WIRELESS *for the* WARRIOR

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(Incorporating Wireless Sets No. X32D and 34, SIS Mk.17 and Mk.18)

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The Pamphlet Series.
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March 2022

About this pamphlet.

In this retyped but otherwise unchanged reproduction of S.E.E. Report No. 798 were the results of the first investigations at S.E.E. on the possible application of frequency modulation to British military radio communication. This unique document gives evidence that frequency modulation for British Army communication was very seriously investigated from 1941 onwards. An original of this document is held in the archive of the Royal Signals Museum, Blandford Camp, Blandford Forum, UK.

In the appendices of this pamphlet is other relevant information such as a list of additional documents along with photographs, technical data and circuit diagram of an experimental wireless set used during the investigations.

In the second edition of this pamphlet is added 'Electrical and Mechanical Engineering Regulations (Telecommunications)' A 013, where principles, practical applications and a basis was laid for future use of FM in the British Army. In addition some known details are given on the aborted development of Wireless Set No. 34, and the operational use of FM from 1943 onwards in the SIS 'Ascension' system.

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S.E.E. REPORT NO.798

NOT TO BE PUBLISHED

SUBJECT :- INTERIM REPORT ON THE APPLICATION OF FREQUENCY MODULATION TO SERVICE USE

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AT:- SIGNALS EXPERIMENTAL ESTABLISHMENT
WARNHAM COURT, NR. HORSHAM, SUSSEX.

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Interim report on the application of frequency modulation to service use.

Summary.

The advantages claimed in America for frequency modulation as an alternative to amplitude modulation for telephony have been critically examined. They have been found to be attainable with conventional circuits and very convincing in the field. Frequency stability requirements, though more stringent than on amplitude modulation, can be met without undue complication.

It appears that for Service use quite a low value of deviation is frequently desirable. On the 2-8 Mc/s band frequency modulation with a deviation of +- 5 kc/s has been tested against amplitude modulation with the same input power. It was found that a considerable improvement was obtained with frequency modulation, this improvement being most marked in the presence of strong impulse noise such as ignition interference.

A description is given of the work now in progress by S.E.E. and by the Trade.

1. Introduction.

The characteristic difference between F.M. and A.M. is that on F.M. application of modulation causes the frequency of the radiated wave to vary, instead of its amplitude as on A.M. This variation occurs at the modulation frequency and the extent of the variation is proportional to the depth of modulation, or the loudness of speech. Now on A.M. loudest speech corresponds to a variation in the amplitude of the emitted wave between 0 and twice its unmodulated value. On F.M. however, it is obviously impracticable to vary the frequency to such an extent and an arbitrary figure must be chosen to represent the maximum extent of the frequency swing which may occur. This figure is known as the deviation of the system and is defined as the maximum swing of frequency to either side of the carrier frequency. Typical values of deviation are from 5 to 75 kc/s. The properties of the F.M. system depend markedly on the value of deviation used and this value must therefore be chosen so as best to fit the specific requirements of the system, and the sender and receiver designed accordingly. F.M. therefore differs from A.M. in the design of the sender and the receiver and also in certain propagational features which are described below.

Up to the present, wireless telephony communication has been very largely carried out by means of A.M. Recent work in America and elsewhere has, however, shown that the different properties of F.M. make it in some ways more suited to Service use. An investigation of the applicability of F.M. to Military requirements is now in progress; some of the results already obtained are described below.

S.E.E. are investigating the properties of F.M. mainly in order to become familiar with the technique and to obtain data for future use, while the Trade have been asked to design various F.M. sets which if successful could after a little development serve as prototypes for production.

Before describing in detail the work in progress at S.E.E. and by the Trade it will be convenient to refer to the principal features of F.M.

2. Principal Features of F.M.

(1) F.M. enables an increased sender efficiency to be obtained, so that for a given radiated power both sender power consumption and size are considerably reduced while the receiver is only slightly more complicated.
The reduction in battery consumption thus afforded may be of considerable value.
The saving in size increases with the power of the sender, but is slightly off-set by the fact that one more stage is necessary in the receiver on F.M. than on A.M.

The gain in efficiency results from the fact that with F.M. and R.T. sender may be modulated at low level with subsequent power amplifiers operating at full efficiency. This is not possible with A.M. With a given output valve an increase in power output of about four to one is obtainable compared with grid modulation, with an associated gain of two to one in efficiency. Alternatively for equal sender inputs the radiated power is twice as great on F.M. as on A.M.

It should be pointed out that since C.W. is not a modulated wave no increase in sender efficiency can be obtained by the use of F.M.

(2) The F.M. receiver is less responsive to noise than the A.M. receiver, so that when a signal is being heard on A.M. above a background of noise the signal on F.M. will appear to suppress the noise, even though the signal to noise ratio at the aerial is the same on each system. Thus a signal which is just readable on A.M. becomes readily so on F.M.

This is especially noticeable when the source of noise is impulse or ignition interference. As this type of interference (generated by vehicle, atmospherics, etc.) frequently determines the useful range on A.M., greater ranges will be obtained when F.M. is used. Alternatively the problem of vehicle-interference suppression will be considerably eased.

The theoretical basis for the noise suppression of F.M. is well established. Briefly it may be stated that when two carriers or a carrier and noise are being received on an F.M. receiver the stronger signal "demodulates" or suppresses the weaker, so that the receiver tends always to respond to the stronger signal. This is discussed further in 5 (2) and 5 (3) below in relation to the capture and threshold effects.

3. Choice of Operating Frequency.

The features described above were recently confirmed in America and the suitability of F.M. mobile communication demonstrated. For the most part frequency sets on the 30-40 Mc/s waveband were used, with a radiated power of 25 Watts, and a deviation of between 15 and 20 kc/s. Before seriously proposing the possibility of F.M. for Service use in this country it was however, necessary to obtain further knowledge on the subject.

In particular it was necessary to decide in which frequency bands F.M. would give the greatest advantage. It was originally thought that in order to obtain any worthwhile advantage from F.M. it would be necessary to use an exceedingly large deviation. This would have implied that each station would occupy considerably more ether-space than on A.M., so that F.M. could only be used on high frequencies.

On the other hand, if F.M. was to be used for vehicle communication, to which it appeared most suited, propagation characteristics rendered the use of high frequencies undesirable. Also from the standpoint of a possible change over to F.M., it appeared desirable to work on the normal A.M. band of 2-8 Mc/s. This would not be possible with high deviation F.M.

Work at S.E.E. has shown that for communication purposes considerable advantage can be obtained from the use of narrowband F.M., i.e. F.M. with quite a low deviation, of the order of +- 5 kc/s. This investigation has therefore centred largely around the Army bands of 2-8 Mc/s and 20-30 Mc/s.

The main questions to be settled by the investigation were the following:

(1) Circuit design:

The method of producing and receiving F.M., their reliability and complexity. Design of auxiliary test apparatus, and ease of maintenance etc.

(2) Performance in the field:

Extent of the improvement given by F.M. in the field, the optimum deviation and usable carrier frequencies. Effects of interference noise, etc.

These points have now been largely answered, and the conclusions with respect to circuit design and field performance are described below in 4 and 5 respectively. The present Trade position is covered by 6.

4. Circuit design.

Work on the design of F.M. Senders and receivers has shown that the circuits involved are straightforward and present no undue difficulties in alignment or in maintenance. While it is not proposed to consider in detail the circuits used, mention will be made of some of their more important features.

(1) Senders.

F.M. senders fall into two classes, namely the crystal controlled phase modulated type and the frequency modulated self-oscillator type. In comparison with the crystal controlled type, self-oscillators are inherently more liable to frequency drift but are considerably simpler and more flexible.

The modulator circuit used with self-oscillators usually consist of a "reactance valve" so connected across the oscillator tank circuit as to look like a reactance whose magnitude is varied in sympathy with the modulation applied to its grid. Such a circuit readily gives linear low-level modulation, but tends to reduce the oscillator stability. This question of stability is one of the governing features of F.M. sender design, and is being investigated in some detail.

Stabilised supplies may be used, while several circuits are available for increasing sender stability. A two valve reactance element is one method, in which the effect of variation of reactance tube parameters with supply voltages etc, is balanced out. Alternately, the sender oscillator may be locked to the receiver frequency-changer oscillator by means of a standard automatic frequency control circuit. Such a circuit is directly applicable to F.M. because the two elements necessary - the reactance tube and the discriminator are already present in the sender and the receiver respectively.

The mechanical or short-term stability of the oscillator must also be made as high as possible since any vibration etc., causes F.M. which will appear directly in the receiver. This may be achieved by rigid mounting of wiring and components, isolation of sources of mechanical vibration etc., etc.

The single-frequency sets which have been used for American Police communication by F.M. are of the crystal-controlled phase-modulated type. Phase modulation is a particular form of F.M. and may be converted into pure F.M. by means of a correcting network. A two-tube balanced modulated is commonly used which does not reduce the frequency-stability of the sets. More valves are however necessary than with the reactance-tube modulator and the size of the sets is increased accordingly. Also, the setting-up adjustments become more involved. S.E.E. have been able to perform field trials on four such sets, and their performance is described in 5 (1) below.

(2) Receivers.

The general design of F.M. receivers is now fairly standardised. It is customary to use a superheterodyne circuit in which the second detector is replaced by the combination of amplitude limiter and F.M. detector or discriminator.
Experience with receiver construction has shown that: -

a) The optimum conditions for limiting depend on the received signal strength. For Service use it is best to design for efficient limiting at quite low signal strengths. Owing to space requirements a single stage limiter is generally used.

(b) It has been found that the usual discriminator circuit described by Foster and Seeley, (P.I.R.E., March '37) is very simple, very sensitive and easy to align. Provided reasonable care is taken in the layout, excellent results may be obtained with a form of construction little more involved the standard I.F. Transformer.

(c) In F.M. receiver design the same care must be taken of stability of the oscillator as with the sender. Both the long and short-term stabilities must be made as high as possible.

(d) The use of a low pass audio filter considerably improves the signal/noise ratio of the received signal. Satisfactory results may be obtained with quite simple air-core coils.

Mention may be made here of the fact that the background noise heard on an F.M. receiver, is of higher pitch than on A.M. This is advantageous since for the same degree of noise, less loss of intelligibility is caused by the higher-pitched F.M. background.

4. Circuit design. (Cont.)

(3) Maintenance.

Although considerable auxiliary apparatus has been developed in the present work, it may be stated that for the maintenance of F.M. gear little apparatus is necessary beyond that normally used on A.M., and the alignment of the circuits is equally straightforward.

All the necessary measurements can be made on the following three instruments:

(a) Receiver alignment and sensitivity measurements appear to be very simply carried out on an A.M. signal generator, and the only use of an F.M. signal generator would appear to be to provide a dynamic test of the overall response of the receiver. For this purpose a two-valve adaptor unit consisting of a frequency changer, the local oscillator of which is frequency-modulated by a reactance valve, may be all that is necessary. The unit would be applied to frequency-modulate the output of the A.M. signal generator. Design of such a unit is in hand at S.E.E.

(b) A simple high-impedance D.C. voltmeter is also necessary for lining up the discriminator circuit. Such a unit may be quite simply constructed, and will require one valve.

(c) Radio-frequency measurements on the sender are carried out in the same manner as on A.M. Deviation may be measured by Crosby's method (R.C.A. Review April '40) but this method is not suited to production testing. An F.M. test-set consisting of a low-sensitivity receiver of wide band-width has been constructed at S.E.E. and found very useful. The sender is modulated at any frequency and tuned in on the test set. The following measurements may then be made.

(i) Deviation may be read off a calibrated scale.

(ii) Linearity of modulator, with or without pre-amplifier, may be measured as either frequency or input voltage is varied.

(iii) The modulated output may be aurally monitored.

(iv) Distortion may be determined by coupling an oscillograph or wave-analyser to the output terminals

5. Range trials.

Trials in the field have largely confirmed the result which had been claimed in America, F.M. giving increased range and considerable immunity from noise interference.

Direct comparisons of sets using various deviations between 5 and 75 kc/s and corresponding bandwidths were first made, using the 20-30 Mc/s band. It was found that the general results obtained with quite low deviations were very little worse than those obtained with large deviations. In these tests the receiver bandwidth (at 6 db down) was between 2 and 2.5 times the sender deviation, it having been established that this was the optimum ratio. A working range of 2-3 miles between stationary vehicles was obtained with an aerial power of 1 watt and a quarter-wave vertical aerial.
The success obtained with low deviations suggested immediately that F.M. might be directly applicable to the 2-8 Mc/s band. A sender and receiver have therefore been designed so as to work on this band. The sender deviation is + 5 kc/s and the receiver bandwidth 10 kc/s, which is approximately the value used for Army A.M. sets on this band. The sender input power was made equal to that of Wireless Sets No. 19 and strictly comparative tests of the F.M. sets have been made against Wireless Set No.19. The results of these tests, which have proved extremely interesting, are described below.

(1) Ranges obtained.

(a) 2-8 Mc/s band.

Both F.M. and A.M. sets were mounted in vehicles using 8' rod aerials and the same aerial coupling system. On A.M. a limit range of 12-15 miles was obtained and on F.M., 16-20. These figures are based on a statistical examination of results taken on various frequencies and at various sites, and should be read in conjunction with (2) below. It would appear that the F.M. link is approximately 10 db stronger than the A.M. link, but this figure has not been directly measured.
The receiving vehicle was completely unsuppressed and on A.M. range of only 4-6 miles was obtained on the move while on F.M. ranges of 8-10 miles were obtained.

Finally it may be stated that in no case yet encountered has the A.M. link been more intelligible than the corresponding F.M. link.

The results of these trials are summarised in Table I.

(b) 20-30 Mc/s band.

While these tests were in progress, advantage was taken of the opportunity to test the fixed frequency American "Motorola" sets referred to in 4 (1) above. These sets work on 24 Mc/s and use a 7' rod aerial with an aerial power of about 25 watts. Ranges of up to 20 miles were obtained over the same country, the terrain being moderately flat. The deviation used is 15 kc/s and the sets exhibit remarkable immunity from ignition interference. Compared with the 2-8 Mc/s F.M. link, the Motorola link was slightly stronger. The country used for the tests was moderately flat, and over hilly country this result may be reversed on account of the high frequency of the Motorola sets.
The Motorola sets show a considerably greater degree of immunity from noise than the 2-8 Mc/s set.

It may be pointed out that the Motorola sets work into a greater wave resonant aerial and the input power to the last stage is 60 watts as compared with about 15 watts for the 2-8 Mc/s set.

An interesting feature of the Motorola receivers is the use of a 'squelch' circuit for eliminating the background noise when no carrier is being received. As the Motorola sets normally work into a loudspeaker this feature is very pleasant and was found in this case to be extremely useful. It is extremely doubtful whether 'squelch' would be desirable on sets working only into earphones. It must also be pointed out that a relatively complex circuit is used to produce the squelch action while some loss in sensitivity must occur unless some form of on/off switch or other control is provided.

(2) Threshold Effect.

It was mentioned earlier that on F.M. a strong carrier tends to suppress the background noise of the set. As the range is increased this noise suppression is maintained until the peak noise strength is equal to the carrier strength.
Beyond this point, called the improvement "threshold", the signal/noise ratio rapidly deteriorates. On A.M., this effect is absent, and as range is increased the signal grows progressively weaker until it is unreadable.

The existence of the improvement threshold produces two effects:

(a) If two A.M. sets are being worked at slightly less than limit range, signals will be readable but only with difficulty above the background noise. On F.M. under similar circumstances, noise will be largely suppressed and the signal far more readily readable.

(b) On F.M., ranges appear to be far more sharply defined than on A.M., and in some cases this may cause loss of contact, since although the operator may be at limit range he will still receive an apparently powerful signal. However the fact that the threshold always occurs beyond the A.M. working range largely compensates for this effect.

(3) Capture Effect.

This is the suppression of a weaker signal by a stronger one as mentioned in 5 (2) above. It is responsible for the fact when two signals on the same frequency differ by more than about 6 db only the stronger on is heard. The consequence of the capture effect have been most closely studied at recent U.S. Army manoeuvres where a large number of F.M. sets (including the Motorola sets referred to in 5 (1)) were used these were all set up on exactly the same frequency and their service ranges frequently overlapped.

A rigid operating system was used whereby each signal was repeated until acknowledged. As soon as the operating technique was mastered it was found that although frequent cases of capture occurred, no difficulty was caused, and the scheme was very highly commended.

It might be expected that the capture effect would render F.M. receivers more susceptible than A.M. to jamming or C.W. interference, but tests with both locally produced C.W. and fortuitous interference have shown that this is not so. See Table II.

(4) Multipath Transmission.

When the radiated signal passes from sender to receiver over two or more distinct paths (e.g. by ground-wave and by sky-wave) distortion may occur. Tests in America have shown that on F.M. this distortion is more frequent and more severe than on A.M.
Very few listening tests have however been made, although preliminary narrow-band observations have recently been carried out at S.E.E., on a frequency of 5.5 Mc/s and with a deviation of +- 5 kc/s. The range was 30 miles, and it appeared from previous tests that multipath transmission was to be expected. The distortion was not appreciable on speech, although fading did occur and with tone modulation some distortion was visible on a oscillograph.
These tests were however not extensive and it may be that under different conditions severe distortion will be obtained. According to American information phase modulation gives practically no more distortion than A.M. This is reasonable since the sideband spectrum of a phase modulated wave is not radically different from that of an A.M. wave. Further knowledge on the subject of multipath transmission is very desirable, and it is hoped to continue the tests shortly.

5. Range trials. (Cont.)

(5) M.C.W. Reception.

It has been shown that F.M. increases the useful R.T. range to the point were the signal becomes lost in noise. The M.C.W. range is therefore likely to be little greater than on R.T., although some advantage may be obtained from a tuned audio filter. Tests on M.C.W. by F.M. are now proceeding.

(6) F.M. and A.M. working

Although it was found possible to receive F.M. on A.M. receivers and sometimes vice-versa, this entails difficulties in operation and a loss in efficiency. The full advantages of F.M. will only be realised if both F.M. senders and F.M. receivers are used. Hence if a changeover to F.M. is contemplated it will be desirable to have during the change-over periods sets capable of either F.M. or A.M. working. Further information on the reception of F.M. by A.M. receivers is very desirable.

(7) Operation.

On F.M. inaccurate tuning causes distortion and reduces the signal/noise ratio if noise is present. An accurate netting system is therefore necessary. Methods of netting on F.M. differ slightly from those used on A.M., but have not yet been fully investigated.

6. The Trade Position.

The trade are designing various 5 watt, 25 watt and 350 watt sets. From two to six of each set will be built. The first two of the 5 watt sets have recently arrived at S.E.E. for test. The reminder are expected during the next six months.

(a) E.K. Cole Ltd., and Pye Radio are both independently considering the design of a set to be interchangeable with the present Wireless Set No. 19 and to provide similar facilities with alternate narrow-band F.M. and A.M. working on 2-8 Mc/s.

(b) Mullard Valve Company have already produced two sets with an aerial power of 5 watts on the 20-30 Mc/s band and a deviation of +- 40 kc/s. These sets are transceivers, the sender oscillator being controlled from the receiver oscillator by means of an A.F.C. circuit. The sets fit no immediate Military requirement but will be of considerable technical interest. Two more sets are being produced.

(c) G.E.C. Ltd., are developing two 25 watt and two 350 watt sets. This 350 watt set is primarily intended for use in A.C.V.'s for long range R.T. working. Narrow band F.M. and alternative phase modulation will be provided. Carrier exaltation circuits in the receiver may be tried with a view to combating selective fading. The frequency bands will be 20-30 Mc/s for the 25 watt and 2-12 Mc/s for the 350 watt sets.

(d) Murphy Radio are designing a 5 Watt set covering the frequency bands 2-8 Mc/s and 20-30 Mc/s with narrow-band F.M. and A.M. on all bands. This set will give similar facilities to Wireless Set No. 22 now under development and will be interchangeable with it.

(e) E.M.I. Ltd. are designing a 25 watt F.M. set to work on 20-30 Mc/s. This set is largely investigational and incorporates several experimental features. These include variable deviation, +- 5, 10 and 25 kc/s, crystal or controlled self-oscillator operation, push button tuning with six preset frequencies and adjustable squelch control (this feature silences the receiver background noise when no carrier is being received).

(f) S.T. and C. Ltd., have submitted proposals, but as requirements have changed they have been asked to consider an alternative scheme.

7. Conclusions.

An investigation of the applicability of F.M. to Army R.T. communications has led to the following conclusions:

(1) F.M. shows the following advantages:

(a) For a given power an increase of about 25% in range is obtained.

(b) F.M. offers considerable immunity from interference, especially vehicle or impulse noise. The problem of vehicle interference suppression is therefore very considerably reduced by the use of F.M.

(2) These advantages are maintained even with deviations as low as +- 5 kc/s. Thus it is possible to use practically the same channel-width on F.M. as on A.M.

(3) The circuit necessary to produce and receive F.M. offer no difficulties.

(4) Maintenance is straightforward and very little auxiliary apparatus is necessary.

(5) The advantages given by F.M. are largely restricted to R.T. Operation.

(6) The advantages have only been verified for ground-wave working. If on any set considerable sky-wave working is likely it may be desirable to design the set to work on both frequency modulation and phase modulation.

(7) For pack sets or other low-power equipment, although the saving in battery power and freedom from noise will still be obtained, the increased receiver complexity may make the overall size of the set greater than on A.M. This increase in size and weight may outweigh the advantage to be gained in battery consumption.

