monitor BM-1

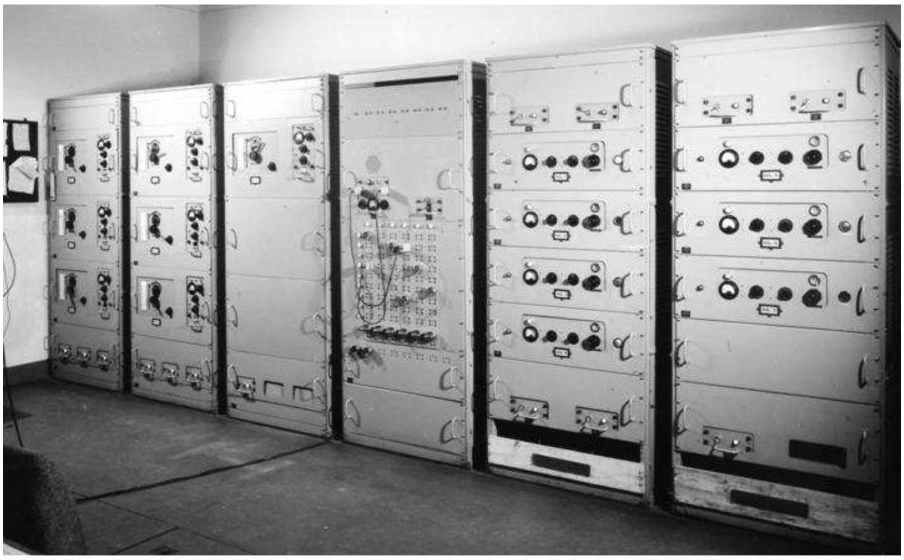
Earlier mention was made of this unit and samples of both the standard frequency and the VFO frequency were combined here using a pair of ACSP/3 valves. The difference frequency was amplified again by an ACSP/3 before being amplified to LS volume with an AL60. The VFO would be adjusted to zero-beat using this unit.

The author and the VFO-4

When the author arrived at Daventry in 1971, these wartime units were still very much in use. However, the set-up was greatly simplified as a Hewlett Packard frequency counter with Nixie Tube display was employed. This was locked to a precision 5 MHz standard. The BM-1 was still being used to get the zero-beat and then checked with the counter. By the time the author had returned in 1975, the drive frequencies on the site for all the 14 senders were derived from separate Marconi frequency synthesisers driven from a standard precision 1 MHz source.

Jeff Cant and the VFO-4

Following this ToTT is an article from retired BBC engineer Jeff Cant, who had long-term experience with these units at Woofferton. He has written a humourous, personal account about the day-to-day use of the drives and the traps into which young, inexperienced, Technical Assistants could fall. Mention is made of the (exclusive to Woofferton) 'Drive League'. The author hopes the reader enjoys it.



The Variable Frequency Oscillators and Harmonic Generators which produced the RF drive for the senders. Taken in the Control Room on 24th August 1944.

