The Right Tunes? Wavemeters for British Army and Air Force uses in World War One time

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Abstract — **Wavemeters used to set British land and air transmitters and receivers to the correct frequencies in the time period of WW1 are described, following an overview of earlier naval developments and the designation of 'tunes' which arose from the discovery that receivers could be 'tuned' to separate out multiple simultaneous transmissions. This was mostly in a context of spark transmitters and Morse Code. Illustrations of circuit diagrams and actual equipment are used to explain how this laid a foundation for development of many innovative RAF wavemeters during the rapid technological progress of the interwar years, followed by many more wavemeters to support the radar developments of WW2 and the Cold War.**

Index Terms — Electromagnetic measurements, Military communications equipment.

TELECOMMUNCATIONS BEFORE WORLD WAR ONE

From the beginnings of radio communications, it became necessary to correctly tune transmitters and receivers to their intended frequencies, particularly to prevent mutual interference, and as the number and types of transmissions increased, this became more essential.

For marine communications it was evident that radio provided a facility that could not be matched by any other method, and the British Royal Navy expended much effort on novel developments, initially under the aegis of their Torpedo School. This was all Wireless Telegraphy (e.g. Morse Code communications); Radio Telephony (transmission of speech or music) was expected to have no serious applications. Spark, Arc and Alternator based transmissions were all used, and automatic receivers were devised to print fast Morse Code. Naval transmitters used substantial voltages and currents at the spark: for example 16kV and 17A for 18 words per minute Morse. Use of five-inch sparks prior to 1900 is reported, achieving a 5800 yard (17400 feet) range. 800 sparks per second could provide a penetrating audible signal in a crystal receiver.

The Admiralty ensured the meticulous documentation of experiments and installations.

A. Separating transmissions and tuning

The Admiralty believed that only one powerful spark transmitter could operate at a time in each area, until Marconi demonstrated around 1900 that by 'tuning', more than one could operate simultaneously and be independently heard by suitably-tuned receivers. The concept of tuning had been previously discovered by Lodge [1], but it seems that because of the monopoly position allocated to Marconi, the Admiralty learned about and adopted the idea from Marconi.

'*A tune*' at 400 feet (e.g. 2.5MHz) and '*B tune*' at 1025 feet (950kHz) were separated sufficiently for such simultaneous operation, and the Admiralty decided to add further '*tunes'* for their own use, at first with the intention that their wavelengths would be kept secret.

They designated *R*, *S*, *T*, *U* (*R*=378kHz, *S*=298kHz, *T*=234kHz, *U*=196kHz) by 1907 [2], chosen so that there would be no interference between them when maximum power was used at 2 miles separation. Several more '*tunes*' were added later.

B. Measuring the frequency and knowing the 'tune'

Setting up the transmitters and receivers to the correct 'tune' was not easy, and all equipment was subject to frequency drift during use. There was therefore a need for calibrated instruments to set up and maintain correct wavelengths. These were the first wavemeters,

The wide bandwidth of spark transmitters could be controlled by adjustment of the rate of decay of the train of damped oscillations which they generated, and for this instruments called decremeters were developed [3].

J.A. Fleming (University College London), who supervised the Cornwall end of the famous transatlantic radio communications of Marconi, is reported to have said:

"… The wavelength of the electric waves sent out from Poldhu Marconi station in 1901 was not measured because I did not invent my cymometer or wavemeter until October, 1904.." [4].

Prior to this wavemeters had been developed (e.g. by Dönitz, German patent date 4th April 1903) and perhaps even marketed commercially in Germany (for example by Telefunken – then called *Gesellschaft für drahtlose Telegraphie m.b.H., System Telefunken*, founded 1903 in Berlin).

The Dönitz wavemeter is described in a German Patentschrift [5] which explains how heating of a mercury thermometer indicates resonance, so the response time would have been long.

Soon Spark, Arc and Alternator based transmissions were all in use by the British Navy, and automatic receivers could print the Morse on paper strips. In some cases, additional means was provided to 'quench' each spark prior to the start of the next to improve audibility.

Alternators, usable only for the longer wavelengths, were capable of generating a single frequency (CW), which was keyed on and off to produce the Morse signal. However, simple crystal receivers could not decode such a signal, since they gave audible output only from the starting and stopping of each dot or dash. To overcome this, a beat-frequency oscillator was needed in the receiver, a facility not generally available until much later on. Instead, 'Interrupted Continuous Wave' (ICW) was used by having a buzzer which interrupted the transmission at an audio rate, so that what was transmitted was still a train of damped oscillations.