(8) On F.M., inaccurate tuning causes distortion. This, taken with the increased susceptibility to drift of the sender, implies that an accurate netting system is essential.

(9) While A.M. receivers will receive F.M. signals, the noise suppression effects are lost and the received signal may be distorted. It will in general not be possible to receive A.M. on an F.M. receiver. However if narrow-band F.M. is used it will be possible to provide alternative A.M. and F.M. reception with little extra complication.

(10) It thus appears that F.M. is particularly suitable as a means of providing R.T. communication between vehicles, since both the interference from the vehicle and also that from outside sources are largely suppressed.

TABLE I.

Signal strengths obtained with Wireless Set No.19 and F.M. set of equal input power under identical conditions and with no external interference.

NOTE: The R strengths given are estimated values, averaged in some cases over many observations. They illustrate the noise-suppression features of F.M. referred to in 5 (2) above.

Mileage	Frequency	Received A.M. signal	R Strength		Received F.M. Signal
8 ½	5,5	Readable with slight difficulty	R6	R8-9	100% readable
11 ½	5,5	100% readable	R7	R8-9	100% readable
11 ½	3,5	100% readable	R7	R9	100% readable
13 ½	3,5	100% readable	R8	R9	100% readable
14	3,5	100% readable	R7	R9	100% readable
15	3,5	25% readable	R4	R9	100% readable
16 ¼	3,5	25% readable	R3	R7-9	100% readable
17	5,5	Unreadable	R2	R7	100% readable
18 ¼	3,5	25% readable	R2	R6	100% readable
18 ½	3,5	Unreadable	R2	R8	100% readable
19 ½	3,5	No signals	Nil	Nil	No signals
20	3,5	No signals	Nil	R1	Unreadable
20 ¼	3,5	Unreadable	R1	R5	100% readable

TABLE II.

Effect of interference on A.M. and on F.M.

NOTE: The wanted signal was transmitted either on Wireless Set No.19 or on the equivalent F.M. sender, both sets using the same input power and having been netted to the same frequency.

Mileage	Frequency	Interference	Received A.M. signal	Received F.M. Signal
8 ½	5,5	CW	Unreadable	Just readable
11 ½	3,5	CW	Readable	Readable
11 ½	5,5	CW	20% readable	100% readable
13 ½	5,5	Strong CW	No signal	Signal present but unreadable
13 ½	5,4	CW	25% readable	100% readable
14	4,5	CW	Readable with difficulty	100% readable
14	5,5	CW	Unreadable	100% readable
15 ½	4	Strong CW	Unreadable	Unreadable
16	3,5	CW	Unreadable	100% readable
16 ½	4	Strong carrier	Unreadable	Unreadable
17	6	Strong RT	No signal	No signals

APPENDIX 1

Function of the SEE/SRDE organisation till its move to Malvern.

(Partly retrieved from: *SRDE, Function and Organisation*, written in 1963.)

The Signals Research and Development Establishment (SRDE) had its origin in the Wireless Telegraphy Experimental Station, which was formed at ALDERSHOT by the Royal Engineers in 1903 following the invention of wireless telegraphy at the turn of the century. This Section, which was quite small at the time, was was transferred to WOOLWICH DOCKYARD and linked with the Inspectorate of RE Stores in the early days of the first World War and then, in 1916, became the Signals Experimental Establishment (SEE) located on WOOLWICH COMMON not far from the Royal Military Academy.
It was a War Office Establishment whose basic objectives and responsibilities were not very different from those of SRDE at the present time, except that it included sections dealing with gun sound ranging and sound location of aircraft. These sections moved away in the early 1920's to the Air Defence Experimental Establishment at BIGGIN HILL, leaving SEE to look after the needs of the newly formed Royal Corps of Signals.

Army Wireless Telegraphy had made enormous strides by the end of the 1914-1918 War, but it was handled by a relatively small number of skilled specialists numbering not more than about 2000 for the whole British Army. In contrast, the Royal Corps of Signals numbered 150,000 in the Second World War, and these were supported by a large number of REME personnel.

By the outbreak of World War 2, the Establishment in common with all research and Development activities was transferred from the War Office to the Ministry of Supply and was renamed the Signals Research and Development Establishment.
After a partial evacuation to HORSHAM in 1941/42 it was moved to CHRISTCHURCH in 1943. In 1959 this Establishment was transferred to the Ministry of Aviation, on the close down of the Ministry of Supply.

The principal tasks of the Establishment were research in the field of communications, and the development of ground communications requirements required by the Army and RAF. The Establishment was however also conducting research and development in certain other fields of which the most important were satellite communications, quantum electronics and visual aids.

S.R.D.E was moved to Malvern in 1980 and lost its identity when it was amalgamated with (RRE) Royal Radar Establishment and (SERL) Services Electronics Research Laboratories to form (RSRE) Royal Signals and Radar Establishment. In April 1991 RSRE amalgamated with other defence research establishments to form the Defence Research Agency, which in April 1995 amalgamated with more organisations to form the Defence Evaluation and Research Agency. In June 2001 this became independent of the MoD, with approximately two-thirds of it being incorporated into QinetiQ, a commercial company owned by the MoD, and the remainder into the fully government-owned laboratory DSTL

APPENDIX 2 Wireless Set No. X32D

Wireless Set No. X32D

Country of origin: England

DATA SUMMAY

Organisation: British Army.

Design/Manufacturer: SRDE/Pye Radio

Year of Introduction: 1942.

Purpose: Experimental set to obtain comparisons between AM and FM communication.

Receiver:

- **Circuit features:** RF, mixer/LO, 2xIF, limiter IF for FM, discriminator, detector, BFO, AF.
- **Frequency Coverage:** 2-8MHz in two ranges: 2-4MHz and 4-8MHz. CW, FM and AM voice.
- **Intermediate frequency:** 460kHz.

Transmitter:

- **Circuit features:** Master oscillator, FM modulator, driver, limiter, RF PA.
- **Frequency coverage:** 2-8MHz in two ranges: 2-4MHz and 4-8MHz. CW, FM and AM voice.
- **RF output:** 10W CW/FM.
- **FM maximum deviation:** ±5kHz.

Aerial: Standard No. 22 Set rods and wire aerials.

Power Supply: (No. 19 Set) Power Supply Unit No. 1 Mk.III.

Weight: 16½ kg. (Set only)

Sizes (cm): Height: 20, length 43, width 30. (Set only)

References:

- Wireless for the Warrior, Volume 1, Wireless Sets 1 to 88, Louis Meulstee, ISBN 1898805 08 3, 1995.
- EMER's Tels F 370/1, Dec. 1944.
- SRDE Handbook No. 445, Wireless Set No. X32D, Nov. 1943.
- SRDE Handbook No. 574B, Wireless Set No. X32D, Provisional Working Instructions, May 1945.
- SRDE Handbook No. 575A, Wireless Set No. X32D, General description and maintenance, June 1945.

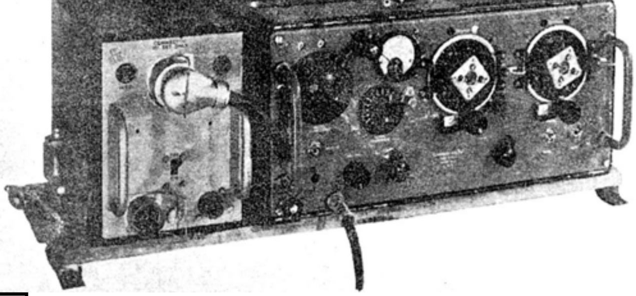
Remarks

Wireless Set No. X32D was an experimental set to obtain comparisons between AM and FM, carried out by the Signals Experimental Establishment. It was produced in a very small quantity and not intended to be issued for operational use.

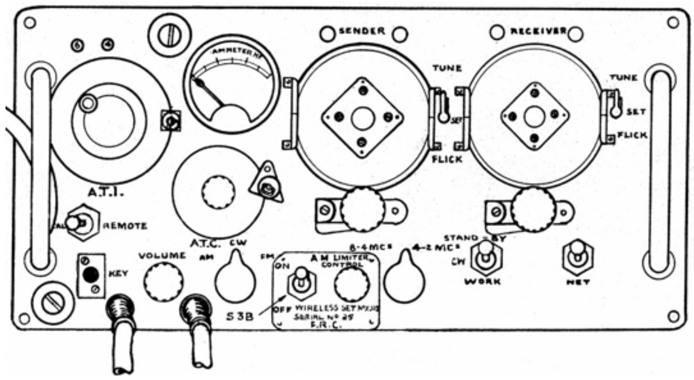
The set comprised a combined transmitter/receiver and a No. 19 Set power supply unit. Based on Wireless Set No. 22, having the same dimensions and general appearance, it had standard 6.3 Volt type valves opposed to the 2 Volt valves in the original set.

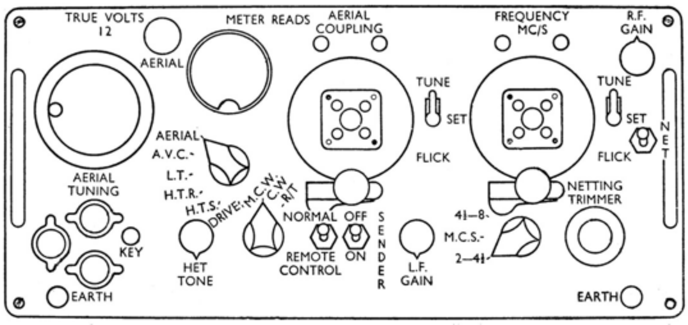
The No. X32D could operate on AM, FM and CW.

Two versions of the WS No. X32D were produced, with and without an AM noise limiter.

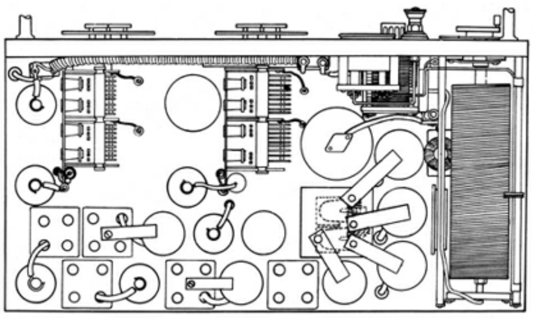


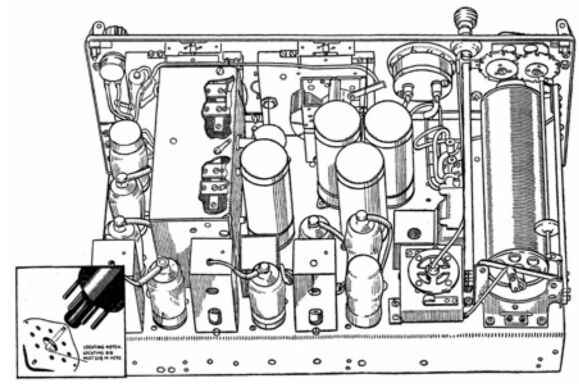
An early version of Wireless Set No. X32D without a later added AM noise limiter.



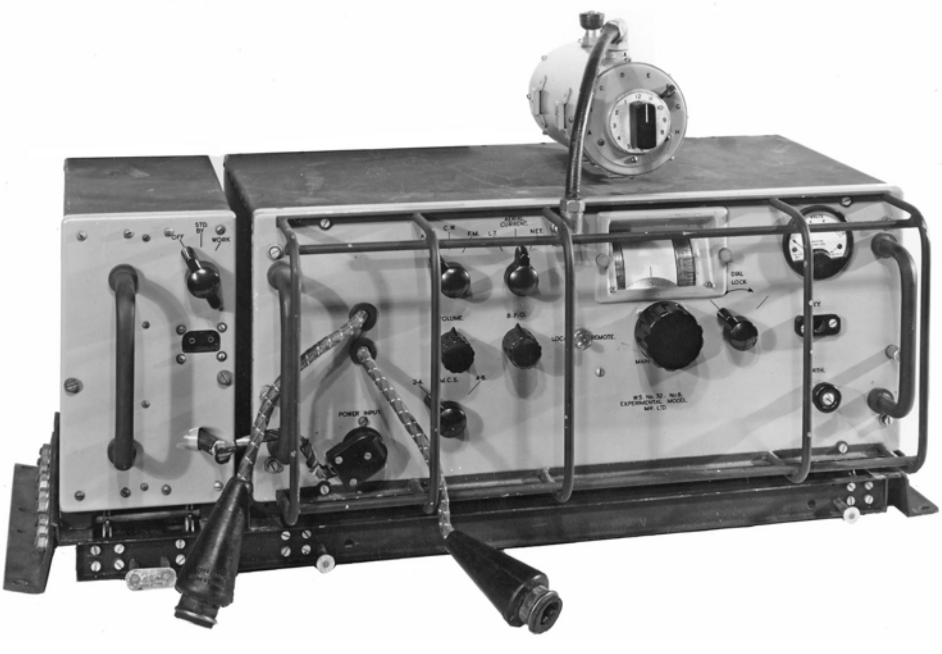


Front panel view of Wireless Set No. X32D (above) and Wireless Set No. 22 (below).
Major differences to the No. 22 Set (apart from the FM feature) were separate tuning dials of transmitter and receiver, and a third dial for the aerial coupling capacitor. The valves were all 6.3V types and the RF power amplifier an ATS25, which led to a much higher RF output. The No. X32D Set with associated No. 19 Set Power Unit No. 1 Mk.III, had the same overall dimensions as a standard No. 19 Set.

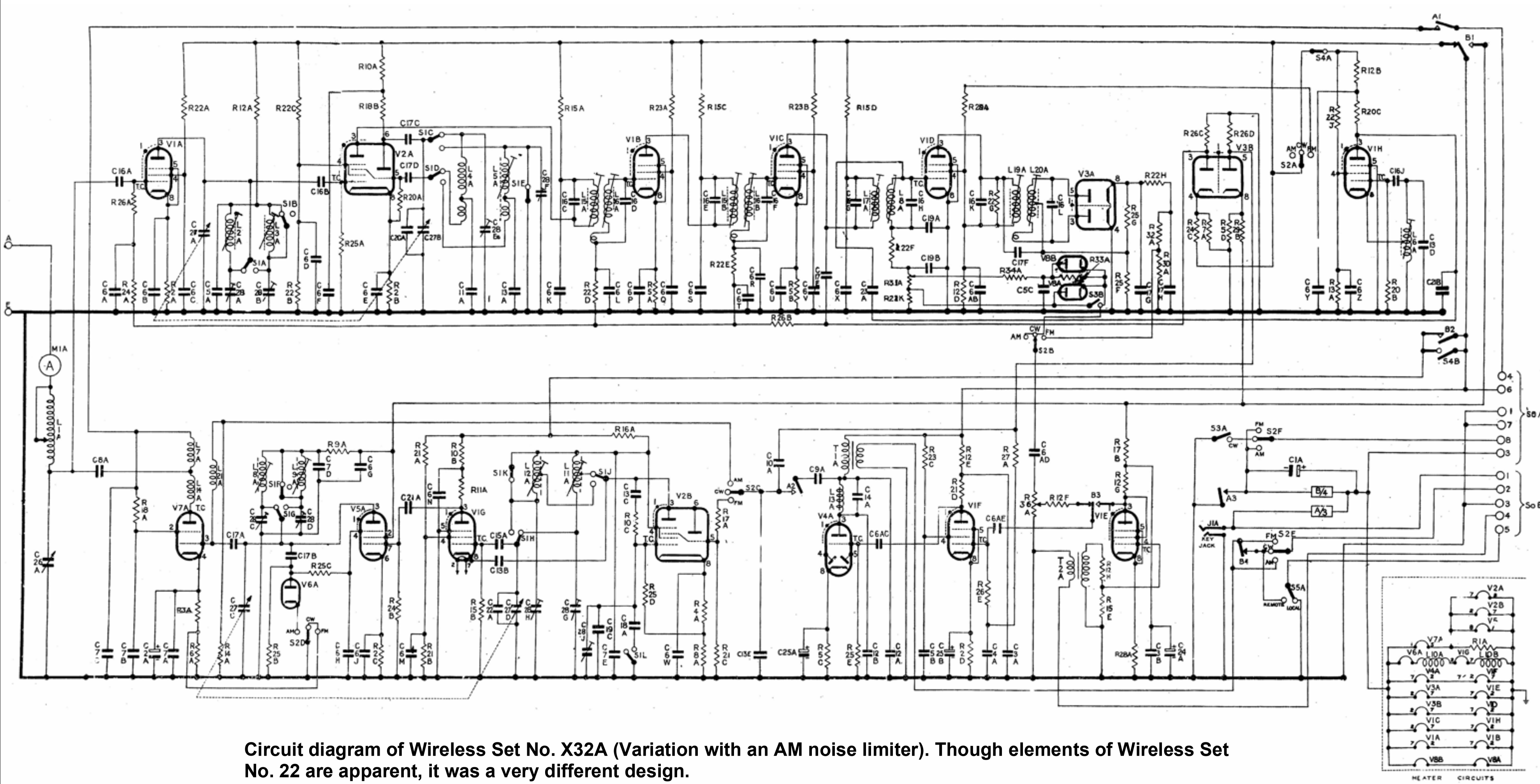




Top of chassis view Wireless Set No. 32D (left) and No. 22 (right).



Wireless Set No. 32 Experimental Model was developed by Murphy Radio. It had a number of elements of Wireless Set No. 21.
It is not known if this set was used during later investigations in the comparison of AM and FM.



Circuit diagram of Wireless Set No. X32A (Variation with an AM noise limiter). Though elements of Wireless Set No. 22 are apparent, it was a very different design.
SO A was the 12-pt connector to the Power Supply Unit No. 1 Mk.III; SO B were the two drop leads for connecting standard No. 19/22 Microphone and Receivers, Headgear Assembly, No. 1.

WIRELESS SET NO. 32D

DATA SUMMARY

PURPOSE

This set has been produced for experimental purposes, to obtain comparisons between A.M. and F.M. communication. It is not available for issue for operational purposes.

DESCRIPTION

The normal receiver stages used are: R.F., mixer, I.F., detector, A.F. and beat oscillator, and output. For F.M. reception the detector becomes a limiter for the I.F. signals feeding a Forster-Seeley type discriminator. The sender employs a master oscillator, power amplifier, two microphone amplifier stages and modulator. For F.M. a control valve is added. The set is housed in a steel case and employs a Wireless Set No. 19 Power supply unit No. 1, Mk. III. There is no send/receive switch, the change-over being made by the microphone pressel switch or morse key.

PHYSICAL DATA

Weight: 76 lb. (sender/receiver, P.S.U. mounted on chassis)
Length: 27 in.
Width: 12 in.
Height: 9½ in.

AERIAL SYSTEM

(*a*) 12 ft. rod aerial for mobile use.
(*b*) Up to 34 ft. rod aerial for ground use.
(*c*) 140 ft. wire aerial for ground use.

FREQUENCY

Coverage: 8-2Mc/s in two bands:—8-4Mc/s, 4-2Mc/s.
Internal: 460Mc/s.

PERFORMANCE

Sender output: 10W (approx.) on C.W. or F.M. R./T.
Receiver sensitivity: (A.M.) 6-7μV for 10mW output and signal noise ratio 20db.
(F.M.) 2-3μV for 20db. quieting.
Receiver selectivity: 60db. attenuation ± 16kc/s.

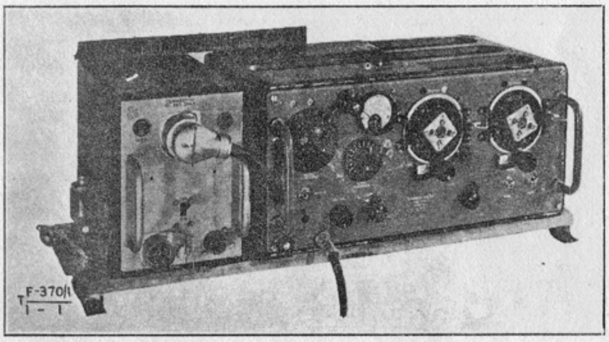


Fig. 1—General view of equipment

Distribution—Special

POWER REQUIREMENTS AND CONSUMPTION

Power supply: 12V accumulator.
Power consumption from 12V accumulator: Standby, 2.0A L.T., Receive, 3.5A L.T., send, 5.5A L.T.

ADDITIONAL FACILITIES

Remote control operation can be carried out by means of Remote control units F, Nos. 1 and 2. Similarly the set may be connected to an exchange and used on R/T from subscribers' telephones.

VALVES

Circuit reference	*Type*	*Receiver*		*Sender*	
		A.M.	*F.M.*	*A.M.*	*F.M.*
V1A	ARP34	Radio freq.	Radio freq.	—	—
V2A	ARTH2	Mixer	Mixer	—	—
V1B	ARP34	1st I.F.	1st I.F.	—	—
V1C	ARP34	2nd I.F.	2nd I.F.	—	—
V3B	ARDD5	A.V.C.	A.V.C.	A.M.C.	A.M.C.
V1H	ARP34	Beat oscillator	—	—	—
V1D	ARP34	Detector	I.F. limiter	—	—
V3A	ARDD5	—	Discriminator	—	—
V1F	ARP34	1st A.F.	1st A.F.	2nd A.F.	2nd A.F.
V4A	AR21	Output	Output	Grid modulator	3rd A.F.
V1E	ARP34	—	—	1st A.F.	1st A.F.
V2B	ARTH2	—	—	—	Control
V1G	ARP34	—	—	Master oscillator	Master oscillator
V5A	ARP35	—	—	Buffer	Buffer
V6A	ARD2	—	—	Drive limiter	—
V7A	ATS25	—	—	P.A.	P.A.