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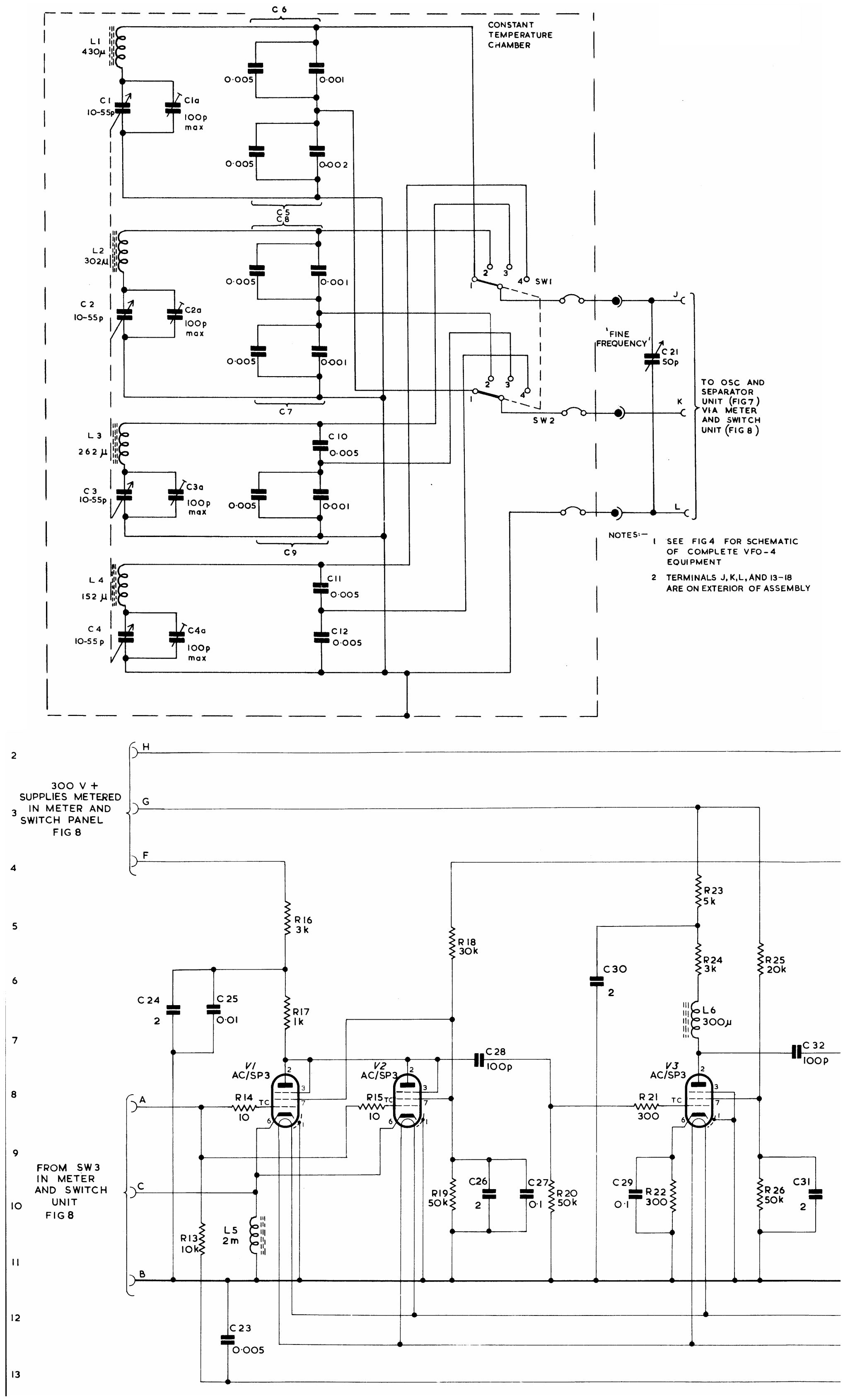


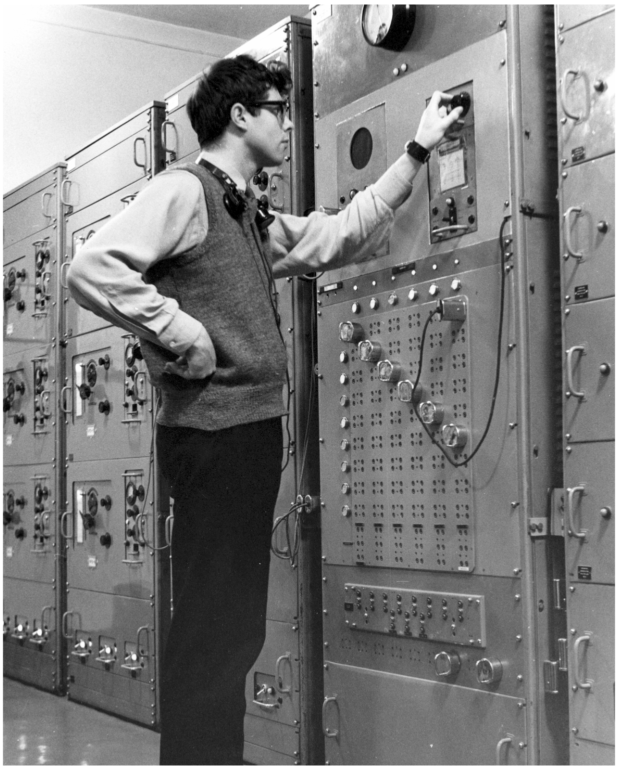
Figure 5. Circuit diagram of VFO-4 (below) with associated LC-circuitry and range switching (above)
NB references on this circuit diagram to 'fig' and 'sw' numbers are to the original source