II. EARLY NAVAL WAVEMETERS

Fig.1 shows the circuit and drawing of a 1913 design of wavemeter, pattern 1492 [6]. A 1913 report states that 26 of these wavemeters were installed on ships 'at sea', which included HMS Hood.

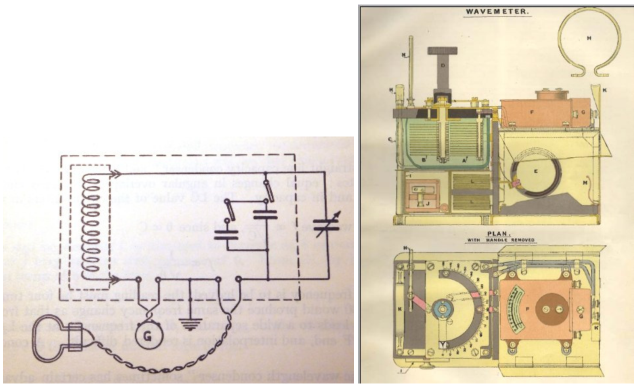

Figure 1. Circuit diagram of pattern 1492 wavemeter, and a magnifient drawing from Navy report [7]

Commonly a wavemeter was an integral part of the transmitter installation on a ship.
Despite the development of many more advanced wavemeters, variants of the simple but reliable Pattern 1492 stayed in use for many years. An Admiralty book of orders dated 5th November 1942 details the process to dispose of these and other obsolete wavemeters [8].

British equipment was calibrated in wavelength (in metres, or feet), the practice of using frequency arising much later.

III. EARLY BRITISH ARMY TELECOMMUNICATIONS

Muelstee describes [9] some 20 different spark transmitter sets used over 1914 to 1918, with ranges from 5 miles to 500 miles. These included small units for use in and around trenches to substantial heavy units such as The *Marconi Wagon Set* (1914), weighing 3 tons, and generating 1·5kW at the spark [10] . Fig.2 shows details of the spark unit of the Army *Forward Spark 20W B Mk.II Rear Transmitter (65metres)*.

Some later sets produced CW, using valves in the transmitter, including adoption of some RAF designs.

For setting up, the Army initially had Forward Sets B Wavelength Standard No.1, a very simple instrument for setting up spark transmitters, followed by Station Testers Mk.I and II, Fig.3 (1915), Forward Sets B wavemeter, Fig.5(a), (1917), also known as Forward Spark B wavemeter. The circuit diagram is shown inside the lid of the wavemeter and Fig.5(b) is extracted from a photograph of the lid.

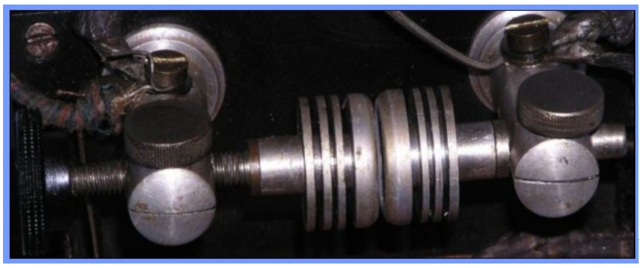

Figure 2. Spark unit of Army transmitter (Kurrajong Radio Museum)