END

ELECTRICAL AND MECHANICAL
ENGINEERING REGULATIONS
[A.C.I. 2031 of 1942]

RESTRICTED

TELECOMMUNICATIONS
A 013

FREQUENCY MODULATION

GENERAL

1. The characteristic difference between frequency modulation (F.M.) and amplitude modulation (A.M.) is that, in F.M., the modulation applied to a sender causes the frequency to vary and the amplitude to remain constant, whereas in A.M. the applied modulation causes the amplitude of the carrier to vary and the frequency to remain constant.

2. In A.M. the amplitude of a carrier modulated 100% varies from zero to twice the value of the unmodulated carrier. In F.M. it is obviously impracticable to vary the frequency to a similar extent, and an arbitrary limit to frequency swing must be set to correspond to 100% modulation. The extent to which the frequency may vary on either side of the nominal carrier frequency is known as the frequency deviation and percentage modulation is therefore defined as the fraction, expressed as a percentage, given by actual frequency deviation divided by maximum frequency deviation permitted on the frequency band in use. The maximum permissible deviation for Army equipment is tentatively fixed at 5 kc. in the 1 to 12 Mc. band, and 15 kc. in the 20 to 60 Mc. band.

3. F.M. enables an increased sender efficiency to be obtained, so that for a given radiated power, the D.C. input power required is considerably reduced. This is a decided advantage when the input power is to be derived from portable batteries. In the case of A.M., a sender power amplifier must be capable of dealing with a peak signal of amplitude twice that of the unmodulated carrier, but, the average depth of modulation being approximately 25%, the stage is normally being under run. A F.M. signal has constant amplitude and hence the power amplifier can be fully loaded and will, therefore, be more efficient. For the same D.C. input to the sender, the radiated power is twice as great on F.M. as on A.M.

4. The F.M. receiver is less responsive to noise than the A.M. receiver; in fact, the signal on F.M. appears to suppress the noise, whereas in A.M. the signal is heard above a background of noise. Thus, speech which is just readable with A.M. becomes readily so with F.M., although the signal-to-noise ratio at the aerial is the same on each system. This is specially noticeable when the source of the noise is static or ignition interference. As this type of interference—generated by vehicles, atmospherics, etc.—freqently determines the useful range, the advantage of F.M. is readily recognized; alternatively the problem of vehicle suppression is considerably eased. The background noise heard on F.M. receivers is of a higher pitch than on A.M. This is a further advantage since for the same intensity of noise less loss of intelligibility is caused. Range trials have confirmed that F.M. sets give increased R/T range and considerable immunity from noise interference. For a given power the increase in range was more than 25%.

5. The general result obtained with quite low frequency deviations is found to be very little worse than with large deviations and it is therefore possible to obtain satisfactory service with deviations as low as plus and minus 5 kc. in the 2 to 8 Mc. band. Thus, it is possible to use practically the same channel width as in A.M. F.M. is, therefore, particularly suitable for providing R/T communication between vehicles, since the range is increased, and both the interference from the vehicle and that from outside are largely suppressed.

CIRCUIT DESIGN OF F.M. EQUIPMENT

6. The circuits involved are straightforward and present no serious servicing difficulties in maintenance and alignment. Frequency stability is certainly much more important in F.M. equipment than in A.M. equipment, but, in practice, it is found that this requirement can be efficiently met without undue complications.

7. The mechanical. or short-term, stability of all oscillators in all types of F.M. equipment must be as high as possible, since any vibrations cause variations in the frequency which represent a spurious A.F. modulation. Because of this, special attention is paid to the rigid mounting of components and the careful isolation of all sources of mechanical vibrations.

SENDERS

8. F.M. senders fall into two classes: the self-oscillator type and the crystal-controlled phase-modulated type.

Self-oscillator type

9. This consists of an oscillator with a second valve connected across the tuned circuit in such a way as to look like a reactance of magnitude dependent on the modulation voltage applied to its grid. With no modulation voltage applied, the circuit is tuned to the nominal carrier frequency. The variation of the apparent reactance of the valve due to the modulation voltage will thus alter the frequency of the oscillator above and below the carrier frequency, at a rate dependent on the frequency of the audio modulating voltage.

10. A typical circuit of this type and the equivalent simplified circuit, assuming the normal convention for pentodes, are shown below in Fig. 1. Here V1 is the oscillator valve, with L1 and C3 forming the tuned circuit. C2 and C4 are made large, so that their reactances can be neglected. V2 is the control valve.

11. Considering the circuit R1-C1, it is clear that across C1 a voltage is obtained with a phase lag on the voltage applied across the whole circuit from the tuned circuit L1-C3. This lagging voltage is applied to the grid of the control valve V2, so that the anode current of this valve will also have a phase lag on the voltage applied across C1-R1. Consequently the circuit containing V2 is now drawing a current with a phase lag on the voltage applied across it from the oscillatory circuit L1-C3. But this property of voltage leading current is the property of an inductance—that is, the circuit containing V2, R1 and C1 now has the properties of an inductance. The magnitude of this inductance will depend on the extent of swing of the anode current—that is, upon the mutual conductance of the valve and, therefore, upon the value of the grid bias applied to the valve. As the virtual inductance formed by the valve stage is connected across L1-C3, it will alter the resonant frequency of this circuit and, therefore, the frequency of the oscillator, to an extent dependent on the grid voltage of V2 and, therefore, on the A.F. modulation voltage applied to the grid.

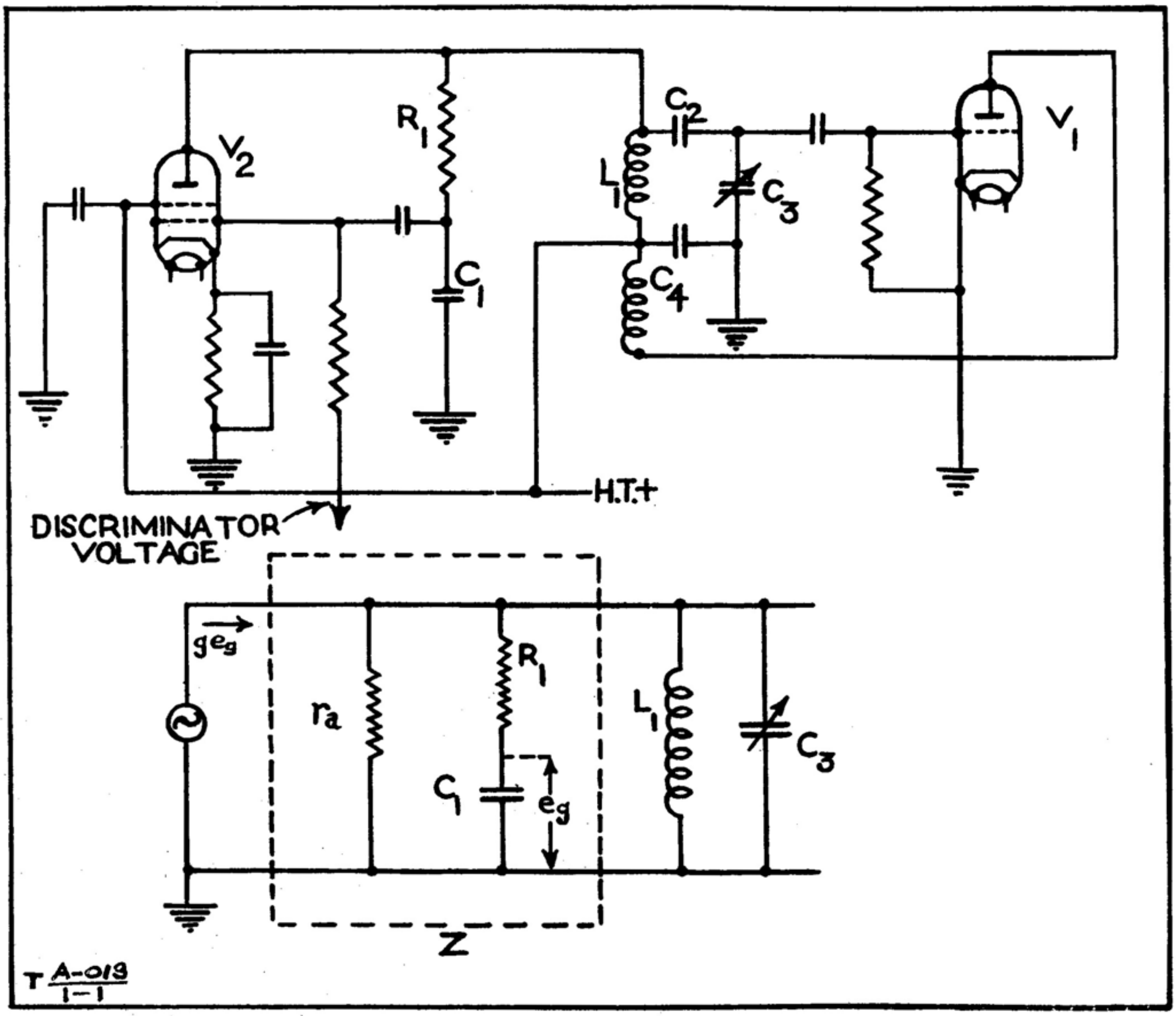


Fig. 1—Method of frequency modulation by reactance valve.

12. It is thus evident that an A.F. voltage impressed on the grid of the control valve will appear as a variation at the audio frequency of the main carrier frequency produced by the R.F. oscillator, the extent of frequency deviation being dependent on the amplitude of the A.F. modulation, but in any event being sufficient to give 100% modulation on the Army frequency bands.

13. The frequency stability of this type is not sufficient to allow of its use without further precautions. Hence, stabilized power supplies are used. The use of the reactance valve, however, permits the application of standard frequency control-circuits to obtain good stability.

14. A discriminator circuit (the operation of this is explained below in the paras. on receivers) is arranged to provide a D.C. voltage, positive or negative according to whether the oscillator is below or above its nominal frequency and of amplitude proportional to the magnitude of the error. This is then fed to the grid of the control valve and as explained above will alter the frequency of the oscillation back to its correct value. In complete stations it is convenient to use the discriminator in the receiver for this purpose.

Crystal-controlled phase modulated type

15. The second type of modulator makes use of the close relationship between phase and frequency modulation. The schematic circuit of this type is shown below in Fig. 2.

16. The output from the crystal oscillator is fed into an R.F. amplifier A1 and also into a balanced modulator stage. This stage is controlled by the modulation voltage from the audio amplifier and is so arranged that with no audio voltage applied there is no output from the stage, while with an audio voltage applied the output consists of the sidebands only of the amplitude-modulated wave, their amplitude being proportional to the audio modulating voltage. This output is passed through a network which shifts the phase of the voltage through 90° with respect to the carrier frequency and is then combined with the output of A1, consisting of the amplified carrier wave. Thus we have at the input to A2 a wave of fixed amplitude at the

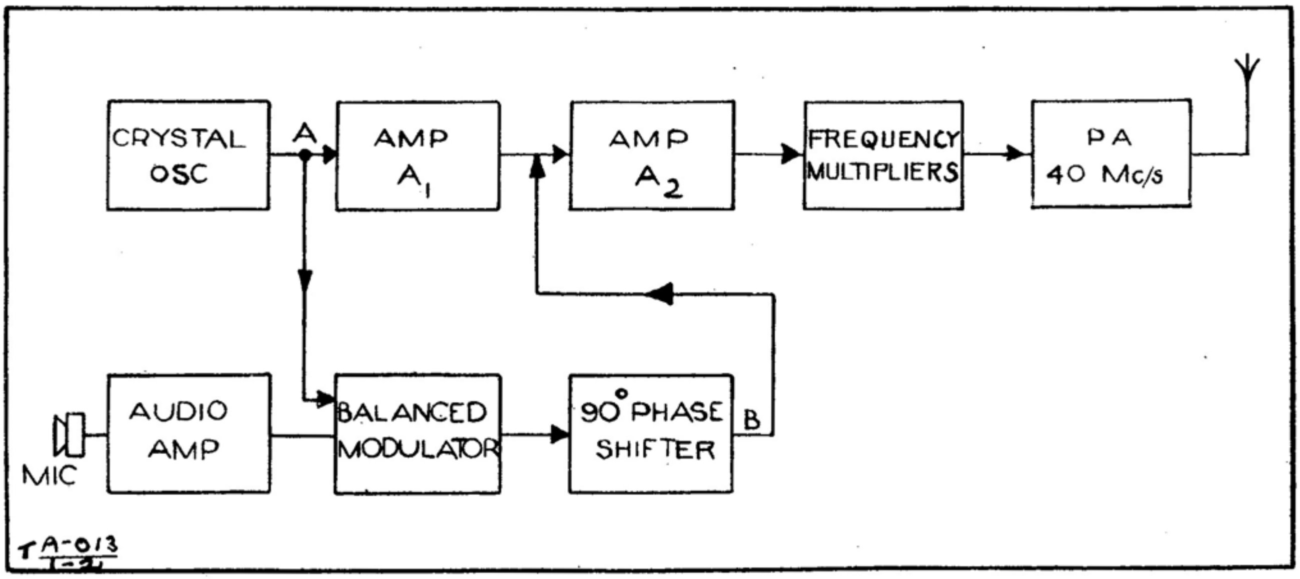


Fig. 2—Method of frequency modulation by phase modulator.

crystal frequency and sidebands 90° out of phase and varying in amplitude according to the audio modulation, but of considerably smaller amplitude than the crystal oscillation owing to the amplification obtained through A1. The addition of the side-bands obviously displaces the carrier wave in phase to an extent determined by the amplitude of the sidebands and therefore of the audio voltage—that is, the carrier will be phase-modulated at audio frequency.

17. It is evident that a certain amplitude of modulating voltage will produce a certain phase shift irrespective of the frequency of the modulation. This phase shift, however, must be achieved in a shorter time for a high audio modulating frequency than for a low one; that is to say, with the higher modulating frequency the carrier frequency must increase to a greater extent in order to achieve the same specified phase lead. Thus, although the phase shift is independent of modulation frequency, the frequency shift of the carrier is proportional to the modulation frequency. But it is an essential quality of frequency modulation that the frequency deviation is proportional to the amplitude of the modulating voltage and independent of its frequency. This, however, can easily be achieved from the first state by arranging for the amplitude of the audio modulation to decrease as its frequency increases. The phase shift at higher audio frequencies will also decrease and therefore the extent to which the carrier frequency must increase to achieve the specified phase shift will also be reduced. Thus, by inserting in the audio amplifier of Fig. 2 a network making the amplification inversely proportional to frequency, the input to A2 can be transformed from a phase modulated wave to a frequency-modulated one.

18. In order not to cause serious distortion in the modulation process, the amplitude of the carrier must be made much greater than that of the sidebands. The extent of the available phase shift is thus severely limited; translated into terms of frequency modulation, it corresponds to a deviation of about 70 cyc. on a carrier frequency of 200 kc. It is therefore necessary to use frequency multipliers after the amplifier A2, so that an output at 40 Mc. is available with a deviation of 14 kc.

RECEIVERS

19. The early stages of F.M. receivers follow exactly the same principles as are used in A.M. receivers. Signals are amplified, transformed to the intermediate frequency and amplified again in the usual manner, although damping resistances are usually connected across the tuned circuits in order to keep the response level over the wider frequency band covered by the frequency-modulated signal. The second detector, however, is replaced by two stages, the limiter and the discriminator.

20. The limiter is in effect a final I.F. valve which is run with low values of screen and anode voltage. The valve is consequently fully loaded at comparatively low values of signal strength and no increase in the amplitude of the signal reaching the grid of this valve can cause an increase in the output. Now random noise and interference are merely sudden increases in the amplitude of the incoming signal. If, therefore, the limiter operates at levels just below those of normal signals, all sudden increases in strength, whether due to fading, circuit noise, or interference, will not reappear after this valve. The noise and all amplitude modulations of this type are thus cut out completely. In addition an efficient form of A.V.C. is produced, since the input to the later stages cannot exceed the level fixed by the limiter. The method of operation is clearly seen from the diagram below (Fig. 3).

21. Owing to the low anode and screen voltages, the signal applied to the grid of the valve will swing beyond the cut-off point of the characteristic on the negative peaks. On the positive swing of the signal, since little or no grid bias is applied to the grid, the valve will run into grid current and build up a negative charge on C, the grid condenser. If the time constant of the combination CR is long compared with the period of the signal, a steady negative bias will be applied to the grid, thus moving the working point of the valve cut-off and clipping off considerably more of the negative half of the applied signal. In addition the positive

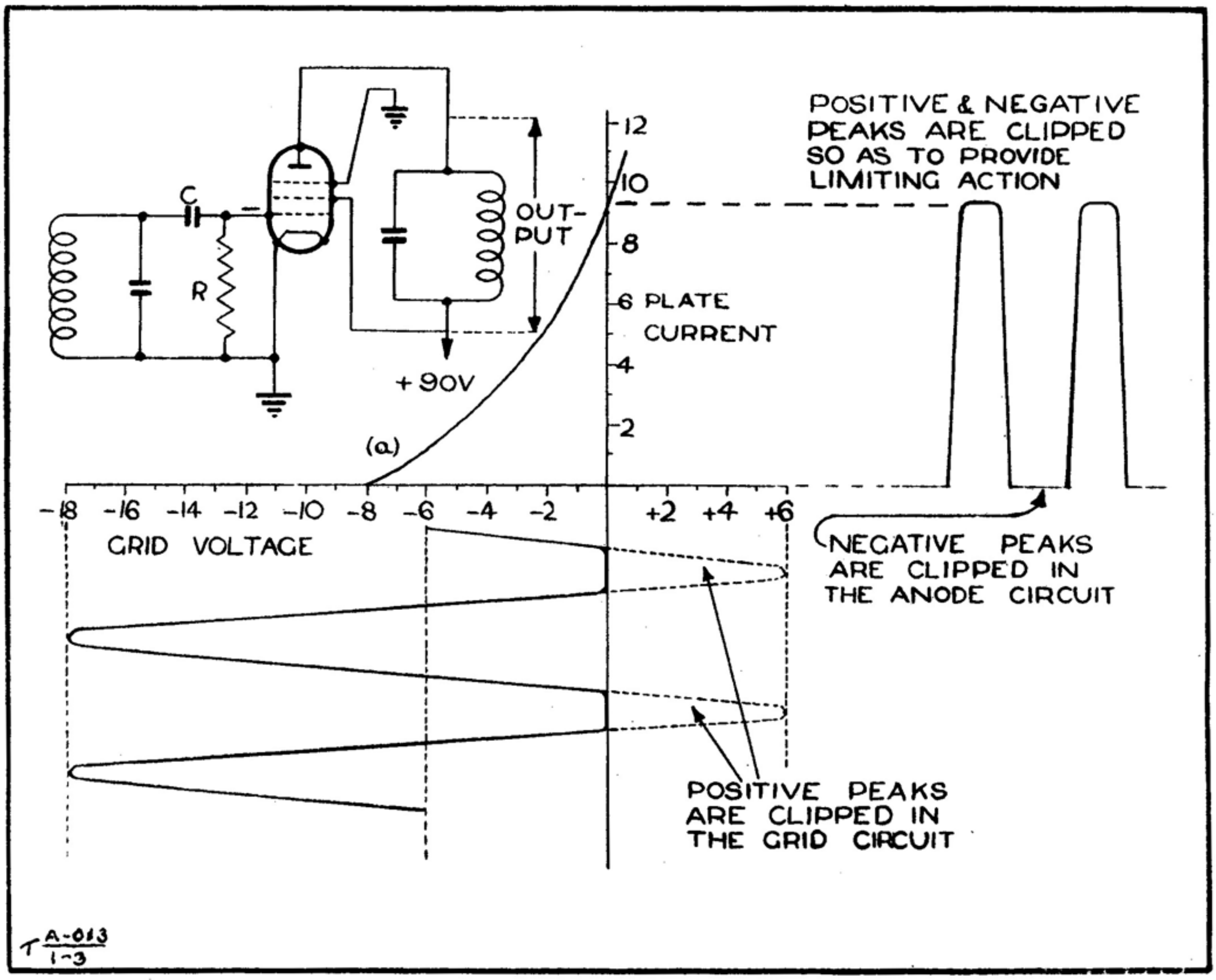


Fig. 3—Basic circuit and performance curves of limiter.

peaks will be damped off, since when grid current flows the input impedance of the valve becomes equivalent to a very low resistance shunted across the input circuit. Thus, as shown in the diagram in Fig. 3, signals of whatever amplitude at the grid of the valve, provided they exceed the small amount required to cover the grid base of the characteristic curve, will appear at the anode at one predetermined amplitude and all peaks due to noise or to an interfering station are eliminated. The output level of the limiter can obviously be adjusted in the design to secure the most efficient operation of the following stage, the discriminator.

22. Having obtained at the output of the limiter a signal of constant amplitude but varying frequency, it is now necessary to convert the frequency variation which represents the speech modulation (the amplitude variations removed by the limiter having been merely random noise) into a form capable of operating an audio amplifier—that is, into a voltage varying in amplitude in sympathy with it. This is done in two steps, by converting the frequency-modulated wave into an amplitude-modulated one, and then by rectifying this in the usual manner. The stage performing these functions is the discriminator. Two main types of circuit are used for this stage.