Operation of VFOs and the Woofferton Drive League

Jeff Cant

Before I start, I must emphasize that, for this exercise, I have only used my memories and those of Harry Field, Dick Lett, and Brian Thomas. When researching my history, I remember seeing a Woofferton-produced hand-written manual on VFOs and their maintenance and construction, but it may have been discarded over the years. The following remarks only apply to Woofferton Drive Room. Practice elsewhere, at Daventry and Skelton for instance, was probably very different and in some cases only experienced TAs would be allowed to work in the Drive Room. At Woofferton, Drive Room (including programme switching, telephone answering and taking down service messages by hand) was an integral part of the shift pattern, followed by Aerial Switching and then three sender positions to make up the 5 day sequence.

Setting up VFOs



Jeff Cant at the Drive Patch Panel in Control Room, Spring 1961

To begin to set up the VFO required the use of a chart of scheduled settings which was kept up to date by recording the actual settings for each transmission. Operationally, the General Supervisory Engineer (Grade C) was supposed to check the settings and shout out the dial settings and meter readings after every change for the Technical Assistant (TA) to write down. These recorded settings were put on the VFO dial from a clockwise direction to just below the required numbers. The settings dial had a narrow paxolin lever bolted across the face of the knob and this was lightly tapped to bring the beat to zero on the headphones. The output frequency was almost universally a multiple of 5 kilocycles and so the FRM outputs of 5 kilocycles were used as a reference.

The story was that Woofferton, the Engineer in Charge, in the person of L. F. Ivin, had modified the setting mechanism by replacing the flexible drive connection with a dog clutch system which naturally gave backlash. I think that I can detect the paxolin lever in the photograph of the Woofferton Drive Room taken in August 1944 so either it was a feature already on the VFOs when they were delivered or Ivin twiddled about as soon as the VFOs arrived. However Brian Thomas does not remember any such paxolin lever on the VFOs at Rampisham.

This initial setting up was done with the fine tune control at the centre position. Any further tweaking was done by this control, the main setting knob was not touched again. The Drive Link Panel was used to connect any VFO to the HGM which was normally tied to a particular sender drive line. This resulted in the Link Plugs ending in a diagonal line across the panel. There was also the possibility of using two senders on one frequency with this panel. After the setting up and zeroing, the HGM was switched to the correct range and the drive appeared up the sender drive line, which was pyrotenax, I think. Small quick frequency changes could be done by waiting for the sender HT to be tripped, then removing the old Drive plug with one hand and connecting a new VFO by pushing the remaining connectors in on a new Drive Plug. I do not remember using this technique but Brian Thomas assures me that it was done.

The checking was done by using the FRM4 and its output of a series of 5 kc/s frequencies to tweak the fine tune on the VFO. From what I remember we checked the FRM4 crystal output with a Droitwich signal, but only when the 200 Kc/s was present. Long Wave came off after the shipping forecast just after midnight. As is said in the technical description, the FRM4 was not a frequency checking device, and only the specific dial settings on each particular VFO would give the required frequency output and that is why the current settings were so very important. It was the mid-1960s before we saw a Frequency Counter at Woofferton.

Steer for zero error

I think Tatsfield were charged with checking every transmission when it began to radiate. This meant, while the sender was on line-up tone, or in the 2 minutes before programme on a Barrage Start, or if it was a crash start after the actual start of programme. I think they also checked transmissions at regular intervals for any drift but I don't know how often.

The procedure at WOF (Woofferton) was to set up the drive and zero it ready for the sender TA to power up the transmitter and later zero it again when the sender came on for scheduled transmission, when a 'Radiate' lamp would light above the Drive Link Panel. Once the senders were transmitting it was considered that a little tweaking would be necessary soon after a programme start as Tatsfield might have too many senders to check simultaneously, so it was wise to have another look-see. Then one tended to check periodically the running drives when setting up the next ones for service.