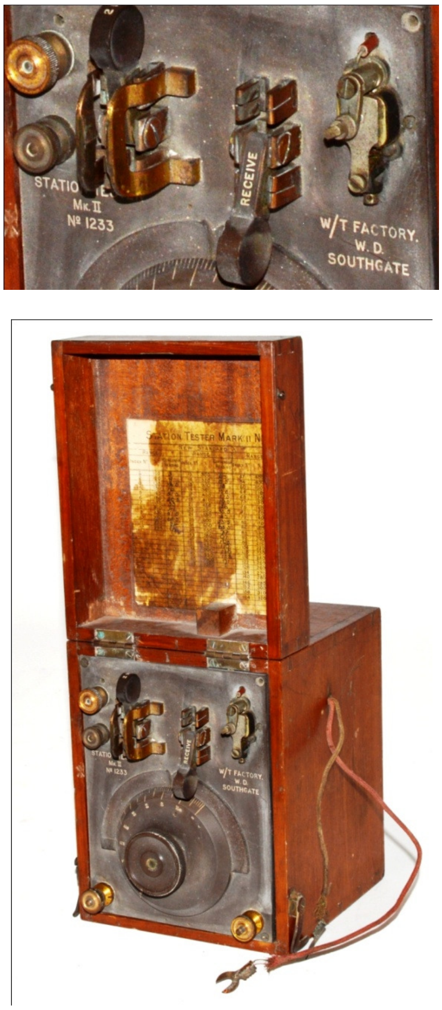

Figure 3. Station Tester Mk II, made in War Department factory, Southgate, London. (Photo: K. Thrower, taken in Royal Signals Museum, Blandford Forum)

Subsequently in WW1 the Army adopted absorption instruments called 'Townsend Wavemeters' (invented by J.S. Townsend at Oxford University [11]). These use a buzzer for frequency setting of simple receivers, and the resonant circuit is a variometer with a fixed capacitor. There were several models, of the same design but for different frequency ranges.

Later, in 1917, a heterodyne wavemeter for Army use was introduced [9], needed with the CW transmitters, apparently identical to one used by the air force (illustrated by Fig.6).

Fig.4 shows this wavemeter together with all the other units need to make a complete transmitter-receiver station [9].

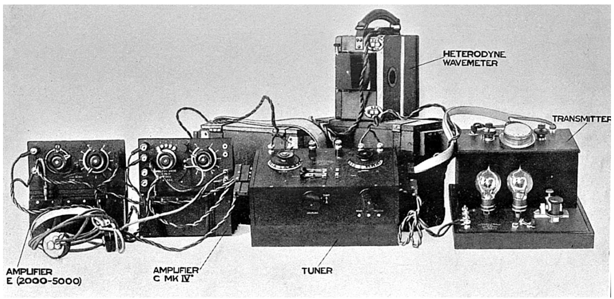

Figure 4. Army W/T set field 60W set with wavemeter

Telecommunications seems to have been of only moderate interest to the British Army "top brass" at this time, unlike the views expressed in the USA, where Brigadier-general Seriven, Chief Signals Officer in the US Army, is reported in 1916 as saying ".. *the enormous importance of radiotelegraphy in military affairs* .." is recognized by all army men and " .. *great attention has been given recently to this method of communication* .." [12].

IV. Early Wavemeters for aircraft applications

Aircraft requirements were rather different, and can be divided into equipment for use in a plane and equipment for use on the ground.

Initially the Royal Naval Air Squadron was under Navy control and the Royal Flying Corps under Army control, with effectively no cooperation. Against some opposition, in April 1918 the two were combined to form the Royal Air Force, under the new independent Air Ministry.

An early responsibility of the Royal Flying Corps was to use radio to report to ground troops their observations, in order to direct artillery fire.

The Royal Flying Corps adopted 'Townsend Wavemeters' with three models (Nos. 1, 2, 3) differing essentially only in their frequency ranges from 1000m to 4000m.

Particularly in a single-seater aircraft, it was very difficult for the pilot to fly the plane AND operate a Morse key! By 1917, aircraft R/T (speech) was beginning, and used for communications between two Bristol Fighter aircraft .

The wavemeter shown in Fig. 6 is from a document in the RAF Museum at Hendon [10], and the single valve used can be seen at the bottom left near the plug-in inductor for the 400-1400m range which is the square unit.

The document states "*The use of the 'beat' phenomena with CW makes working with the heterodyne wavemeter as easy as working with the ordinary wavemeter (Station Tester Mark II) in which a buzzer is used*".