Double-tuned discriminator

23. The first of these uses the response curve of a tuned circuit as a means of transforming frequency variation into amplitude variation. The circuit is shown below in Fig. 4. This consists in essence of two resonant circuits fed from the limiter valve and tuned above and below the unmodulated or central carrier frequency by equal amounts. The outputs from the two circuits are connected to diode detectors, the load resistances of which are connected to give opposing voltages. Thus when the input consists of the unmodulated carrier at the point midway between the resonant peaks of the two secondaries, the outputs of the detectors are equal and opposite, so that the total output of the discriminator is zero. Taking T2 to be tuned to the higher frequency, the output of this circuit will increase as the frequency increases, while the output from T3 and its associated detector will decrease. The total output from the discriminator will thus be a negative voltage and provided that the frequency deviation does

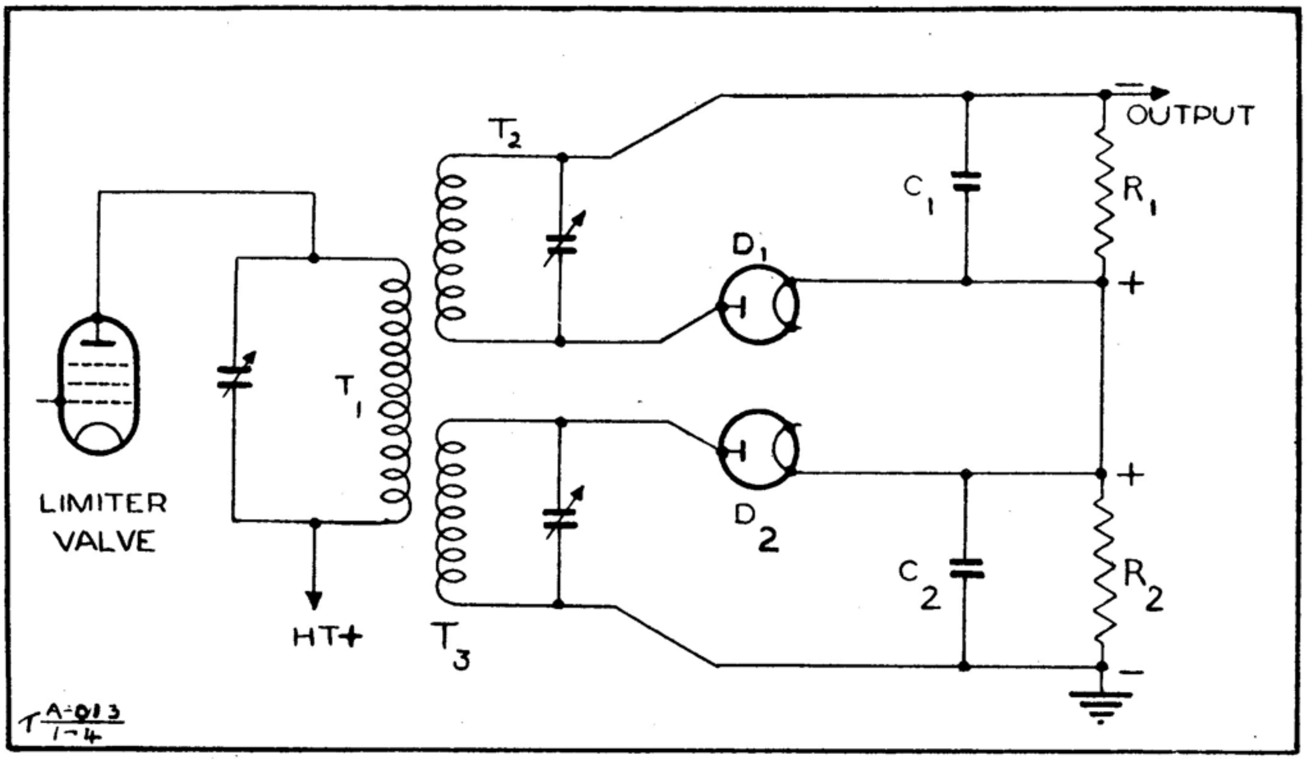


Fig. 4—Double-tuned discriminator.

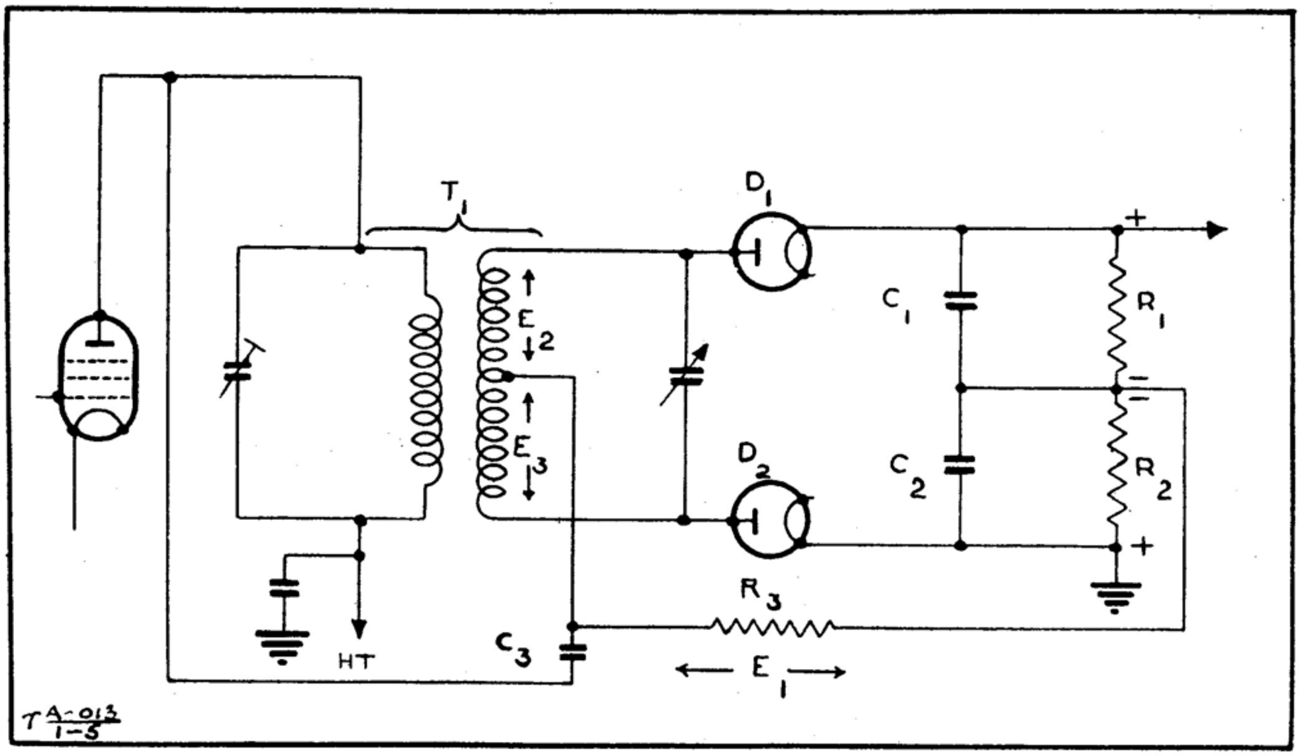


Fig. 5—Foster-Seeley discriminator.

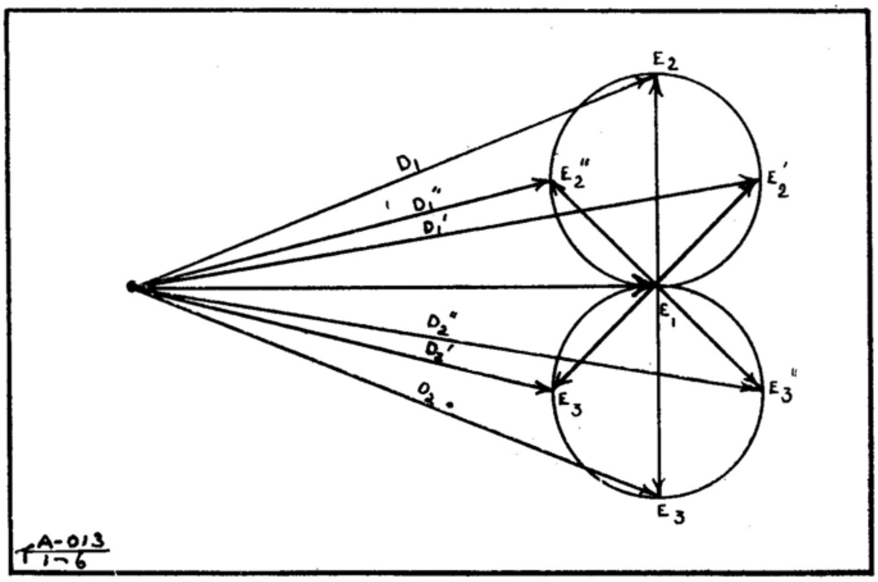


Fig. 6—Vector diagram of the Foster-Seeley discriminator.

not exceed the difference between the resonant frequency of T2 and the central carrier frequency, the amplitude of this negative voltage will increase as the frequency deviation increases. The process is reversed when the carrier frequency decreases, the output from the discriminator in this case being positive. Thus the frequency deviation of the carrier gives rise to a voltage output positive or negative according to the direction of the deviation and of amplitude proportional to the extent of the deviation; that is to say, it reproduces the modulating voltage causing the frequency deviation of the transmitter. This voltage can now be passed to an audio amplifier and loudspeaker circuits in the usual manner.

Foster-Seeley discriminator

24. The second type of discriminator circuit is known as the Foster-Seeley, or phase, discriminator. It makes use of the fact that at the resonant frequency the voltage across the secondary of a double-tuned transformer is 90° out of phase with that across the primary, but at frequencies off resonance the phase difference is greater or less than 90° according as the frequency is above or below resonance. The circuit of this type is shown in Fig. 5. Here both primary and secondary of the transformer are tuned to the central carrier frequency. The secondary is centre-tapped and half the voltage developed across it is applied to the diodes D1 and D2, in each case in series with the primary voltage E_1 developed across the load resistance R3 between the centre taps of the secondary and the diode loads R1 and R2. The values of R3 and C3, the coupling condenser, are chosen so that there is negligible phase difference between E_1 and the voltage across the primary of the transformer. Thus in the vector diagram at Fig. 6 the vectors E_1 and E_2E_3, representing the voltage across the whole of the secondary, can be drawn in quadrature, in accordance with the property of a double-tuned transformer stated above. The voltages applied to the diodes are therefore represented by D_1 and D_2, and since these vectors are of equal amplitude, the resulting output across R1R2 is zero. At frequencies above resonance, however, the vector E_2E_3 will swing away from quadrature and decrease in amplitude, since the secondary is no longer exactly tuned, taking up the position E'_2 E'_3. The amplitude of E_1 will also decrease, but to a smaller extent, and the difference can be neglected. The voltages applied to the diodes are now D'_1 and D'_2, where D'_1 is clearly of greater amplitude than D'_2. The resultant output from the discriminator will therefore be positive. At frequencies below resonance, the phase change will be in the opposite direction, giving vectors E''_2 E''_3, D''_1 and D''_2, where D''_2 is now greater than D''_1. The discriminator output is therefore negative. Thus as in the previous circuit, the frequency deviation of the carrier is transformed into an alternating voltage which reproduces that causing the deviation at the transmitter.

CIRCUIT DIAGRAMS OF TYPICAL SETS

Sender (Fig. 7)

25. Four valves are employed in the sender, an oscillator-doubler, a modulator, a reactance valve and a power amplifier, in a comparatively straightforward circuit.

26. The oscillator-doubler valve is a 6V6 beam tetrode connected in an electron-coupled Hartley oscillator circuit, with the anode circuit tuned to twice the frequency of the oscillations in the grid circuit. The second harmonic of the oscillations is thus picked out and passed on to the grid of the power amplifier valve for amplification and subsequent transfer to the aerial through the aerial relay.

27. The modulator valve is a pentode operating as an A.F. amplifier, to amplify the signal obtained in the microphone transformer to a level capable of efficiently controlling the reactance valve, which produces the actual frequency modulation in the manner explained in the previous paragraphs. The reactance valve itself is a high-slope pentode, using a feedback circuit between grid and anode similar to that previously described, connected directly across the grid circuit of the oscillator valve. The grid of this valve is supplied with the audio signal from the previous stage, the modulator and also with a voltage obtained from the discriminator in the receiver. This voltage will increase if the transmitter drifts away

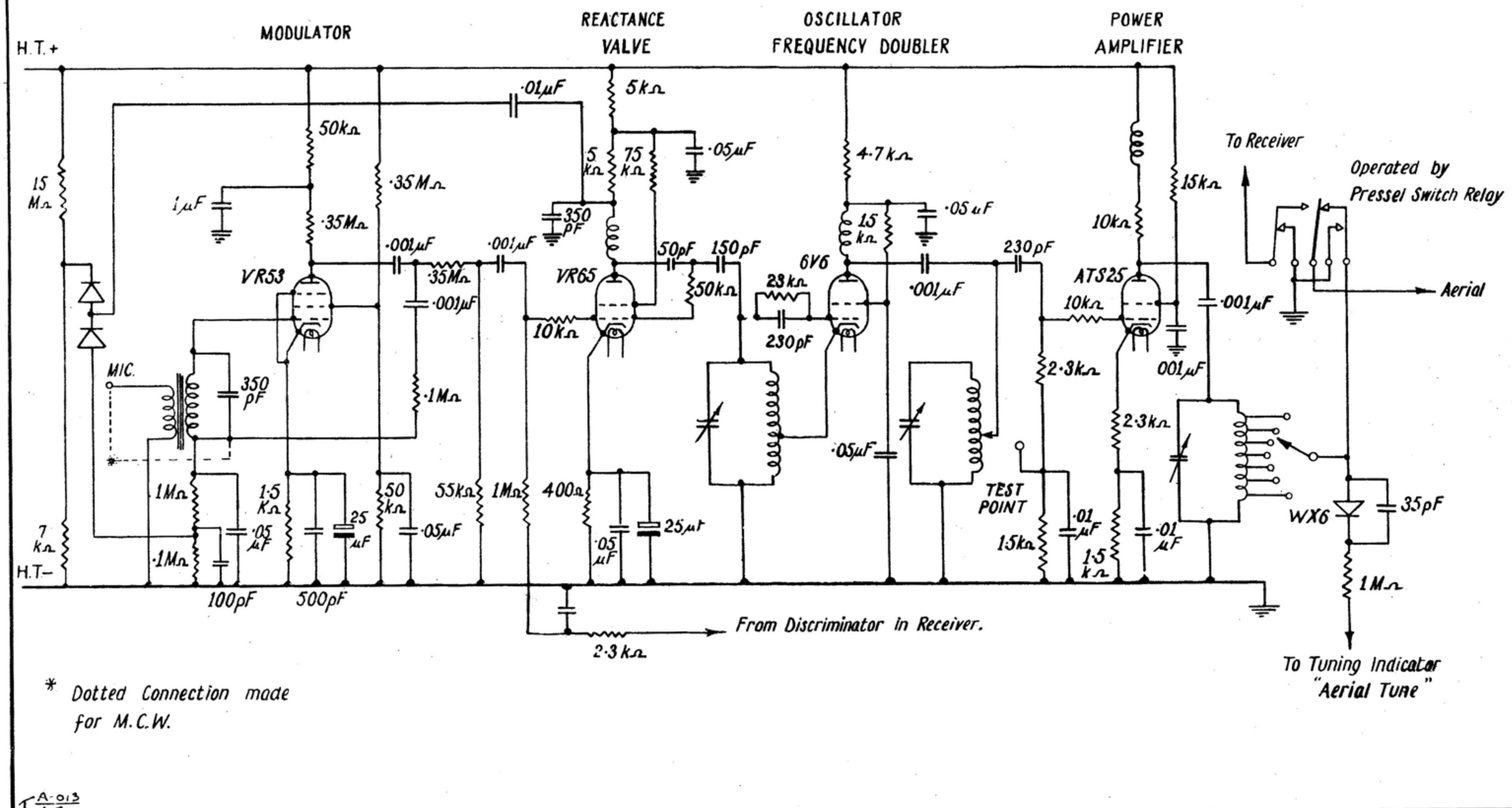
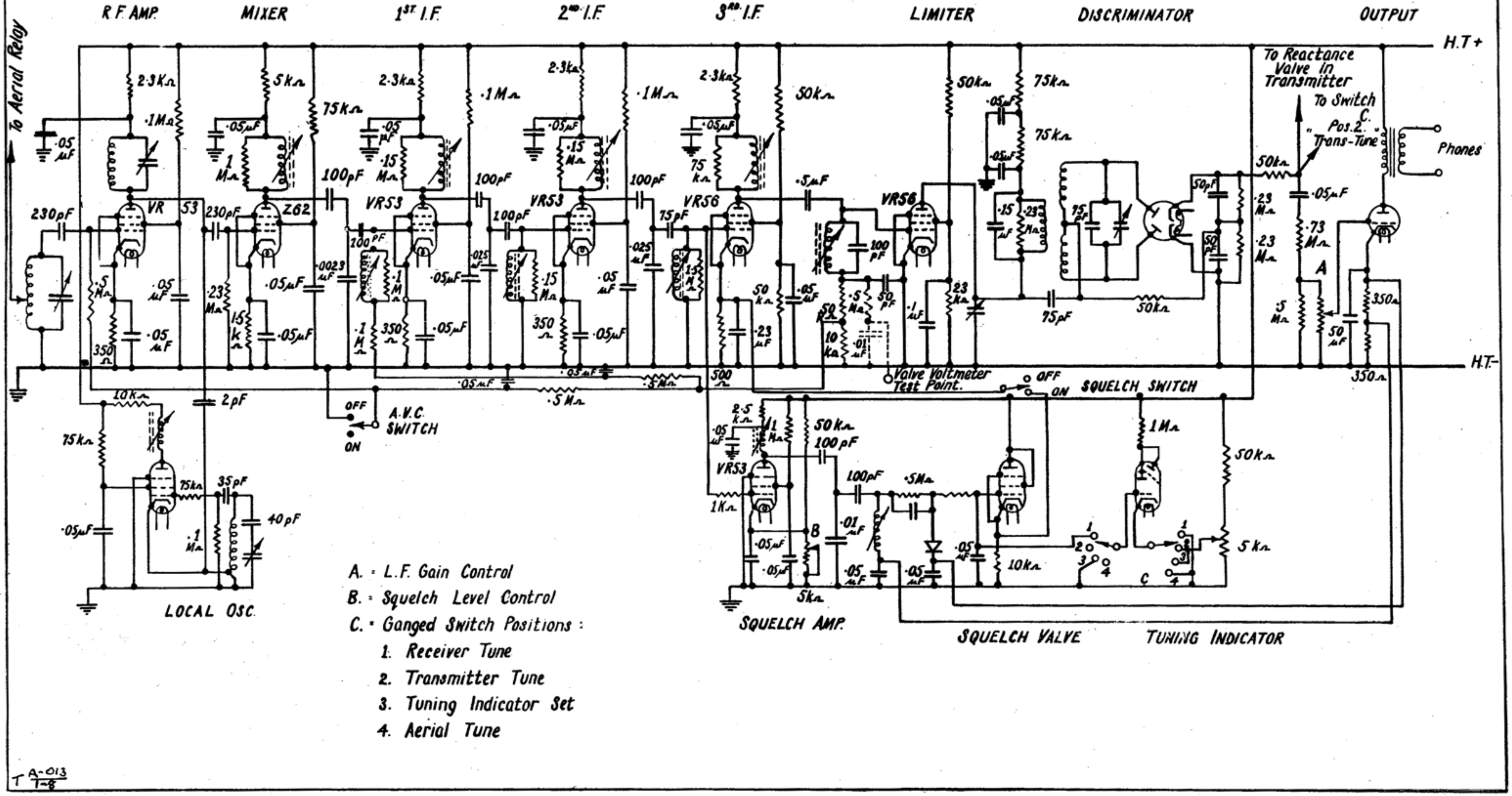


Fig. 7—Circuit diagram of F.M. sender.



Issue 1, 8 June 1943

Fig. 8—Circuit diagram of F.M. receiver.

from its allotted frequency and is arranged to be of the correct polarity to pull the frequency back if this drift should take place. It therefore produces automatic frequency correction of the transmitter. From the A.F. load at the anode of the reactance valve an amplified audio voltage is fed to a pair of Westectors which are given a fixed positive bias from a potentiometer across the H.T. supply. Thus, when the level of the bias is exceeded, the Westectors will rectify the audio signal and provide a negative bias on the grid of the modulator valve—a bias which will increase with the strength of the audio signal. The gain of the modulator valve will therefore tend to be reduced for strong signals at the grid and increased for weak ones. Automatic modulation control is thus provided to maintain the modulation at a constant level.

28. M.C.W. operation can be obtained by making the connection shown in dotted lines in Fig. 7. This then connects the modulator valve as an A.F. oscillator.