At the end of transmission, the new drive frequency would be set up. Once the VFO had been identified as needing a frequency change, the plug was pulled out on the Drive Link Panel. Because the RCA transmitters were self biased it was considered bad form to pull the link plug out while the sender was still radiating; it tended to make bells ring and the Senior Maintenance Engineer (SME) appear in the doorway. However it was said that some senders just carried on. These presumably were the locally built S81 and S82.

Initial calibration

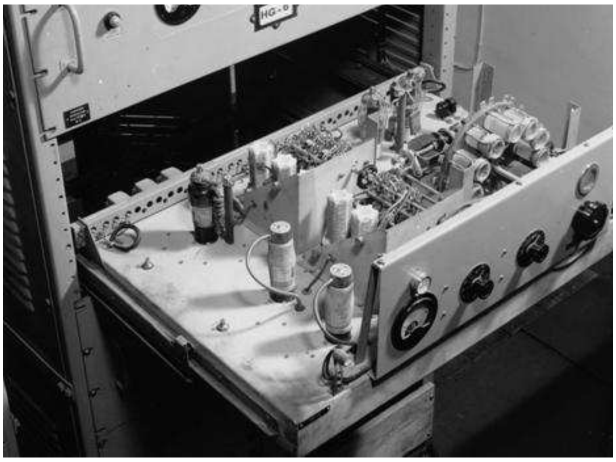
The problem is how they set the VFOs up to get the coarse readings. I assume that Planning and Installation Department (P&ID) would have used test equipment to set up and record settings for the first one or two VFOs, and then compare other VFOs as they were installed and warmed up. At Woofferton we checked every setting on all VFOs every month. They were all checked by running through the settings, the General Supervisory (Engineer) (GS) and Control Room TA performing this task. It was usual on such occasions to use the LS to hear the beat rather than the headphones, and it certainly made sure you got no visitors as the falling tones rang out, and the last few cycles were very low notes and were emphasised by clicks in a headphone transmitter. There was also a visual indication on a large uncalibrated meter which can be seen in the photograph. All these readings were kept on settings sheets for each VFO. The Drives were a very labour intensive part of Control Room duties and it was a source of irritation to some, or pride to others, when the Drive League Chart came out.

Drive League

As far as I know, Woofferton was the only station that actually produced a Drive League; Brian Thomas is certain that it did not feature at Rampisham. Compiling the table was a laborious task. The sheets were actual Tatsfield desk pages from their log where the staff recorded errors for all Short Wave transmissions. The figures for WOF were selected, and a table made up of total errors for each shift. The WOF control room log was then used to identify the Control Room TA responsible, and the figures were finally sent upwards and reappeared as a tabulated Drive League Chart. The average for the whole of WOF was marked and it showed who was better or worse than average!

There were several dodges that could be employed to put the score up on the Drive League, zeroing every VFO and then asking for one spot check, but I suspect that most people did the best they could and tweaked the VFOs when they remembered, and to keep awake during some of the long night shift transmissions from midnight to 0300. When there was a lot of programme switching and the phone from BH rang, there was less time available to spend checking VFOs that were already in use.

I cannot remember the actual warning figure, but I think I was once moaned at by the Assistant Engineer in Charge (AEiC) for a 30c/s error. Harry seems to remember that the ITU figure for accuracy was to be better than 30 parts per Megacycle, with the BBC reference level being half that figure. We were probably required at Woofferton to get to 5 or 6 parts per Megacycle. However, from the Drive League Chart the average error was 6.44 cycles and, if the median frequency is possibly 13 megacycles, the error is about ½ cycle per Megacycle! Pretty Good I would think.



HGMs at Woofferton 24th August 1944

Note from Dave Porter, G4OYX, re: Barrage Transmission and Crash Starts.

Barrage Transmissions were arranged so that many single frequencies would be used for a same programme transmission to make it hard for the East European and Russian jamming stations to take all out at the same time.

Crash Starts (CS) were such that no carrier would be radiated with or without interval signal prior to the start of programme. Again this was so the jammers could not get set up early. Of course it made it harder for the listeners to find the service, unless they were prepared to miss a little at the start.

We still use the CS principle, but for entirely different reasons...we come on for BBC services at programme start -30 secs and for Voice of America, Radio Free Europe/ Radio Liberty and Deutsche Welle at programme start -3 secs. This is purely to save electricity!

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