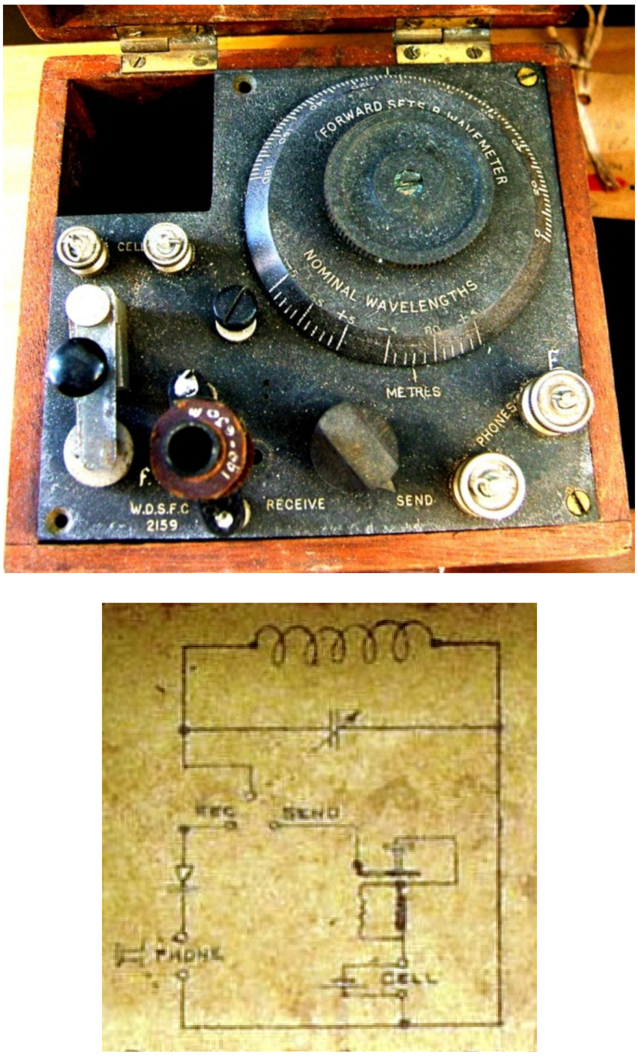

Figure 5. (a) Forward Sets B wavemeter, 65m and 80m (b) circuit diagram as shown inside lid

An early Royal Air Force wavemeter, W3, a 1918 design, covered 75–1000 kHz in four ranges. This was for use in aircraft, to adjust sets T21C and T22. It is basically a Townsend design. Fig.7 shows the circuit and the wavemeter. The RAF then also used what they called Syntonisers, which were heterodyne based instruments using a single thermionic valve, which they distinguished from Wavemeters, although the requirement was essentially the same. Fig.8 and Fig.9 show an RAF Syntoniser.

Fig. 10 shows one the RAF did call a wavemeter, which can be seen to be a Townsend type. They described Syntonisers as follows: "*These instruments are small generators of high-frequency alternating current which may, by adjustment of a variable condenser, be made to give out C.W. of any desired wavelength within their range*" [13].