Receiver (Fig. 8)

29. The circuit of the receiver as far as the third I.F. stage is that of a normal superhet, using R.F. amplifier, mixer and separate local oscillator and three I.F. amplifiers. A pentode is used in each stage. The I.F. employed is 1,600 kc. and the I.F. transformers are shunted by resistances to obtain the necessary bandwidth. The fourth I.F. amplifying stage is arranged to work as a limiter, by reducing the values of H.T. voltage applied to anode and screen. No cathode bias is used. The D.C. voltage developed by the flow of grid current through the 10 kΩ portion of the grid resistance is smoothed and applied to the R.F. and first I.F. stages as A.V.C. The limiter is designed to be fully loaded with about 20 V signal at its grid. This value is obtained from an input to the aerial of about 2μV.

30. The discriminator is the Foster-Seeley type previously described, using a double diode valve in which the cathodes are separate. The A.F. output from the discriminator is taken to the grid of a triode output valve with a transformer in its anode circuit.

31. Suppression of noise in the absence of a carrier is provided by the squelch circuits, which are arranged so that the arrival of a signal of magnitude above a certain level at the grid of the third I.F. stage removes from that valve a paralysing bias, which otherwise silences the receiver. The squelch amplifier is fed from the grid of the third I.F. stage. The amplified signals appearing at its anode are rectified and applied as a D.C. bias to the grid of the squelch valve, thus controlling the valve current in the presence of a signal. The voltage drop across the cathode resistor is applied as additional bias in the cathode of the third I.F. valve, and the system is arranged so that this valve is allowed to conduct only in the presence of a carrier of predetermined level at its grid. The level at which the valve opens up is controlled by a potentiometer applying to the cathode of the squelch amplifier a positive bias which the signal must exceed before the amplified signal can appear at the anode for rectification and application to the squelch valve.

32. A magic-eye tuning indicator is also provided, which can be switched to provide three different indications :

(*a*) *Receiver tune.* In this case the grid of the indicator is connected to the grid of the squelch valve. As the voltage at this point will be greatest when the receiver is tuned exactly to the incoming carrier frequency, the magic-eye will give a fairly accurate tuning indication, independent of the frequency deviation of the transmitter.

(*b*) *Transmitter tune.*

(*c*) *Tuning indicator set.* These two positions (*b*) and (*c*) are used in conjunction. At the tuning indicator set (*c*) position, the grid of the magic-eye is earthed, and the shadow angle adjusted to any convenient point by means of the cathode potentiometer. At the transmitter tune (*b*) position the output of the discriminator is connected to the grid of the magic-eye. When an incoming signal is exactly tuned, the D.C. output of the discriminator is zero, so that no deflection of the shadow of the magic-eye occurs when switching the tuning indicator from the set to the transmitter tune positions. This method can be used for accurate tuning of the receiver to an incoming signal or for netting the local sender to the receiver, provided facilities are available for working the sender on reduced power to avoid paralysing the receiver.

33. The intermediate frequencies of Army F.M. wireless sets will be standardized to permit the use of fixed frequency signal generators. The frequency used will be 460 kc., 1·6 Mc., or 9·72 Mc., according to the R.F. frequency band of the set.

METHODS OF ALIGNMENT

34. It is possible to adjust the alignment of F.M. receivers with the equipment normally used for A.M. receivers, but the following special test equipment will be required in addition for precision testing :

(*a*) A frequency-modulated signal generator ;

(*b*) A D.C. valve voltmeter ;

(*c*) A deviation meter.

Items (*a*) and (*c*) are not yet in general production in this country, but the development of such instruments for Army requirements is in hand. Item (*b*) is to be provided by a modification to the existing valve voltmeter (" Voltmeter, Valve, 150 V, No. 1 "), to include facilities for D.C. measurements.

35. A specification for testing and expressing overall sensitivity of F.M. reception sets has not yet been approved and the following suggested alignment procedure may be consequently modified with the actual introduction of F.M. sets into the service. It should, however, in its present form assist workshop staff to carry out repairs to F.M. wireless sets pending receipt of the appropriate manuals. A.M. test equipment is used as far as possible.

DISCRIMINATOR ALIGNMENT

Using A.M. testing equipment

36. Two methods are available as follows :

(*a*) The output of an A.M. signal generator, set exactly to the intermediate frequency, is connected between the grid of the limiter valve and chassis, using a

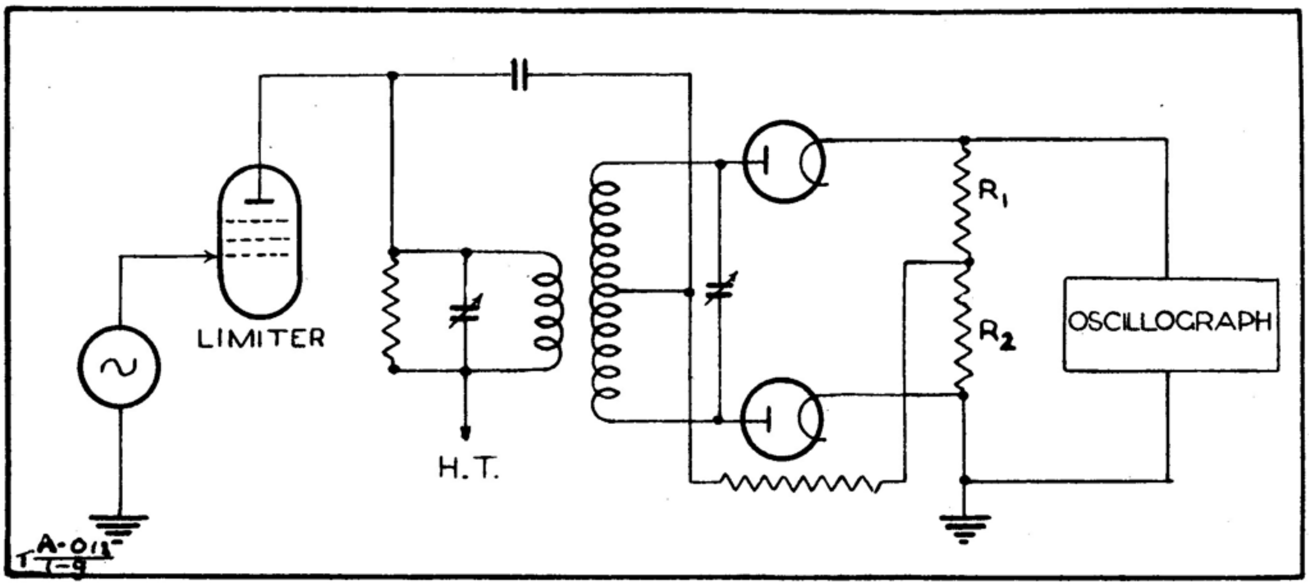


Fig. 9—Visual alignment of discriminator.

condenser, say, ·006μF, in series. The D.C. valve voltmeter is connected between the cathodes of the discriminator. The secondary of the discriminator transformer is then tuned for zero deflection. If the secondary is tuned to either side of this point the meter reading should change in polarity. The signal generator is next offset above the intermediate frequency, say, by 25 to 30 kc. and the reading on the meter noted. This test is repeated with the signal generator set to a similar deviation below the intermediate frequency and the readings obtained should be the same within 20%, but opposite in polarity.

(*b*) The signal from the generator is fed into the I.F. stages at any convenient point with the output carefully set at the stipulated intermediate frequency; with the D.C. valve voltmeter connected across one of the diode loads, the primary tuning is adjusted for maximum indication. The voltmeter is then connected across the output of the discriminator and, without changing the frequency of the signal generator the secondary is tuned for zero output. If the signal generator is modulated, the tone will be heard in the phones of the set when the discriminator is tuned slightly off resonance on either side of the intermediate frequency: the silent point between is the correct setting. The final adjustment, however, should be made by means of the unmodulated carrier and meter.

Using F.M. testing equipment

37. If a frequency modulated generator is available the discriminator can be accurately set up by a visual method. The F.M. signal generator is connected to the signal grid of the limiter valve and the oscillograph to the output of the discriminator (see Fig. 9). By selecting the correct time-base speed on the oscillograph the response curve of "X" type shown in Fig. 10 is obtained.

38. A is the curve obtained when the output of the signal generator is swinging from above to below the intermediate frequency, whilst B is the curve obtained when the frequency is swinging in the reverse direction. The

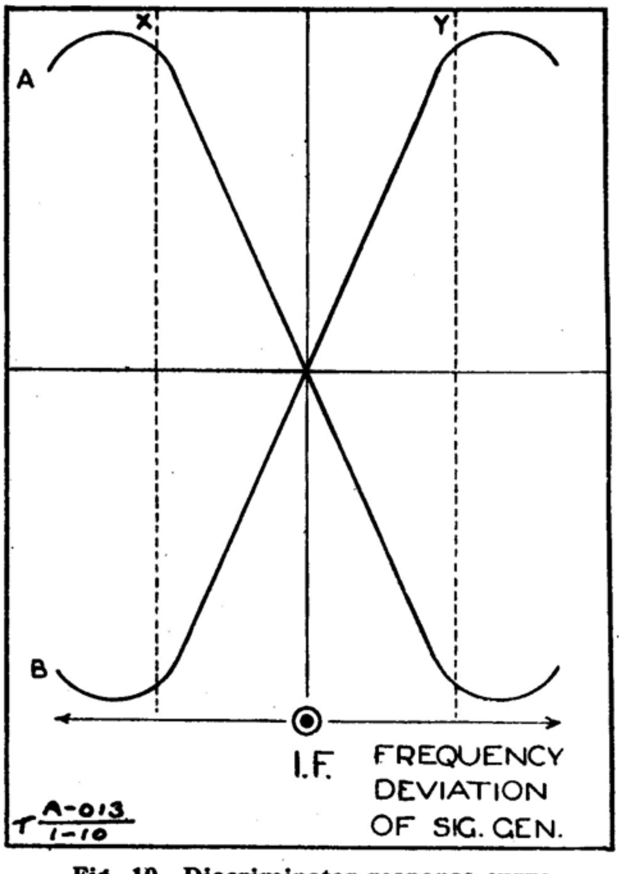


Fig. 10—Discriminator response curve.

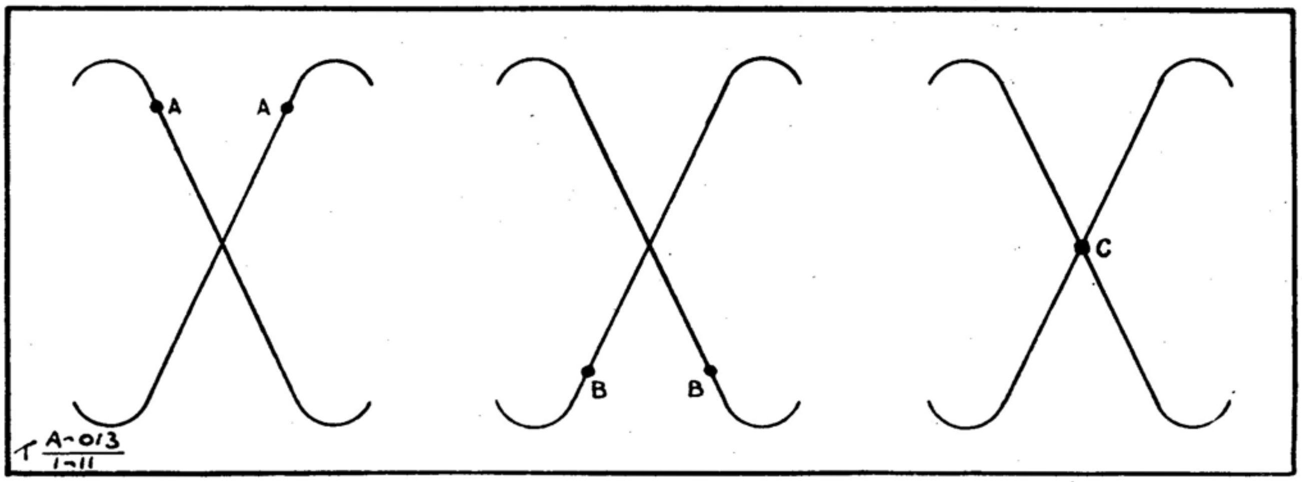


Fig. 11.—Calibration of discriminator response curve.

useful operating portion is the linear sweep between X and Y and in the design the selected deviation is limited to this range.

39. The first adjustment is the tuning of the primary to produce the greatest overall height of the curves. The adjustment of the secondary controls the cross-over point. Alternate adjustment of the primary and secondary tuning is continued until maximum response is obtained with the cross-over point midway between the two peaks.

40. If it is desired to check the frequency range over which the output of the discriminator is linear, an accurate fixed spot frequency is applied by a separate oscillator in parallel with the signal generator, of *just* sufficient amplitude to indicate a beat on the curve.

41. Thus a spot frequency producing a beat at A on Fig. 11 would indicate the limit of deviation above the intermediate frequency, at B the limit below, and at C the position of the intermediate frequency, which in a correctly tuned discriminator is exactly at the cross-over point.

I.F. ALIGNMENT

42. The A.M. signal generator is connected to the grid of the mixer valve and the D.C. valve voltmeter in the grid circuit of the limiter valve, in such a manner that it will have no detuning effect on the preceding I.F. stage; for instance, referring to the schematic diagram, Fig. 8, of a typical set, this condition is met by making the connection to the live end of the 50 kΩ resistance—as shown dotted—and using a 0·5 MΩ series resistance, ·01 μF decoupling condenser and a screened lead.

43. The I.F. transformers are then peaked in the usual manner, using a shunting resistance, of the order of 1,000Ω across the primary of an I.F. transformer whilst peaking the secondary and *vice versa*. Finally a check is made to ensure that the selectivity curve is approximately symmetrical about the mid frequency. The input voltage required to produce a given voltage on the limiter grid is a measure of the efficiency of the I.F. circuits.

44. The pass band of the I.F. circuits on a F.M. reception set is purposely designed to be flat over a wider range than in A.M. sets, in order to accommodate the frequency deviation. The I.F. band width is determined in the usual manner, by adjusting the output of the signal generator, at the intermediate frequency, to obtain a suitable reading on the D.C. valve voltmeter connected to the grid of the limiter. The output of the generator is then doubled and its frequency varied until the deflection of the meter falls to its original level. This test is carried out above and below the I.F. frequency. The band width between these two points, at 6 db down, is not to be under a stipulated value, according to the rated maximum deviation of the particular wireless set.

45. The slope of the band width curve is noted by taking the spread in frequency at 60 db down, *i.e.* by increasing the output of the generator 1,000 times and restoring the voltmeter reading to normal by varying the frequency. In this case the ideal setting is the minimum practical width obtainable, and pending the issue of the approved specification figures comparison with a known good set is suggested.

R.F. ALIGNMENT

46. The output of the A.M. signal generator is applied to the appropriate point and the D.C. valve voltmeter connected in the limiter grid circuit as in the I.F. alignment. The alignment procedure is then exactly the same as for A.M. reception sets, but using an unmodulated carrier, *i.e.* oscillator alignment, R.F. trimming and calibration checking. It is necessary to check the design of the oscillator circuit, for it is possible that in the F.M. reception sets, the oscillator frequency may be tuned to the signal frequency *minus* the intermediate frequency. The readings of the D.C. valve voltmeter plotted against their respective signal generator input voltages will give a measure of the efficiency of the R.F. and I.F. stages and can be compared with those obtained on other sets of the same type.

RECEIVER OUTPUT MEASUREMENTS

47. The signal generator is connected to the input of the

receiver and the D.C. valve voltmeter across the diodes of the discriminator. The signal generator frequency is varied in steps of 5 kc. up to the rated maximum deviation of the particular wireless set. The readings at these respective settings, above and below the mid-band signal frequency are noted. These readings will give the peak value of A.F. signal at the discriminator output for a given frequency deviation of the input signal. A signal of this amplitude from the B.F.O. is now applied at the input to the A.F. amplifier and the output read on an output meter plugged in the phone jack. The tone and volume controls should be set to obtain maximum output. The figures thus obtained represent the deviation sensitivity of the set for a given frequency deviation of the R.F. signal.

48. In the absence of a frequency modulated signal generator the relative sensitivity between F.M. receivers of the same type can be judged by means of the quieting signal; this is the least value of unmodulated signal that will depress the noise level by a given amount, say 20 db, by saturating the limiter valve and thereby cutting off peaks due to random noise. The signal is applied through the appropriate dummy aerial.

SENDER AND RECEIVER PRECISION MEASUREMENTS, USING F.M. TESTING EQUIPMENT

49. The sender unmodulated carrier output is tested in the usual manner by measurement of the power in a standard dummy aerial. The frequency deviation is measured by modulating the carrier to a given depth and measuring the deviation direct on a deviation meter. Such instruments are not available at present, but are in course of development.

50. As regards the receiver, the only need for a F.M. signal generator is to measure the overall performance. This is carried out by connecting the signal generator to the input of the receiver *via* an appropriate dummy aerial and measuring the output into a standard output circuit.

SPECIFICATION FOR TESTING AND EXPRESSING OVERALL PERFORMANCE OF F.M. EQUIPMENT

51. An agreed testing technique for the manufacturers and the services is being investigated, but has not yet been finally decided. The following extracts from tentative specifications are therefore included as an indication of the form in which the final specification is likely to appear, for the guidance of workshops in testing this type of equipment.

Standard test frequencies

52. For sets with less than three to one frequency coverage, the standard test frequencies shall be chosen approximately as follows :—

One at the mid frequency of the band and two more one-sixth of the frequency range from each of the band.

53. For sets with greater than three to one coverage, additional frequencies, if any, shall be chosen at approximately one-sixth of the frequency range from the mid frequency. Where only one test frequency is employed this shall be the mid frequency of the band.

Standard test modulation

54. Standard test modulation is 900 cyc. to a deviation of 30% of the rated maximum deviation of the system.

Standard deviation

55. The maximum rated deviation is fixed at 5 kc. in the 2–12 Mc. band and 15 kc. in the 20–60 Mc. band.

Standard output

56. The standard output is 5 mW measured in a non-reactive load replacing two pairs of telephones in parallel. This load shall be 120Ω for two pairs of DLR or moving coil telephones. If for any set the load is normally one pair of telephones the load shall be 240Ω.

Standard dummy aerial

57. (*a*) For receivers to be connected to a low-impedance transmission line, the standard dummy aerial shall be a resistance of 70Ω.

(*b*) For receivers to be connected to other specific forms of aerial, the standard dummy aerial shall reproduce the constants of such aerials.

Overall sensitivity

58. The overall sensitivity is expressed as the least value of signal with standard test modulation, which, when applied through the appropriate dummy aerial, produces from the applied signal the standard test output. All controls shall be adjusted for maximum gain and a 900 cyc. filter may be used to remove output due to noise. The overall sensitivity is to be expressed in μV.

Useful sensitivity

59. The useful sensitivity is the lowest value of unmodulated carrier which, when applied through the appropriate dummy aerial will produce a noise output 10 db below the output produced when the same carrier is modulated with standard test modulation. Any tone controls should be set for the best approximation to a level audio frequency response curve and all gain controls adjusted to maximum output. No extraneous noise should be present in the above test, *i.e.* the noise should be due only to the thermal noise of the first tuned stages. It is measured on a meter having the same time constants as given in B.S.S. 727. The useful sensitivity is to be expressed in μV.

Quieting signal

60. The quieting signal is the least value of unmodulated signal which, when applied through the appropriate dummy aerial, depresses the random noise level by 20 db. The position of the controls should be stated and any low frequency volume control should be set so that no overloading takes place in the low frequency portion of the receiver. Any radio frequency gain controls should be set to maximum. No extraneous noise should be present, *i.e.* the noise measured should be due to the thermal noise in the first tuned circuit and be measured on a meter having the same constants as given in B.S.S. 727. The quieting signal is to be expressed in μV.

MATHEMATICAL TREATMENT

Theory of reactance valve

61. Referring to the equivalent circuit in Fig. 1,

Let E = voltage across L_1

e_g = voltage applied to grid of V_2

g = mutual conductance of V_2

Z = equivalent impedance presented by V_2 and associated circuits across L_1.

$E = g\, e_g\, Z.$

$$\text{Now } e_g = E \frac{\frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{E}{j\omega C_1 R_1 + 1}$$

$$Z = E\,\frac{j\omega C_1 R_1 + 1}{g\,E}$$

$$= j\omega \frac{C_1 R_1}{g} + \frac{1}{g}$$

$$= j\omega L' + R'$$

$$\text{where } L' = \frac{C_1 R_1}{g},\ R' = \frac{1}{g}$$

Thus the impedance presented across L1 includes a virtual inductance of value $\frac{C_1 R_1}{g}$, and since g can be varied by varying the bias applied to the grid of V2, the value of the virtual inductance and therefore the frequency of oscillation of V1 vary with the voltage impressed on the grid of V2.