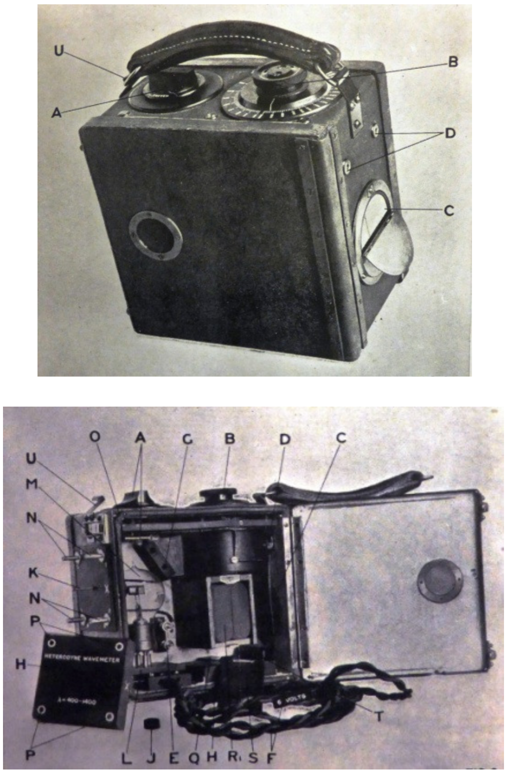

Figure 6. Heterodyne Wavemeter for aircraft uses

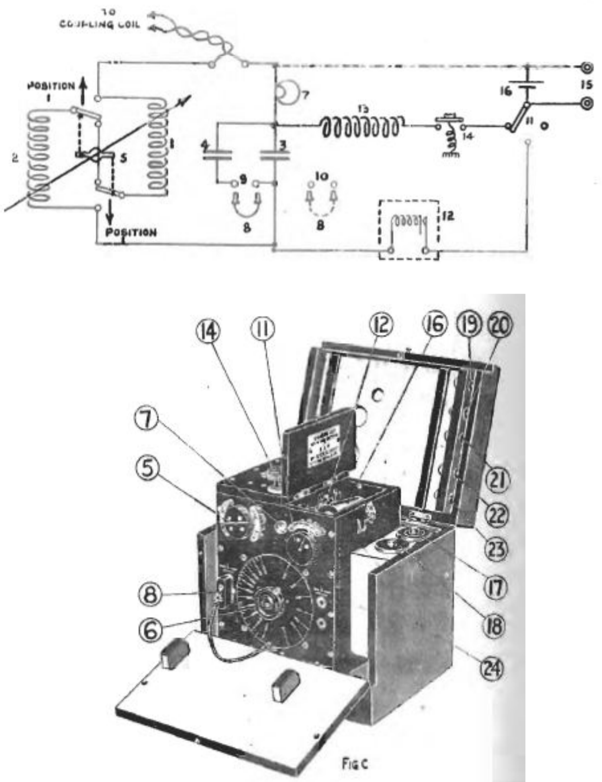

Figure 7. Circuit diagram of W3 wavemeter and an external view

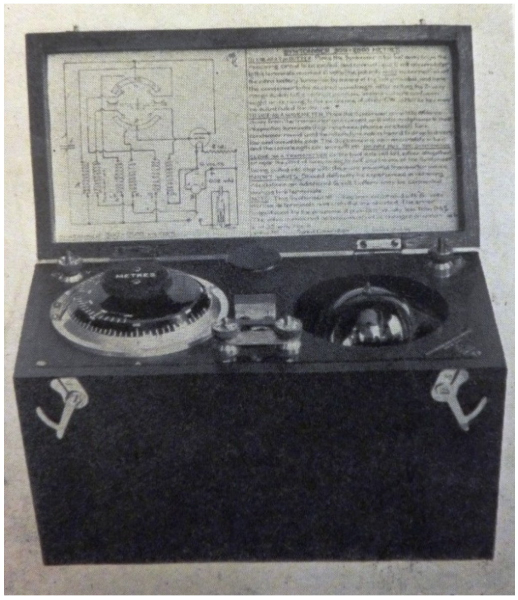

Figure 8. RAF Syntoniser 300-2500 metres

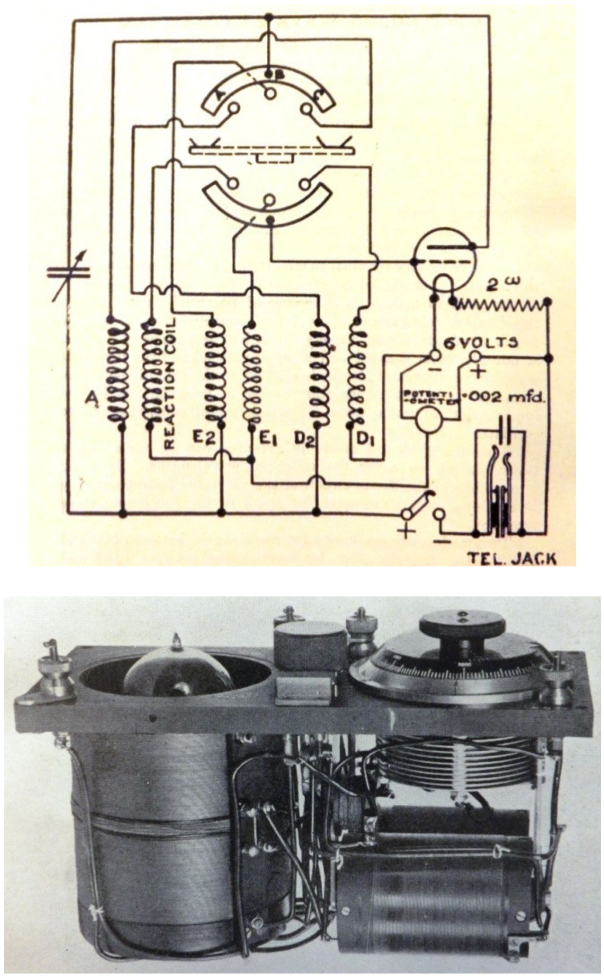

Figure 9. Circuit and internal view of Syntoniser, 300-2500 metres

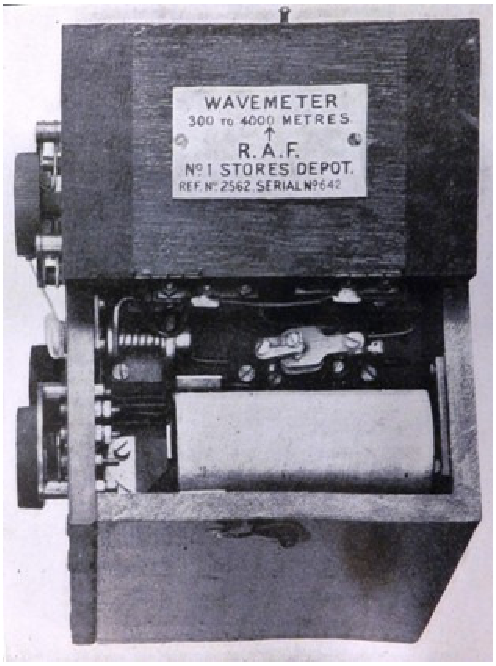

Figure 10. RAF Townsend-type wavemeter.

V. Wavemeters Types

The two principal kinds of wavemeter are the absorption type and the heterodyne type.

A. *Absorption wavemeters*

The simplest wavemeter comprises a calibrated resonant circuit which can be coupled to the transmitter under test, and an indicator of the signal strength in the resonant circuit. Commonly a continuously variable capacitor with a precision reduction-gear drive and perhaps a vernier scale was resonated with a fixed inductor. To provide different ranges, either plug in inductors were used or else different inductors switched into position by a range-switch. Some models used a variometer (continuously-variable inductance) with a fixed capacitor.

The first absorption wavemeters were passive, with a small filament lamp or in some cases a neon discharge tube to indicate the signal strength. Some used a thermocouple connected to a microammeter. Later, designs with a valve could be used to rectify the signal and produce an indication on an ammeter. Quartz crystals were also used occasionally to calibrate wavemeters at one spot frequency, since they have the property of glowing in response to signals at their resonant frequency.

The circuit simplicity of these early wavemeters belies the extreme care needed to devise and achieve switching and tuning arrangements and layout to meet adequate tolerances.

To give a linear relationship between angle of rotation and wavelength, variable capacitors require a non-linear shaping of their movable vanes, because of the square-root relationship between capacitance and wavelength at resonance [6]. Correct calibration of wavemeters was naturally important: the Admiralty sent wavemeters to the National Physical Laboratory where high-speed photography of the spark-train enabled the L and C calibration to be decided, a technique which the Navy also investigated [14].

Care is needed in using simple wavemeters with powerful transmitters: if coupled too closely, the lamp or indicating device can easily be destroyed, but, more importantly, false maxima are possible between closely-coupled resonant circuits tuned to the same frequency because the frequency response splits to a double peak with increased coupling (Fig.11). Circuit variations can easily result in the peaks being of unequal height. Misunderstandings can arise from this, with some users believing incorrectly that with a large and powerful transmitter, the largest of the two peaks must be at the transmitter frequency.

B. *Heterodyne wavemeters*

Non-linear mixing of a locally generated signal with the signal under test can provide an audio range beat-frequency signal, which decreases in frequency as the mixed signals' frequencies converge, becoming zero when the frequencies are the same. Operation involves adjusting the audible tone for 'zero beat'. Gross errors can arise from tuning in to a harmonic, so common practice was to first use an absorption wavemeter to get a rough indication of the frequency and then a heterodyne wavemeter to get as accurate a measure as possible.

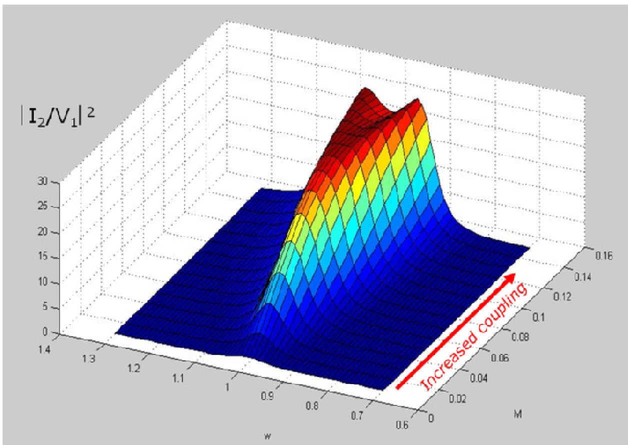

Figure 11. Double hump in frequency response of coupled resonant circuits

Although a passive instrument can be used to check a transmitter frequency, it clearly cannot set a receiver to a prescribed frequency, or check the calibration of a receiver frequency dial. An oscillator associated with a passive wavemeter provides a solution to this obstacle: the wavemeter is used to set the oscillator to the prescribed frequency, and then the receiver under test is tuned to the signal from the oscillator. The Navy used this method, and so wavemeter-oscillator pairs intended for use together were developed.