The condition for resonance in the oscillatory circuit is

$$\omega\left(\frac{L_1 L'}{L_1 + L'}\right) = \frac{1}{\omega C_3}$$

$$\therefore\quad \omega^2 = \frac{1}{C_3}\left(\frac{L_1 + \frac{C_1 R_1}{g}}{\frac{L_1 C_1 R_1}{g}}\right)$$

$$\therefore\quad f = \frac{1}{2\pi}\cdot\sqrt{\frac{1}{C_3}\cdot\frac{L_1 g + C_1 R_1}{L_1 C_1 R_1}}$$

The alteration in frequency df for a small change dg in the mutual conductance of V2 is found as follows:

$$f^2 = \frac{1}{4\pi^2}\cdot\frac{L_1 g + C_1 R_1}{L_1 C_1 R_1 C_3}$$

$$\therefore 2f\,.\,df = \frac{L_1\,dg}{4\pi^2 L_1 C_1 R_1 C_3}$$

$$\therefore df = \frac{dg}{4\pi^2 C_1 R_1 C}\cdot\pi\cdot\sqrt{\frac{L_1 C_1 R_1 C_3}{L_1 g + C_1 R_1}}$$

$$= \frac{1}{4\pi\, C_1 R_1}\cdot\sqrt{\frac{L_1}{C_3}\cdot\frac{C_1 R_1}{L_1 g + C_1 R_1}}\cdot dg$$

$$= \frac{1}{4\pi\, C_1 R_1}\cdot\sqrt{\frac{L_1}{C_3}}\cdot dg\,.\sqrt{\frac{1}{1 + \frac{L_1 g}{C_1 R_1}}}$$

Here, assuming normal values of components,

$$\frac{L_1 g}{C_1 R_1} \ll 1$$

and the last term is approximately equal to 1.

$$\therefore\ df = \frac{1}{4\pi\, C_1 R_1}\cdot\sqrt{\frac{L_1}{C_3}}\,.\,dg$$

Normal values in the circuit given in Fig. 1 for a frequency of 5 Mc. are:

$L_1 = 10\mu H$
$C_3 = 100\mu\mu F$
$C_1 = 25\mu\mu F$
$R_1 = 20k\Omega$

Thus for a change dg of 1 mA/V, by substitution in the above formula, df $\doteqdot$ 50 kc.

Theory of phase and frequency modulation

62. The difference between phase modulation and frequency modulation is best explained by a brief mathematical analysis.

Adopting the usual convention of representing a sinusoidal voltage by a vector rotating with angular frequency of ω radians per second,

$$v = A \sin\theta$$

$$\text{where } \theta = \int \omega dt + \phi$$

Three methods of modulating this voltage are now available.

Amplitude Modulation.

$A = A' + A \sin pt$, where p is the angular frequency of the audio modulating voltage.

$$\theta = \omega t + \phi$$

$$\therefore v = (A' + A \sin pt)\sin(\omega t + \phi)\ .\ .\ .\ .\ .\ (1)$$

Phase Modulation..

$$\phi = \phi' + \delta\phi \sin pt$$

$$\theta = \int \omega dt + \delta\phi \sin pt + \phi'$$

$$\therefore v \doteq A \sin(\omega t + \delta\phi \sin pt + \phi')\ .\ .\ .\ .\ (2)$$

Frequency Modulation.

$$\omega = \omega' + \delta\omega \sin pt$$

$$\theta = \int(\omega' + \delta\omega \sin pt)\,dt + \phi$$

$$= \omega' t - \frac{\delta\omega}{p}\cos pt + \phi$$

$$\therefore v = A \sin(\omega' t - \frac{\delta\omega}{p}\cos pt + \phi)\ .\ .\ .\ .\ (3)$$

Thus it will be seen that in phase modulation the extent of the phase shift of the carrier is independent of the frequency of the modulating voltage: in frequency modulation the extent of the phase shift is inversely proportional to the frequency of the modulating voltage.

Clearly a system which would normally produce phase modulation will produce frequency modulation if a network is introduced to perform the above correction. This is done in the F.M. transmitter described in para. 7 above.

Referring to Fig. 2,

Output at A = $A \sin \omega t$

and Output from audio amplifier = $A' \sin pt$

$\therefore$ Output from modulator = $B \sin \omega t \sin pt$

$\therefore$ Output at B = $B \cos \omega t \sin pt$, since the phase-shifting network introduces a phase shift of 90° at the carrier frequency.

$\therefore$ Input to $A_2 = C \sin \omega t + B \cos \omega t \sin pt$
$= k \sin (\omega t + \psi)$
where $k \cos \psi = C$
and $k \sin\psi = B \sin pt$
$\therefore \quad k^2 = C^2 + B^2 \sin^2 pt$
$= C^2 (1 + \frac{B^2}{C^2} \sin^2 pt)$
$\doteqdot C^2$, since due to the amplification of A_1, C is much greater than B.

Also $\tan \psi = \frac{B}{C} \sin pt \doteqdot \psi$

$\therefore$ Input to $A_2 \doteqdot C \sin (\omega t + \frac{B}{C} \sin pt)$.

This by comparison with equation (2) above is a phase-modulated wave, where $\delta\phi = \frac{B}{C}$ and $\phi' = 0$.

Now insert in the audio amplifier a network making the amplification inversely proportional to frequency.

Output from audio amplifier $= \frac{A}{p} \sin pt$

$\therefore$ Output from modulator $= \frac{B}{p} \sin \omega t \sin pt$

$\therefore$ Input to $A_2 = C \sin \omega t + \frac{B}{p} \cos \omega t \sin pt$
$= k \sin (\omega t + \psi')$
where $k \cos \psi' = C$
and $k \sin \psi' = \frac{B}{p} \sin pt$
$\therefore \quad k^2 \doteqdot C^2$ as before
and $\tan \psi' \doteqdot \psi' = \frac{B}{pC} \sin pt$

Input to $A_2 \doteqdot C \sin (\omega t + \frac{B}{pC} \sin pt)$.

This by comparison with equation (3) above is a frequency-modulated wave, where $\delta\omega = \frac{B}{C}$ and $\phi = \frac{3\pi}{4}$.

END

ALIGNMENT PROCEDURE FOR F.M. EQUIPMENTS USING A.M. TEST GEAR

GENERAL

63. The following paragraphs give a complete alignment procedure for F.M. equipments using A.M. test equipment. This procedure is given in general terms and it is not intended to apply to any specific equipment. All detailed information will be given in the E.M.E.Rs. on the individual equipments.

64. The symbols used are given in Table 1.

Symbol	*Units*	*Meaning*
fa	cycles/sec.	An audio frequency in the speech range (300—3,000c/s)
fc	cycles/sec.	A radio frequency (several megacycles/sec), or the mean I.F.
fd	cycles/sec.	The maximum (or peak) value of a sinusoidal frequency variation about a mean value of fc
fd (max.)	cycles/sec.	The known largest deviation for which any specific set is designed—corresponds to 100% modulation in A.M.
Va, Vc	volts	The maximum (or peak) value of A.C. voltages
β	radians	The maximum (or peak) value of an angle which varies sinusoidally with time

Table 1—Symbols used in this regulation

65. In the case of a combined sender and receiver any crystal oscillator should be aligned first and used as a frequency standard for further adjustments. Should the receiver provide an A.F.C. bias to the sender reactance valve, then the sender should be calibrated against the receiver. Sender-mixer sets will usually be found more convenient to calibrate as receivers. Other things being equal, however, if the receiver can be run at the same time as the sender, then the A.F. output from a discriminator whose calibration has been determined can be used to check the fd of the sender.

66. F.M. receivers which cater for more than one fd (max.) will have corresponding variable selectivity in the I.F. stages, in which case it may be found more convenient to align the I.F. stages on the narrowest bandwidth position. All I.F. tests and R.F. sensitivity test should be repeated for each bandwidth, ensuring that the mid-I.F. and the centre of the discriminator characteristic are identical. In some designs the A.F. output corresponding to fd (max.) on each bandwidth may have been maintained constant by modifying the slope of the discriminator characteristic and/or the gain of the A.F. amplifier.

67. Similar remarks apply to A.M./F.M. receivers which will normally be found easier to align on A.M., using a modulated signal and output meter. On F.M. it will then be necessary to check I.F. bandwidth, limiter characteristic and to align the discriminator to the mid-I.F.

68. The performance of a V.V. on D.C. can be improved by connecting a 0·1µF condenser between the direct and low terminals on the probe and inserting a 1MΩ resistor at the set end of each of the two leads. The earth of the V.V. should be connected to the chassis of the set. This will be of particular assistance in obtaining equality of positive and negative voltages across the discriminator load.

69. If available, a D.C. microammeter (preferably of the centre-zero type) with a suitable series resistor will often prove more convenient than a V.V. for D.C. voltage indications.

RECEIVER

I.F. alignment and bandwidth

70. (*a*) *Input*. S.S.G., unmodulated to mixer grid at nominal I.F.

(*b*) *Output*. D.C. V.V. across earthy portion of limiter grid resistor, adjust input for about 1V output. Where there are two limiters, the D.C. V.V. should be placed across the first limiter grid resistor.

(*c*) *Method*. Squelch off, A.V.C. off or shorted out. Align I.F. stage in usual fashion; if heavily over-coupled the required damping resistor may be 1kΩ—5kΩ. Bandwidth at 6db. down should equal 2 fd (max.) + 2 fa (max.). The cut-off slope outside these points should be steep. Align any C.W. oscillator to mid-I.F.

Limiter characteristics

71. (*a*) *Input*. S.S.G. unmodulated to mixer grid at mid-I.F.

(*b*) *Output*. A valve voltmeter from the anode of the limiter valve to chassis and a D.C. V.V. (or high-resistance meter) across the slide-back resistor in the grid circuit (see Fig. 12).

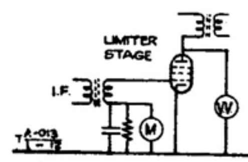


Fig. 12—Limiter characteristic

(*c*) *Method*. Increase the output of the S.S.G. The reading of the meter in the grid circuit should increase due to slide-back action, whilst the anode reading should remain constant due to the limiting action of the valve. A check can also be made by feeding in an A.M. signal of varying degrees of modulating depth and observing the limiter output on a C.R.O.

I.F. sensitivity

72. (*a*) *Input and output*. As in sub-paras. 70 (*a*) and (*b*).

(*b*) *Method*. If a limiter grid D.C. voltage is specified

Distribution—Class 800. Codes Nos. 4 and 5 for the receiver, note the required input. Otherwise take the arbitrary input level (*a*) of Fig. 13.

Discriminator primary (Foster-Seely circuit)

73. (*a*) *Input.* S.S.G. unmodulated to mixer grid at mid-I.F., signal level to lie between (*b*) and (*c*) in Fig. 13.

(*b*) *Output.* D.C. V.V. across *half* discriminator lead (or across whole load if secondary is slightly mistuned to give a small reading).

(*c*) *Method.* Tune primary (limiter anode circuit) for max. reading.

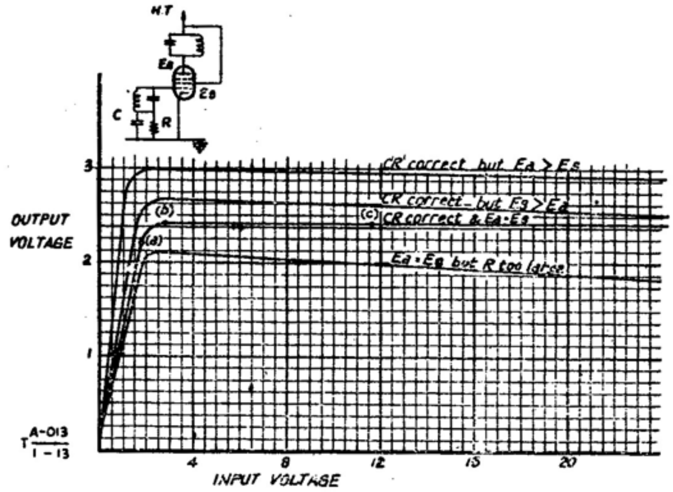


Fig. 13—Correct and incorrect operation of limiter circuit

Discriminator secondary (Foster-Seely circuit)

74. (*a*) *Input.* S.S.G. unmodulated to mixer grid at mid-I.F. ± (fd + fa), signal level to lie between (*b*) and (*c*) in Fig. 13.

(*b*) *Output.* D.C. V.V. across *whole* load, reversing connections as necessary when voltage changes in polarity.

(*c*) *Method.* With input at mid-I.F., tune secondary until output passes *through* zero ; leave set exactly for zero output. Vary input frequency and graph output voltage against input frequency up to ±(fd + fa). Check linearity, readjusting primary, if necessary, to obtain equality of positive and negative readings within 10%. Note V.V. reading for this max. deviation (*d*).

(*d*) Repeat operations given in paras. 73 and 74 until satisfactory results are obtained.

A.F. amplifier

75. (*a*) *Input.* B.F.O. (through high resistance) across whole discriminator load, with A.F. V.V. reading input across discriminator.

(*b*) *Output.* O.P.M. matched to receiver.

(*c*) *Method. F.M:* fa 900c/s—check that output power is approximately proportional to the square of the input voltage up to the V.V. reading obtained as in para. 74 (*d*). Check that with a constant input voltage the output is reasonably independent of fa between 300 and 3,000c/s.

P.M. : fa 3,000c/s—check that output is proportional to square of input, as for F.M. When fa is reduced it should be necessary to reduce Va in the same proportion to maintain a constant power output. That is, the gain of the amplifier should increase 6db. when fa is halved (lowered one octave).

R.F. calibration

76. (*a*) *Input.* S.S.G. unmodulated to mixer grid or aerial terminal.

(*b*) *Output.* D.C. V.V. across whole discriminator load, as in para. 74.

(*c*) *Method.* Disconnect any A.F.C. to L.O. Check S.S.G. frequency against a standard and then adjust L.O. trimmers and padders for zero output from discriminator at appropriate tracking points. Alternatively, if a C.W. oscillator can be fed into the limiter anode circuit exactly at mid-I.F., the zero-beat method can be used with 'phones. Local oscillator may be *below* signal frequency.

R.F. alignment

77. (*a*) *Input.* S.S.G. unmodulated to aerial terminal.

(*b*) *Output.* As for I.F. alignment in sub-para. 70 (*b*).

(*c*) *Method.* Tune receiver or S.S.G. for zero beat or zero output across discriminator. Adjust R.F. circuits for max. output across limiter grid circuit.

R.F. sensitivity

78. As for I.F. sensitivity (para. 72) to give a specified D.C. voltage at limiter grid.

Miscellaneous receiver tests

79. (*a*) *Second channel (image) ratio.* As for A.M., output at limiter grid.

(*b*) *I.F. breakthrough.* As for A.M., output at limiter grid.

(*c*) *A.V.C.* Purpose to prevent overloading of stages previous to limiter ; sometimes the action of the limiter may be assisted by a lower value of A.V.C. time-constant, thus feeding back a portion of the demodulated A.M. Test as for A.M. output at limiter grid. In general the set should be tuned with a low input voltage and the L.F. output set to a high arbitrary level. The drop in output should then be noted on reducing the R.F. input to a given low value.

(*d*) *Squelch (or Q.A.V.C. or inter-station noise suppression).* Check range of variable control: should operate with any aerial input from 2—5µV up to well above limiter threshold. If on I.F., circuits should be accurately tuned to mid-I.F.

(*e*) *Tuning and netting.* The fact that the D.C. output from the discriminator is zero at fc can be utilized to operate a visual tuning device, such as a magic eye or meter, in order that the operator can tune his receiver accurately to a distant transmission and subsequently tune his sender to the same frequency. In the case of a magic eye the bias may need adjustment for correct indications. In some sets a C.W. oscillator at mid-I.F. may be employed as in A.M. sets.

(*f*) *Signal/noise ratio.* With squelch and C.W.

oscillator switched off, note the minimum unmodulated signal input at aerial to reduce the random noise level by 20db. (quieting signal).

(g) *Frequency stability*. A greater degree of short-term L.O. frequency stability is required than in A.M. Check the local oscillator against a crystal oscillator.

SENDER

Calibration

80. M.O. may run at a sub-multiple of emitted frequency; check against suitable standard, as for A.M. Ensure that modulation stages are inoperative and short any A.F.C. line from receiver to reactance valve. To prevent damage to subsequent stages it may be advisable to reduce their anode and screen voltages, or to over-bias them until they have been tuned. The receiver may be taken as the frequency standard, in which case the A.F.C. bias will be the indication. The P.M. or indirect F.M. senders (which do not employ a reactance valve) the M.O may be crystal-controlled, thus needing no calibration.

Alignment and power output

81. Tune each circuit for either minimum anode current of the preceding valve or maximum grid or anode current of the following valves, being careful to see that the following valve does not pass excessive anode current due to its anode circuit being mistuned. This is of particular importance in the P.A. stage. Where frequency multiplication is used, the usual precautions must be taken to guard against selecting an incorrect harmonic. Finally, tune the unloaded P.A. tank circuit for minimum anode current, connect a suitable dummy aerial with series thermo-ammeter or parallel valve voltmeter and proceed to load the P.A.

A.F. stages (modulation amplifier)

82. (a) *Input*. B.F.O. via suitable attenuator to microphone jack.

(b) *Output*.

(i) F.M. (reactance valve): A.F. V.V. at grid of reactance valve, M.O. inoperative, or keep R.F. from V.V.

(ii) P.M. (Armstrong's system): A.F. V.V. across one or both halves of secondary of A.F. transformer which feeds balanced modulator.

(iii) P.M. (saturated choke): A.C. milliammeter in series with output, taking care to insert at a point which has no R.F.

(c) *Method*. With fixed fa, 900c/s-check limits with which output is proportional to input (sensitivity and amplitude linearity). Maintaining a constant output at a suitable low level, vary fa 300—3,000c/s and determine whether the input voltage required is:—

(i) Independent of fa: direct F.M. or P.M.,

(ii) Proportional to fa: indirect F.M., or

(iii) Inversely proportional to fa: indirect P.M.

A.M.C., where included, should operate at a specific input level. Check delay and efficiency.

Modulated stage, static tests

83. Before any deductions are made from these tests check that the performance on A.C. and D.C. is essentially similar.

84. P.M.: no static tests can conveniently be applied.

85. F.M.: Short any A.F.C. bias from receiver discriminator: ensure no output from A.F. stages. Determine standing D.C. bias between cathode of the reactance valve and the grid to which the A.F. is applied. This must be taken at a point in the grid circuit which is cold to the R.F. from the M.O. Between this point and the cathode arrange a D.C. source which can be continuously varied from zero to twice this standing bias. Apply the normal standing bias and tune in the emitted carrier to zero beat in a wavemeter or receiver equipped with a C.W. oscillator. Vary the D.C. bias each side of its standing value and measure the change in emitted frequency by any convenient method. If necessary, alter the standing bias to a value which gives a linear voltage frequency relationship between the limits of $\pm$ fd (max.).

86. The A.F. stages should be capable of providing *peak* output voltage without distortion equal to the D.C. voltage which produced fd (max.) above. A.M.C. delay should be adjusted to prevent this output being exceeded.

87. Calibration will be affected by any change in bias of the reactance valve. The reactance valve is usually of the same nature as the fixed reactance in the oscillatory circuit, in which case it may be adjusted for calibration at the L.F. end.

Carrier modulation, dynamic tests

Measurement of fd by previously calibrated discriminator (or a deviation meter, if available).

88. Sender output unmodulated at any suitable fc. Tune an aligned F.M. or P.M. receiver whose fd (max.) equals or exceeds the fd (max.) of the sender to same frequency so that there is zero D.C. output from the discriminator. The coupling to sender must be sufficient to operate above the limiter threshold point. Connect an R.M.S. calibrated A.F. V.V. across discriminator and B.F.O. via suitable attenuator to microphone socket of sender. Modulate the sender at 900c/s and increase input voltage (Va) until the discriminator output voltage (Vc) indicates that fd (max.) is attained.

(a) Amplitude linearity, keeping fa constant, fd should be directly proportional to Va.

(b) Frequency linearity, keeping Va constant and varying fa between, say, 300 to 3,000c/s.:—

F.M.: fd to be independent of fa.

P.M.: $\beta \left(=\frac{fd}{fa}\right)$ to be independent of fa.

Measurement of B, using the Bessel function relationship between amplitudes of carrier and sidebands.

89. (a) Tune to the unmodulated carrier with an A.M. receiver which incorporates a sharp I.F. crystal filter. With the A.V.C. switched off, measure with a V.V. either the R.F. applied to the signal diode (retuning the last I.F. secondary as necessary) or the D.C. developed across the earthy portion of the diode lead. Modulate the sender, fa to be high enough compared with the filter bandwidth at —20db. to ensure that adjacent sidebands do not pass the filter. The V.V. will thus indicate the carrier amplitude, which will be

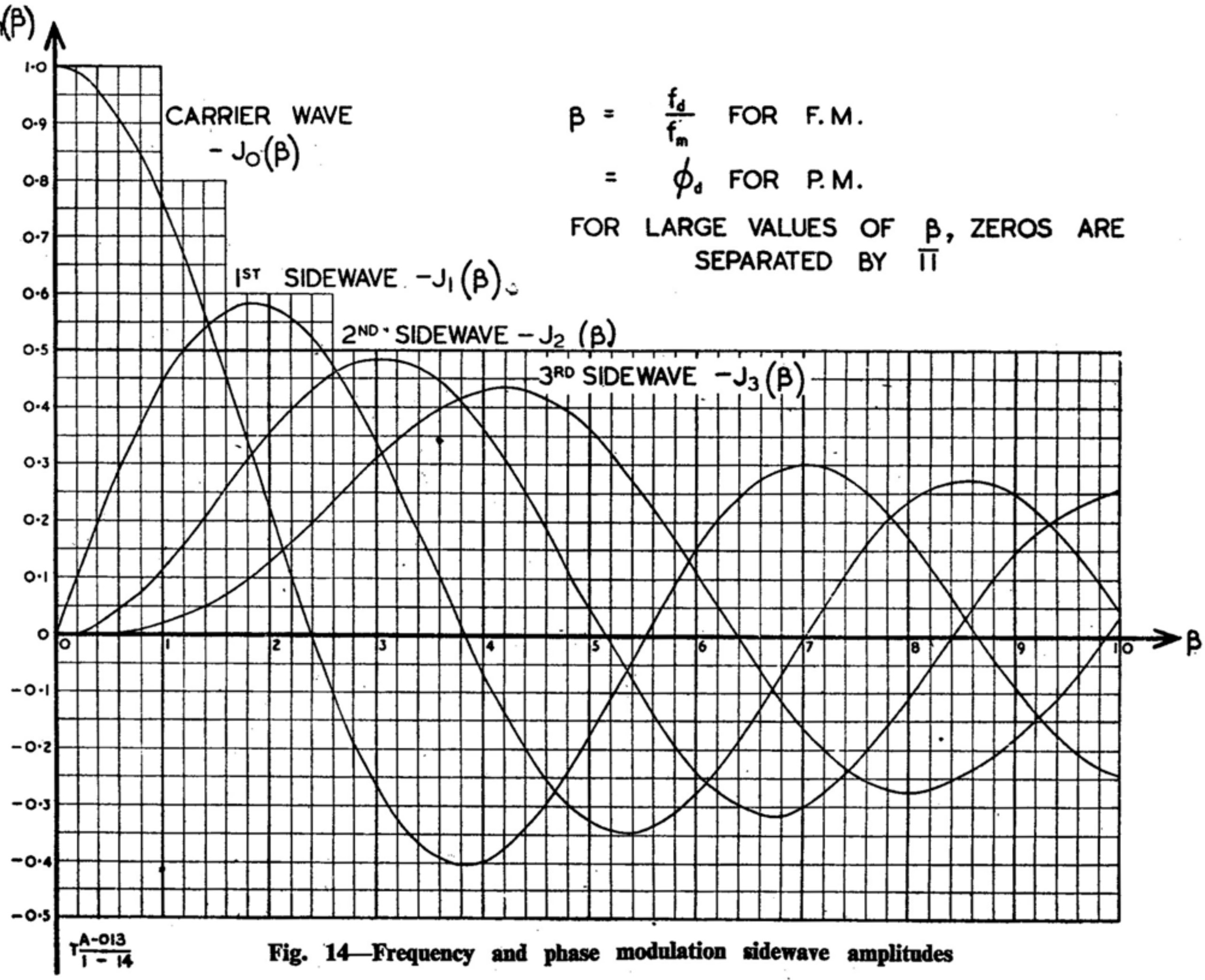


Fig. 14—Frequency and phase modulation sidewave amplitudes

B	N	Bandwidth A	Bandwidth B
24	29	58	2·4
21	26	52	2·5
18	23	46	2·5
15	19	38	2·5
12	16	32	2·7
10	14	28	2·8
9	13	26	2·9
8	12	24	3·0
7	11	22	3·1
6	9	18	3·0
5	8	16	3·2
4	7	14	3·5
3	6	12	4·0
2	4	8	4·0
1	3	6	6·0

Table 1—Bandwidths (see Fig. 14)

Notes.

1. *B*: Is the modulation index defined above.
2. *N*: Is the number of pairs of sidewaves required to include all those of greater amplitude than 0·01 of the carrier amplitude.
3. *A*: Gives the bandwidth as a multiple of fm.
4. *B*: Gives the bandwidth as a multiple of fd.
5. Maximum bandwidth required by a system is that which corresponds :—
   For F.M., to maximum fd and maximum fm
   For P.M., to maximum ød and maximum fm.

zero when $\beta = 2{\cdot}4$ radians and become zero again when $\beta = 5{\cdot}5$, $8{\cdot}7$ etc. The relative amplitude of any sideband can be similarly determined, provided the receiver can be sufficiently accurately tuned, and other values of β ascertained with the aid of tables or graphs of Bessel functions.

(i) Amplitude linearity, keeping fa constant, β be directly proportional to Va.

(ii) Frequency linearity, keeping Va constant and varying fa from the lower limit set by the receiver crystal filter up to, say, 3,000c/s :—

F.M. : fd ($=$fa $\times$ β) to be independent of fa.
P.M. : β to be independent of fa.

(*b*) Alternatively, if a ganging oscillator or its harmonics be substituted for the receiver local oscillator and the D.C. V.V. replaced by a C.R.O. whose time-base frequency modulates the G.O., then a number of sideband amplitudes can be compared on the C.R.O. screen. It will be found necessary to use the C.R.O. amplifiers and to feed the G.O. into the receiver aerial terminal to obtain sufficient L.O. voltage at the mixer. This arrangement is sometimes referred to as a " Panoramic Monitor."

Measurement of transmitter frequency deviation with wide-band F.M.

90. (*a*) It is required to check that a variation of modulating voltage gives a corresponding linear variation of deviation frequency up to the maximum fd specified for the set. In order to measure the deviation frequency, use is made of the fact that for a cerain modulating voltage and ceratin modulating frequency, the carrier disappears. The carrier amplitude falls to zero when :—

$$\frac{fd}{fa} = 2{\cdot}4 \text{ or } 5{\cdot}5 \text{ or } 8{\cdot}7$$ according to the A.F. amplitude. Hence if the A.F. voltage at which the carrier amplitude has fallen to zero can be ascertained, the fd can easily be calculated from the above expression.

(*b*) Connect a B.F.O. to the microphone input of the F.M. transmitter and couple a wavemeter to the output (see Fig. 15). It may be necessary to feed the B.F.O. output through an A.F. attenuator in order to obtain readable voltages on the valve voltmeter. With B.F.O. output at zero, adjust the wavemeter to give a beat note of about 250c/s. The provision of a low-pass filter to cut off at about 500c/s between the wavemeter and 'phones is desirable, but can be dispensed with at the expense of making the check more difficult to carry out. This 250c/s beat note indicates the presence of the carrier. Set the B.F.O. to 1kc/s and gradually increase the output voltage from zero. At a low A.F. voltage

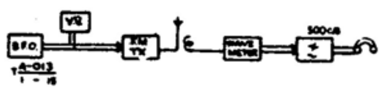


Fig. 15—Measurement of transmitter frequency deviation with wide-band F.M., using B.F.O.

a pair of sidebands will arise and the wavemeter will give the following beat notes :—
(i) 250c/s, with carrier.
(ii) 750c/s, with lower sideband.
(iii) 1,250c/s, with upper sideband.
Any further sideband will merely give beat notes of a higher pitch (Fig. 16).

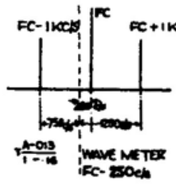


Fig. 16—Sidebands obtained with B.F.O. at 1kc/s

(*c*) The desirability of the filter to eliminate all beat notes other than that between the carrier and wavemeter is now evident, otherwise it requires a certain amount of practice to pick out the required note against the others.

(*d*) The modulating frequency (in this case 1kc/s) must not be chosen so as to be twice the difference between carrier and wavemeter, otherwise both carrier and one sideband will give the same beat note.

(*e*) Gradual increase of B.F.O. output will eventually reduce the carrier to zero, this being indicated by the disappearance of the 250c/s beat note. At this point fd$=$fa $\times$ 2·4, i.e., 2·4kc/s. The amplitude of modulating voltage can be measured on the valve voltmeter and the first plot of fd against fa is obtained.

(*f*) Another zero, and consequently another value of fd, may be obtained by increasing the modulating voltage when fd is given by fd$=$fa $\times$ 5·5.

(*g*) Change the modulating frequency and repeat the observations so as to obtain sufficient data to plot a graph of fd against the amplitude of the modulating voltage. This should be linear as in Fig. 17.

Fig. 17—Graph of A.F.C./amplitude of modulating voltage

Absence of amplitude modulation

91. This can be checked by observing the sender output on a C.R.O., a peak-reading V.V. across the dummy aerial or a R.M.S.-reading thermo-ammeter in series with the dummy aerial ; no change from the carrier condition should be observed up to the limits of modulation. Some A.M. will always be present at the modulated stage, but correct operation of subsequent stages should prevent this being radiated.

Send-receive tracking

92. With direct F.M. or indirect P.M. a correcting D.C. bias may be fed to the sender reactance valve from the receiver discriminator, possibly via a D.C. amplifier.

Correct tracking will be indicated by zero bias over the entire tuning range.

Overall fidelity, sender and receiver

93. In any particular combination of sender and receiver it may be found that neither of the A.F. amplifiers has a linear or inverse frequency law. In such cases it should be checked that when the sender is modulated from a B.F.O. and the receiver accurately tuned, the receiver is proportional to Va and independent of fa.

FAULT-FINDING

94. For purposes of fault-finding the ganging oscillator can be used as an F.M. signal generator, provided no attempt is made to use it as an accurate standard of either frequency or voltage amplitude. Being designed to operate from a saw-tooth wave form, it does not give a linear response with a sinusoidal wave form. It will, however, give a frequency-modulated signal when used with a B.F.O. which will be a useful source for a simple overall receiver check (Fig. 18).

95. Connect a B.F.O. to the X and EARTH terminals of the ganging oscillator via a step-up transformer. This latter

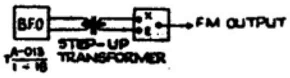


Fig. 18—Coupling of B.F.O. for fault-finding

is required because the ganging oscillator is designed to operate from a peak voltage of the order of 100V. Variation of the B.F.O. output control will vary the frequency deviation.

END

Note. Delete word END from page 14

APPENDIX 5 Mk.17

(Reprint from WftW Volume 4 Supplement Chapter 13).

Mk.17 (v1.02)

Country of origin: England

DATA SUMMARY

Organisation: MI6 SIS.

Design/Manufacturer: SIS Section VIII, Whaddon Hall/ Little Horwood workshops.

Year of Introduction: Probably 1943.

Purpose: Agents, Resistance groups.

Receiver:

- **Circuit Features:** Superheterodyne with RF stage, mixer, local oscillator, 2x IF stage, limiter, discriminator, AF output. FM R/T.
- **Intermediate Frequency:** Not known.
- **AF Output:** Headphones.
- **Valves:** 6AK5 2x, 954, 6SK7 3x, 6H6.

Transmitter:

- **Circuit features:** Master oscillator/doubler, RF power amplifier, microphone amplifier/FM modulator.
- **Valves:** 6V6 2x, 6J7.

Frequency Coverage: 30-36MHz.

Power Supply: 6V accumulator. Vibrator 4256 - G5, rectifier 6X5.

Size (cm): Height 28.5, length 27.2, width 15.2.

Weight (kg): 9.6.

Accessories: Microphone, headphones, aerial.

Serial No. 9832.

Transmitter.				Receiver.	
Freq.	M.O.	Drive.	P.A.	Freq.	Dial Read.
36	6	47	35	36	20
35	17	53	38	35	28
34	27	59	44	34	36
33	39	68	50	33	44
32	52	79	56	32	54
31	67	88	60	31	64
30	84	98	68	30	76

Frequency calibration card. It is interesting to note that the support/protection plate for the card is identical to that of the Mk.21.

REMARKS

The Mk.17 was believed the first version of the 'Ascension' simplex VHF FM communication system ground station. It allowed agents to have direct voice contact with an operator in an aircraft, flying at high altitudes, probably equipped with a wire recorder for later playback of the conversation. Full details of this system are not known though noted is the use of frequency modulation, believed for a high quality recording. The Mk. 17 was built in two separate units, bolted together and mounted in a metal case, forming a single self contained unit. Recommended reading on this topic: The Secret Wireless War, by Geoffrey Pidgeon.

Rear and side view of the Mk.17 metal enclosure.

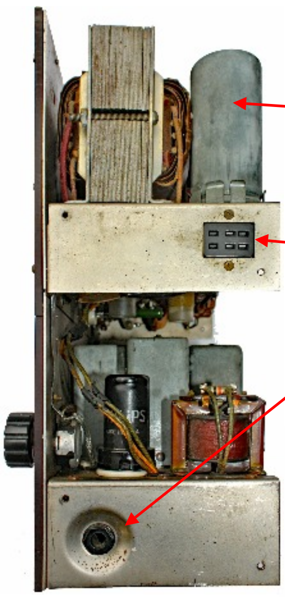
References:

- Many thanks to Eric Pierret, France, for providing the photos and general (technical) information for this chapter.
- WftW Supplements, Chapter 330, Mk.18.
- 'The Secret Wireless War', G. Pidgeon, ISBN 1-84375-252-2.

(Reprint from WftW Volume 4 Supplement Chapter 13).

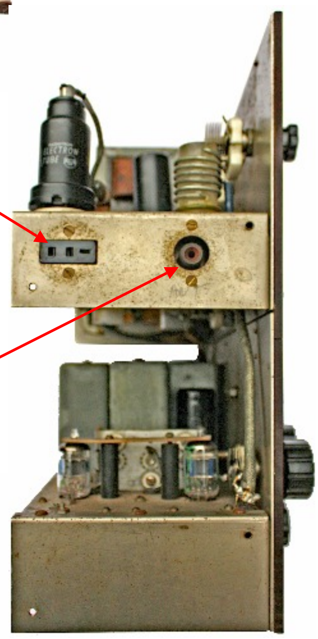
Function of controls Mk.17 receiver.

Bottom view of Mk.17 receiver chassis.

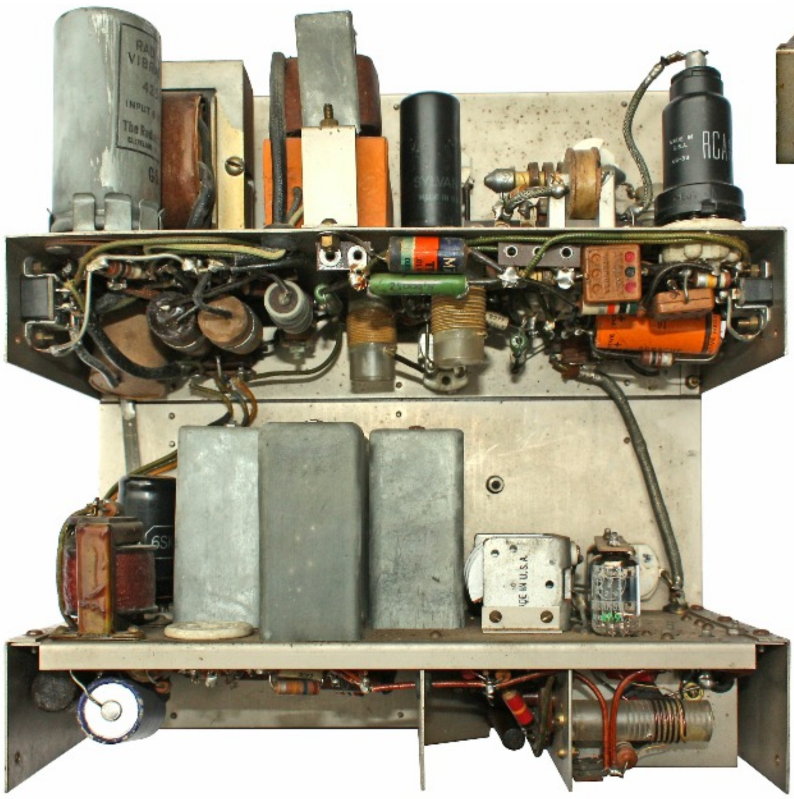


Left hand side view of Mk. 17.

[Technical note from Pete Mc-Collum: ...it appears that the microphone socket is the same as that found on a Webster-Chicago wire recorder. So perhaps the same microphone could be used?]

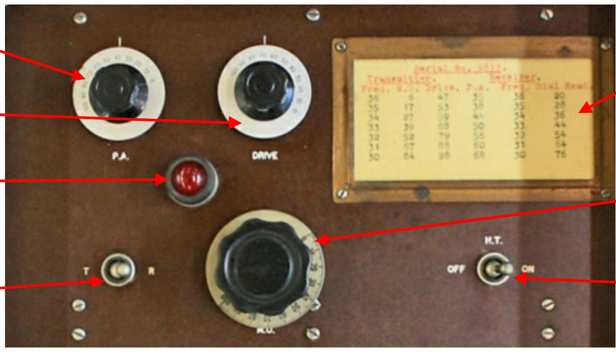


Mk. 17 right hand side view.

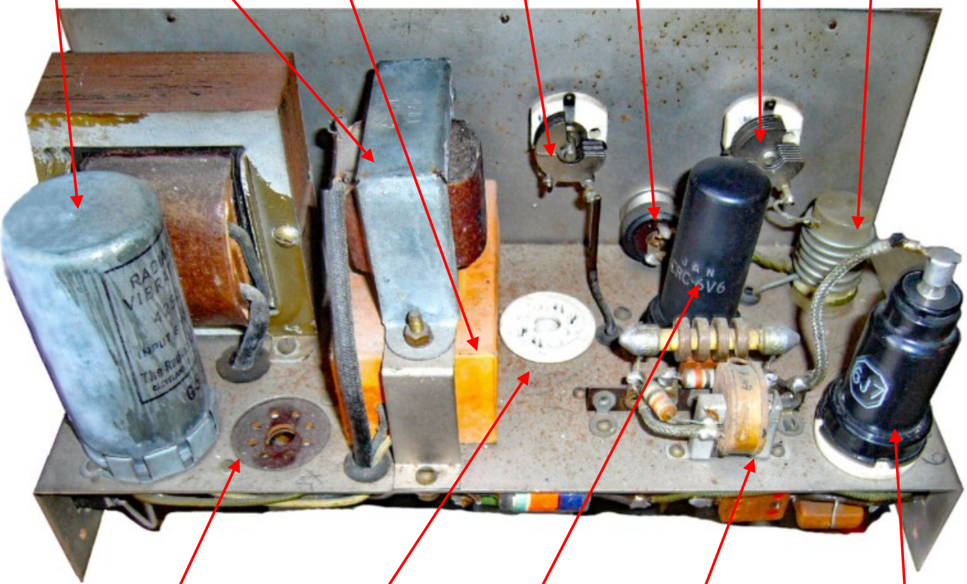


Rear view of Mk.17: transmitter (top) and receiver (bottom).

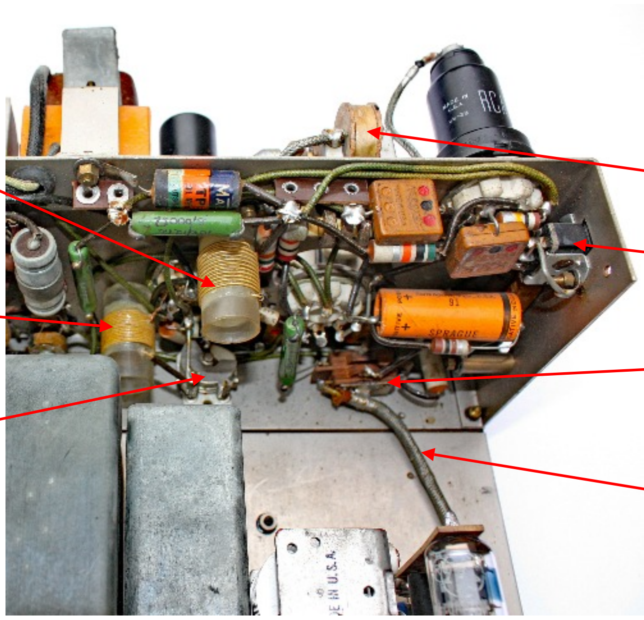
(Reprint from WftW Volume 4 Supplement Chapter 13).



Function of controls Mk.17 transmitter.



Top of Mk. 17 transmitter chassis. Note that the 6X5 rectifier and 6V6 master oscillator valves are missing.



Bottom view of Mk. 17 transmitter chassis and part of the receiver.

APPENDIX 6 Mk.18

(Reprint from WftW Volume 4
Supplement Chapter 330).

Front panel and top view of Mk.18 transmitter-receiver showing transmit (TMit.)/receive (REC.) toggle switch, transmitter RF power amplifier tuning control (left), receiver reaction (REACT.) control (centre) and receiver tuning control (right). Apertures on top of the chassis gave access to the transmitter doubler setting, and RF power amplifier tuning lamp.

Mk.18

Country of origin: England

This Supplement Chapter is a follow up of the Mk.18 section in the *'Great Britain'* chapter of WftW Volume 4.

DATA SUMMARY

Organisation: MI6 SIS.

Design/Manufacturer: SIS Section VIII, Whaddon Hall/ Little Horwood workshops.

Year of Introduction: Probably 1943/early 1944.

Purpose: Agents, Resistance groups.

Receiver:
- **Circuit Features:** RF, Det, AF.
- **Frequency Coverage:** 30-37MHz (believed).
- **AF Output:** Headphones.
- **Valves:** 9001 (2x), 9002

Transmitter:
- **Circuit Features:** Osc/Doubler, RF PA, Modulator (FM).
- **Frequency Coverage:** Preset to a frequency in the range 30-37MHz.
- **Valves:** 6V6 (2x), 6L6.

Aerial: Probably vertically polarised wire dipole.

Power Supply: Separate power supply unit providing LT and HT.

Size (cm): height 6, length 15.5, width 15.3.

Weight (kg): 1.5 (transmitter-receiver only).

Accessories: Microphone, headphones, aerial and power supply unit.

REMARKS

The Mk.18 was a simplex transmitter-receiver for voice (R/T) only. It was probably a later version of the 'Ascension' VHF FM communication system ground station allowing agents to have direct voice contact with an operator in an aircraft flying at high altitudes, equipped with complementary equipment and probably a wire recorder for later playback of the conversation. The transmitter was pre-set on a fixed frequency; the receiver was tunable over a full frequency range of 30-37MHz. The aerial (possibly a vertical wire dipole) was connected via two 4mm sockets. The RF power amplifier was tuned from the front panel on maximum brilliance of a small bulb which was located behind an opening on top of the chassis. See also the Mk.17 in Chapter 13 of the WftW Supplements.