In the case of a heterodyne wavemeter, there is already an oscillator present in the instrument.

Often, heterodyne wavemeters had individually-printed calibration charts or tables, since to achieve good accuracy, each wavemeter had to be calibrated so as to relate its scale readings to actual frequencies.

The most unreliable components were thermionic valves so normally the first step in repair of military equipment was to replace valves. For wavemeters this was inadvisable, since replacing a valve or even moving internal components or wiring would require a re-calibration, to be done only in a laboratory. Opening up wavemeters in the field was therefore generally forbidden.

C. Frequency determination by counting

The requirements of a wavemeter can be met by 'counting', given an accurate standard of time. Measuring the time of a specified number of cycles of a waveform provides the frequency. However, the technology to do this at radio communication frequencies was not available until the mid-20th century.

VI. LATER WAVEMETERS FOR AIRCRAFT APPLICATIONS

The W37 (shown in Fig. 12) is an early (1925) RAF wavemeter, covering 500kHz–6MHz in 3 ranges. A buzzer produces damped oscillations, and a lamp or headphones is used for reception [15]. Although after the time period of WW1, it indicates the development route from the foundations laid down during the war.

Some early wavemeters could generate a audio-rate train of damped oscillations – simulating the output of a spark transmitter. In addition to a lamp for use when tuning a transmitter, the W37 shown in Fig.12 has a buzzer to emit damped oscillations, to check the tuning of simple receivers which would not respond to an unmodulated r.f. sinewave (not having a beat-frequency oscillator), but could be tuned to the buzzer-modulated r.f. signal. The buzzer is the round (brass-coloured) plug-in unit just below the centre on the front panel

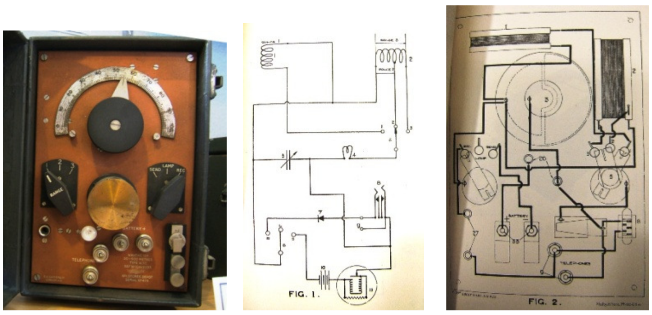

Figure 12. W37 Wavemeter: front, circuit-diagram, rear-layout

W66, for 3-15MHz, is a very simple absorption wavemeter, using a neon lamp to indicate resonance, intended for use in aircraft, for setting or measuring transmitter frequencies.

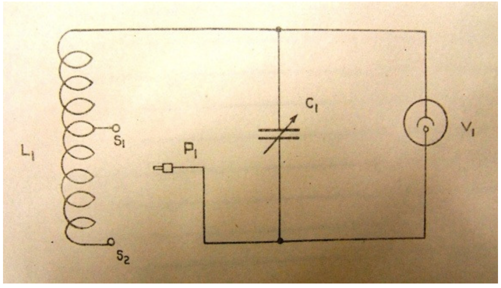

Figure 13. Circuit of W66

Another RAF wavemeter from the post WW1 period is the W69 (Fig.14), which has a triode valve to detect the signal, and illustrates the general appearance adopted by then for many RAF wavemeters.

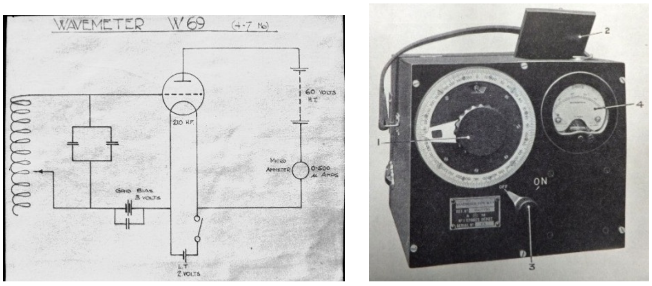

Figure 14. Single-valve used to detect r.f. signal (W69, 4-7MHz).