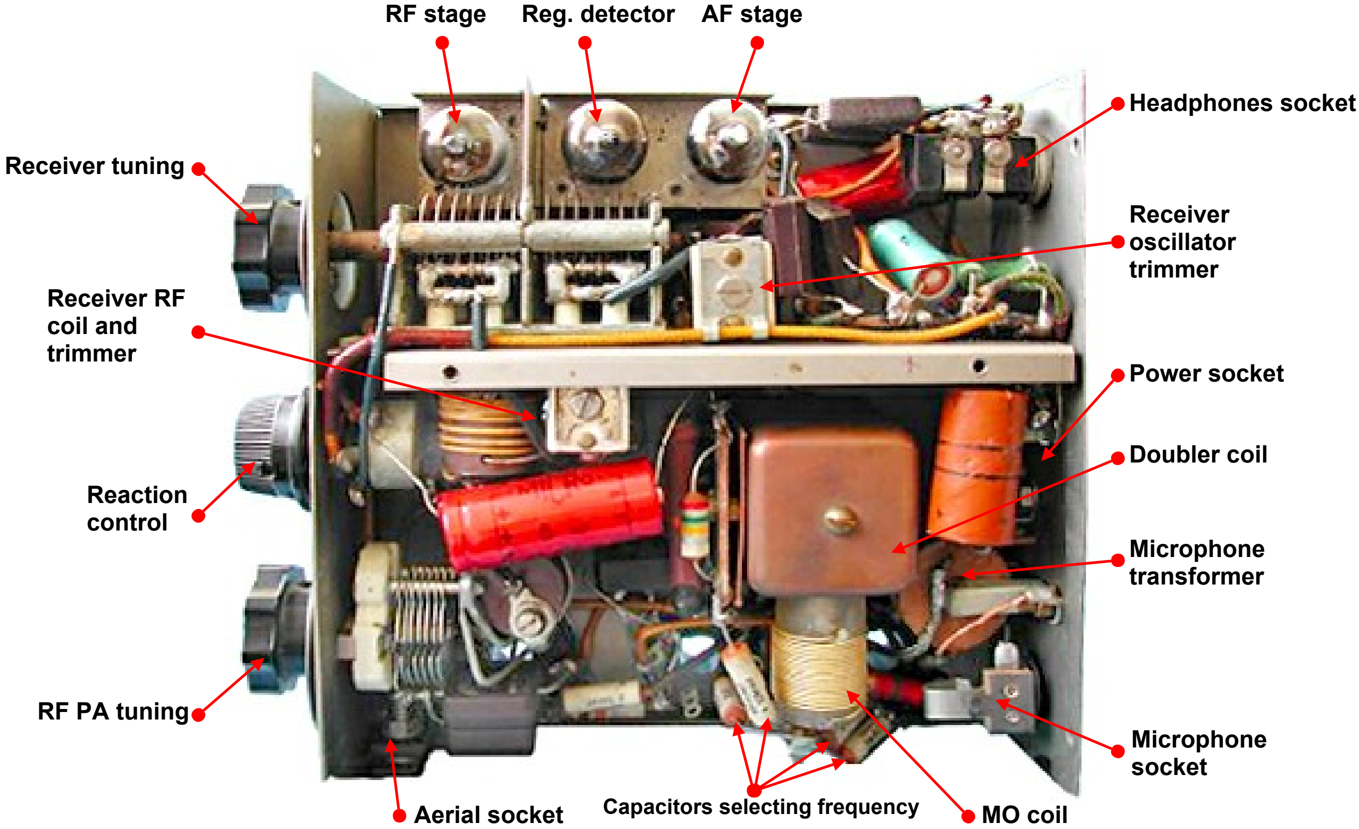
Engraved on the right hand top corner of the chassis was 'MK.18/112', believed to be the type and serial number.

Associated Publications:

- I am indebted to Eric Pierret, France, for permission to use his photographs and providing additional information.
- 'Information held on Allied Clandestine Equipment', a summary by Pat Hawker, G3VA, Mar. 2000. This document is incorporated in 'The Secret Wireless War', (Appendix 6: Agents' Sets) by G. Pidgeon, ISBN 1-84375-252-2, UPSO, 2003.
- 'Information held on Allied Clandestine Equipment', a summary by Pat Hawker, G3VA, amended April 2004.
- Wireless for the Warrior, Volume 4, Clandestine Radio, ISBN 0952063-36-0, Sept. 2004.

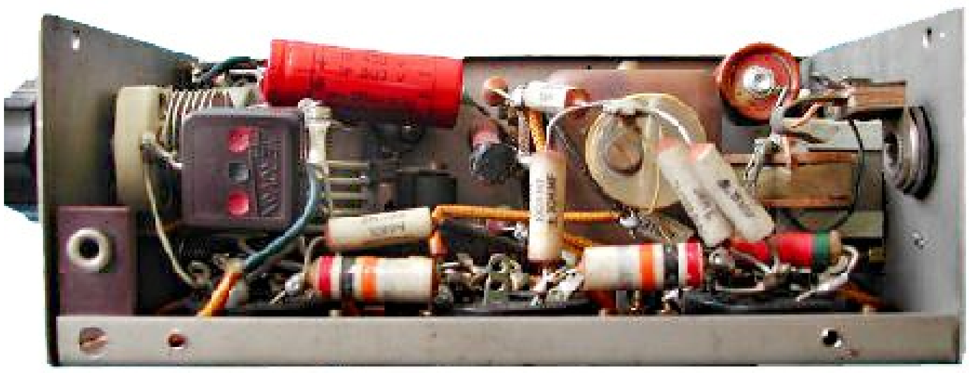
Rear view of Mk.18 transmitter-receiver chassis showing telephone and microphone sockets, a 4-pt Jones socket for connection the power supply unit, and a 4mm earth socket.

(Reprint from WftW Volume 4 Supplement Chapter 330).



Bottom view of Mk.18 chassis with cover plate removed. The top section comprised a three valve receiver and, separated by a metal partition, the lower section the transmitter and modulator. Note that the receiver RF coil and reaction control are located in the transmitter section. Although not confirmed by any surviving technical documentation, it is believed (according to the number of turns on the oscillator coil) that that the transmitter oscillator operated on half of the actual frequency. The MO frequency was fixed, determined by a number of small capacitors.

Left and right hand side views of Mk.18 showing receiver section with three miniature type valves (photograph above) and transmitter (photograph below). Note the 4mm socket in the left hand corner of the bottom picture for connecting the aerial.



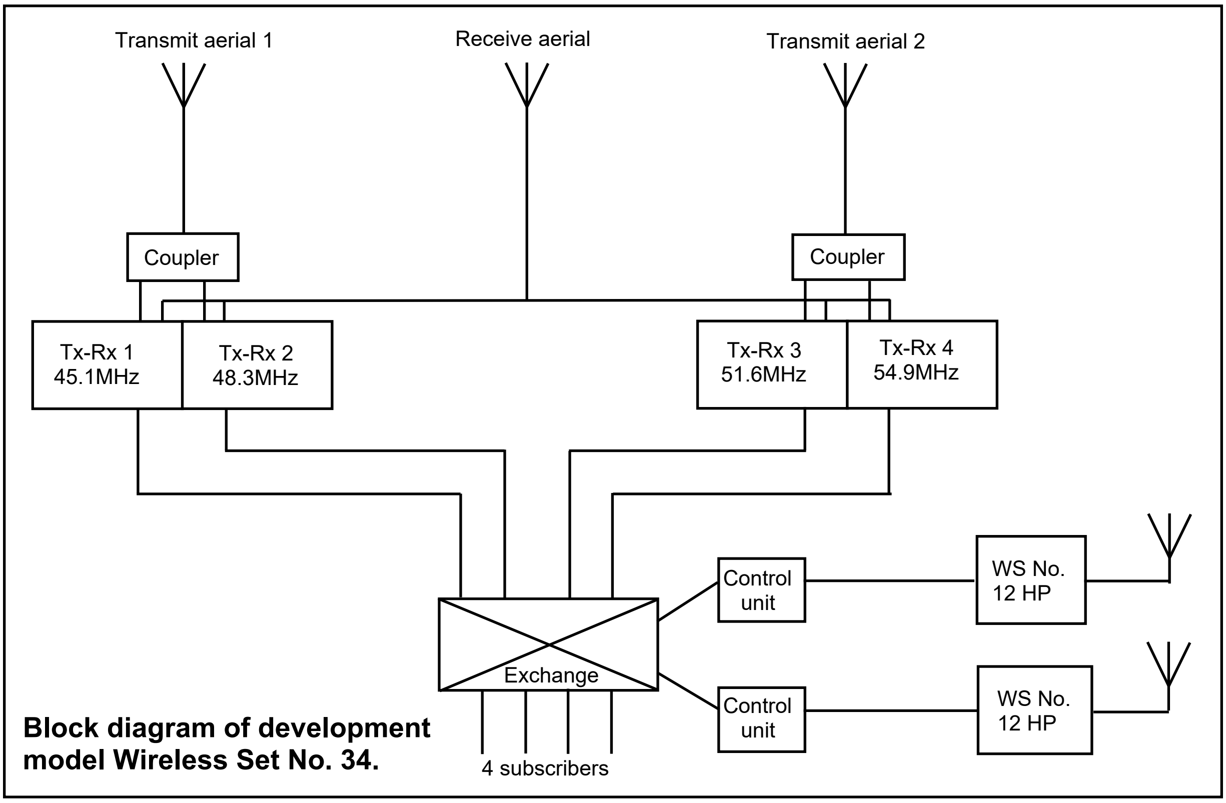
Appendix 7 Wireless Set No. 34.

Wireless Set No. 34 (Development model).

In the early and mid World War 2 period a requirement was raised for improved short range radio intercommunication facilities between Armoured Command Vehicles (ACV) in large HQs when either stationary or on the move. Wireless Set No. 14, initially developed for this purpose and issued in the early days of the war, was not considered suitable as being too complicated and bulky. This need was only partially filled by the "B" set of Wireless Set No. 19, due to the limited range of this set.
Development work was therefore started on Wireless Set No. 34 which was expected to give adequate facilities up to a range of 3 miles or more on the move.
One of the designs consisted of four complete VHF FM R/T transceivers built into a single box similar to that of the No. 19 Set. Its weight was about 60lbs excluding supply unit. Power was derived from 12V DC or AC mains. There were four channels: 45.1MHz, 48.3MHz, 51.6MHz and 54.9MHz. The frequency deviation was ± 40kHz and the range 3 miles when working on the move. Wireless Set No. 34 was intended to be used in conjunction with a Wireless Switchboard allowing the connection of the four No. 34 Set channels (and via a control unit other sets, for example No. 12 HP) to a maximum of four users.

However, during its design severe design difficulties were encountered due to interference from high power sets such as Wireless Senders Nos. 12 HP, 33, SCR-299-A, etc. These difficulties appeared to be insurmountable and no further work was done on the development of this set of which only a few prototype test models were made.

In the Middle East a local modification of Wireless Set No. 18 was produced which enabled it to operate a small loud-speaker at adequate volume. An amplifier was fitted in the battery compartment of the set, the whole operating off the normal vehicle battery and providing a suitable improvised solution to the inter ACV communication problem.



Block diagram of development model Wireless Set No. 34.

Epilogue.

History has shown that (VHF) FM is superior for short range Army communication, which was stated in Chapter 7 of S.E.E. Report No. 798. At the time of compiling this Pamphlet no other reports and minutes of War Office meetings on the use of FM during WW2 could be traced or were available.

Signal Communications, a book in one of a series of volumes, compiled by authority of the Army Council to preserve the experience gained during the Second World War stated:

'Frequency Modulation'

The United States Army had pinned its faith largely on telephones, but as a result of the British Army's experience wireless was developed rapidly, using a new technique, known as 'frequency modulation', for some of the sets used in forward units. In the ordinary type of R/T set, the voice modulated transmitted signal, operating on one frequency, but with a frequency modulated set a narrow band was used instead of a single frequency and modulation was obtained by actually changing the frequency. This had the effect of reducing a great deal of the background noise, which was such an irritating feature of wireless communication, and bringing up the wanted signal much more clearly. Technically the system offered very considerable advantages but there were two main difficulties which prevented it from being introduced into the British Army on any considerable scale while the War was actually in progress:-

a) the increased number of frequencies required

b) the impossibility of changing over any large number of sets at one time. A set designed for amplitude modulation could not work to one designed for frequency modulation and the available manufacturing capacity was not sufficient to permit of a wholesale and instantaneous change.

In *Wireless for the Warrior,* Volume 2, WS 88, page 5, we can read:

In 1944 much congestion of frequencies in the 2-10MHz band was experienced, especially in NW Europe where troop density was such that '..it is rarely possible to find interference-free channels for sets in the 18 and 38 class and almost impossible for the host of 19 and 22 Sets…' (D Signals Liaison Notes, No. 19, Jan. 1945).

Looking at the success of the USA Signal Corps VHF FM sets types SCR-508, SCR-509 and SCR-300, it became clear that the employment of VHF FM would provide the answer to this problem.

Future General Staff policy decided to introduce VHF FM and specifications were drawn up for designs of several models including a replacement for Company/Platoon Wireless Set No. 38. The new set, on which development had already been commenced, was designated Wireless Set No. X88. Two models were initially developed: No. X88A and No. X88B. The latter was supported by the War Office as it was felt that: '…the electrical performance of the X88A might be too inconsistent for field use and … the set is not capable of working to Wireless Set No. 31…'. (D Signals Liaison Notes, No. 25, July 1945).

In the same Volume 2 of *Wireless for the Warrior*, in the Historical Development chapter of Wireless Set No. 31, it was reported that: '…in late 1944, in consideration of … the outstanding success of the USA SCR-300-A at Battalion / Company level communication … it is proposed to manufacture a set in this country as nearly as possible identical with the SCR-300-A…'. (D Signals Liaison Notes). In April 1946 the nomenclature of this set was decided, being known as Wireless Set No. 31 and it was thought of as the ultimate replacement of Wireless Sets Nos. 18, 68 and 46.

Earlier designed HF sets with FM capabilities were Reception Set R209, (1943 development had started) and Wireless Set No. 42 (start of development 1943/44) but eventually abandoned in 1946.

Apart from aborted design of Wireless Set No. 34, trials with commercial VHF FM sets were conducted.

US Army VHF FM sets were recorded to be used in the British Army on a limited scale. As far as currently can be traced, the only operationally used FM communication equipment developed and built during WW2 in the UK were the Mk.17 and Mk.18 agents ground sets, and hitherto unknown aircraft set of the SIS 'Ascension' system. These were engineered and build by SCU using most components imported from the USA.

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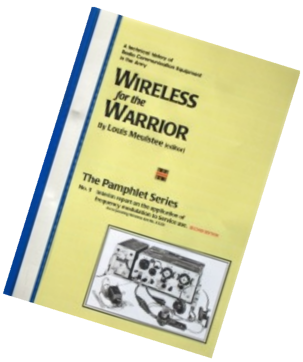
- Photographs and documents courtesy Royal Signals Museum, Blandford Forum, UK.
- Royal Signals Museum website: http://www.royalsignalsmuseum.co.uk
- Proofreading and valuable suggestions for changes by Chris Bisaillion, Canada, and Pete McCollum, USA.

A loose leaf folder for the WftW Pamphlet Series.

Shown right is a suggestion for a simple and inexpensive method to keep the printed pages together in a plastic clear view A4 document folder. Printable front and rear cover sheets, provided with the downloads, will give the folder an attractive appearance.



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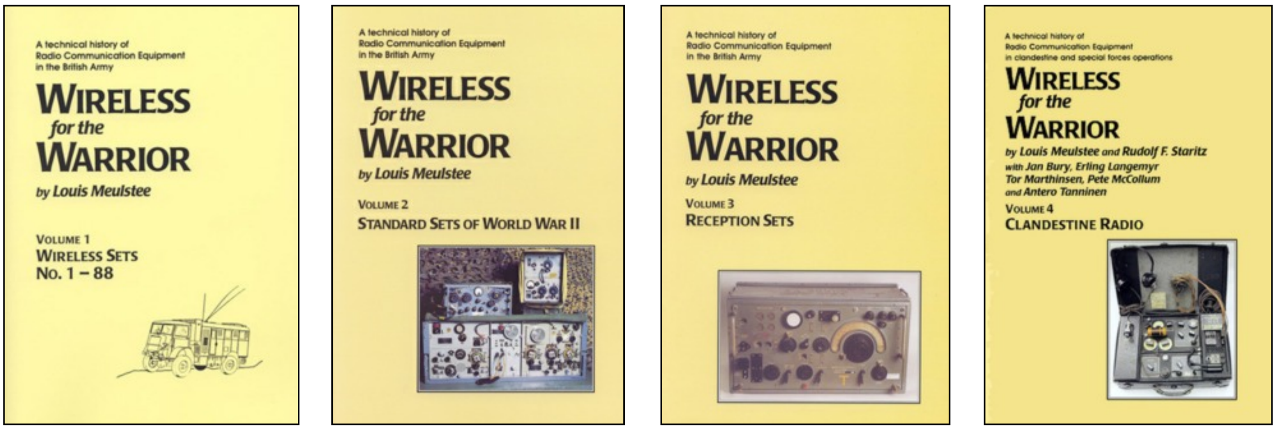
The Wireless for the Warrior range of books (comprising the **Volume** and **Compendium** series) are intended as a source of reference to the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s. Line equipment and military radio communication equipment from other countries is also covered in the recently published Compendiums. For detailed information, review pages and order information visit www.wftw.nl



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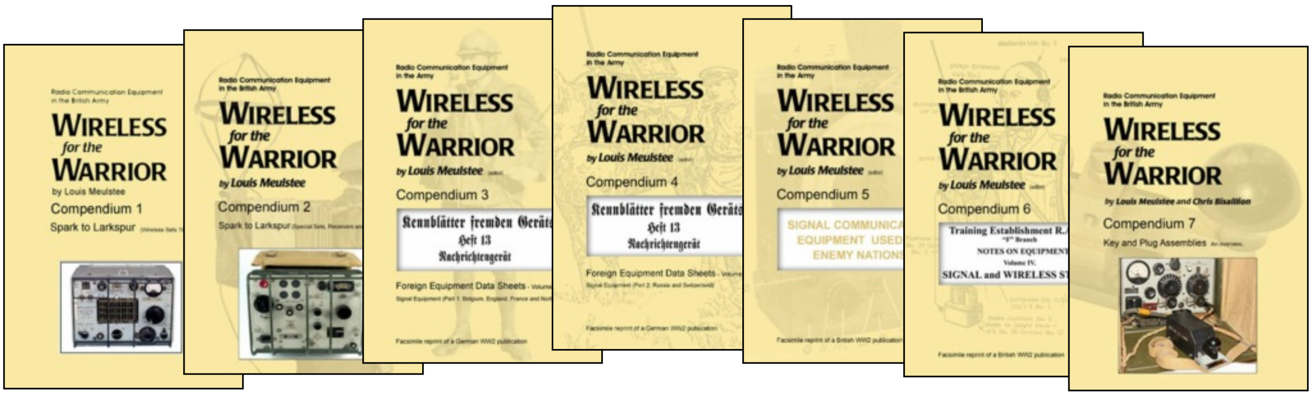
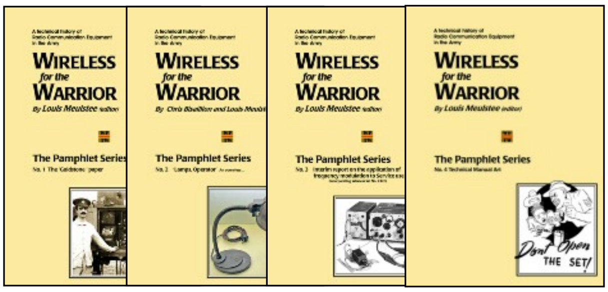
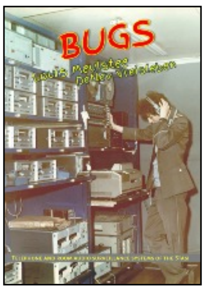
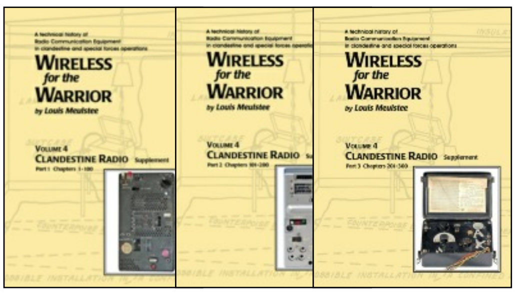


The WftW **Compendium** series is a new addition to the Wireless for the Warrior range, currently comprising 7 books. The new series is principally intended as a practical guide and reference source to vintage military signal communication equipment. The books are particularly valuable to anyone with an interest, professionally or otherwise, in this subject, requiring an elementary but complete quick reference and recognition handbook. Containing condensed data summaries, liberally illustrated with photos and drawings, explanatory captions and short description of the main ancillaries, its pocket size format and laminated soft cover makes it an ideal reference and reliable companion for events such as auctions and radio rallies, or just for browsing at leisure.







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