Some RAF wavemeters for ground use (e.g. not in aircraft), were provided with wooden tripods [16] including W75, W1081(Fig.15), and W1095. Fig.16 shows the W1081 circuit

The rapid radar advances during WW2 led to the development of many different wavemeters for the RAF, to meet the higher frequencies of RAF radar and radio systems. Fig.17 illustrates two much later RAF wavemeters, the widely used W1191, and the W1646 which has a magic-eye indicator (top left of front panel). W1191 had calibrated scales for each of its frequency ranges engraved on its dial, and was replaced by W1191A which relied instead on a calibration book, individually printed for each wavemeter made.

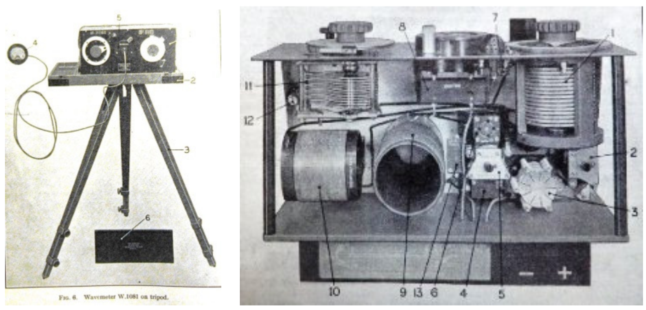
Figure 15. Air Force W1081 tripod and internal view

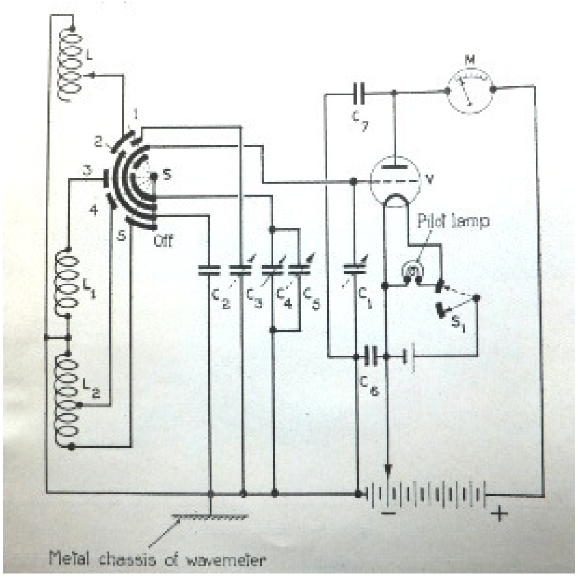

Figure 16. W1081 circuit diagram (135-500kHz & 3-15MHz)

Figure 17. W1191 and W1646 wavemeters

Even taking account of the wide range of needs, and the various frequencies to be catered for, the very large number of different military wavemeter designs is remarkable [17,18].

VII. Identification of Historic Wavemeters

A. *Care in the interpretation of Navy and RAF equipment identification numbers.*

Naval wavemeters are identified by G followed by a numeric code. The numeric sequence is not chronological. For example, G8 was a replacement for G12. Each wavemeter was designated a Pattern Number too.

Admiralty practice was to define 'outfits', designated GA, GB, GC, etc. which comprised a specified wavemeter together with other equipment needed to use it (for example, a designated oscillator, and perhaps a carrying box).

A prefix W was used for some Admiralty 'patterns'. For example, Wavemeter outfit GN comprises Pattern W2508 Wavemeter G73 and Pattern W3988 Oscillator G42, and Wavemeter G60 is Pattern W839.

Later RAF radio equipment generally comprised a 'type' letter followed by a number. Most RAF wavemeters have a designation starting with W. A single numerical sequence was used for the various types of equipment. Thus T1154 and R1155 were, respectively, a transmitter and a receiver. Missing numbers do not easily provide indication of an unknown wavemeter

It is therefore easy to confuse an Admiralty unit with an RAF unit. RAF equipment also has a stores reference of format 10x/nnnn. Thus, wavemeter W42 is 10A/7252.

Conclusions

Wavemeters were essential in the first three quarters of the 20th Century, and the foundations for their designs were laid in the years before and during World War One. Their designs reflect the technology of their day and the rapid progress in telecommunications stimulated by urgent military needs.

Preservation in military and other museums and their design documents and user manuals in national archives, etc. provides an important resource for the understanding of later developments.

Acknowledgements

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