PEAK EFFICIENCY DESIGN ON THE SHORT WAVES

Engineering a Universal
A C & D C Receiver
Especially Designed for
Amateur Band Reception

by

James Millen, M.E.

Price 10 Cents

NC

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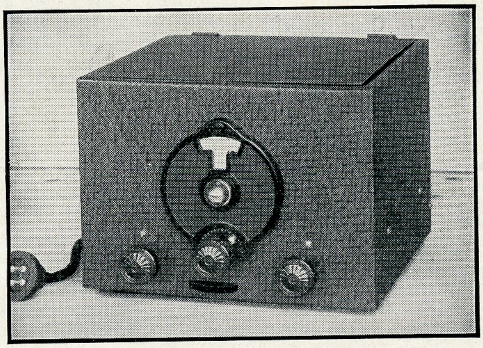
By James Millen, M.E.

THE truly modern short wave receiver represents an advance in engineering design over the moving tickler regenerator of a decade ago comparable with the superiority of the 1933 broadcast receiver with its quiet a-c, perfected radio and audio systems, over its progenitor of that technically distant era. The short wave engineer has partaken of long wave progress in the improvement of audio frequency and power circuits and in the development of tubes, notably the types 58, 36 and 37, which contribute to quiet and stable operation and, in carefully engineered circuits, permit real radio frequency gain even in the region of megacycles! Simultaneously, the short wave engineer had his own peculiar problems to solve, involving the successful ganging of very high frequency circuits, the development of satisfactory shielding, the reduction of stray coupling effects through the progressive design of more and more efficient choke coils and the segregation of circuits, the perfection of volume and regeneration control systems, and the conservation of high frequency energy through the invention of practically no-loss insulating materials.

It is the purpose of this article to describe a receiver — the 1933 model of the famous SW-3 series — in which the successful solutions to all these considerations have been embodied. In addition to its peak efficiency performance on all short wave lengths, its peculiar adaptability to either a-c, battery or intermediate operation (combining battery and line-power in conformation with individual requirements) recommends the SW-3 to the discriminating amateur.



SINGLE-CONTROL TUNING OF TWO TUNED CIRCUITS

Band spreading, calibrated volume control, complete shielding and adaptability to either a.c. or battery operation are the salient features of this receiver. The "set and forget" antenna trimmer control is at the left and the regeneration control at the right, with the operating edge of the calibrated volume control disc immediately below the main tuning dial.

Battery vs. A-C Operation

Although a little over two years ago a-c operation of an amateur-band receiver was considered rather impractical by the amateur fraternity, the readily recognized superiority of alternating current tubes over the battery type resulted in such an accelerated development of the a-c receiver that it was not long before the problems of a-c operation were well mastered and the solutions applied to short wave design.

In recent months, increasing numbers of experienced operators have been switching to the use of combination a-c and battery operated receivers, and additional facts concerning their operation have been determined. It is well known that unless an unusually high quality power-pack is employed for the completely a-c operated high-frequency receiver, it is generally found that the combination of a-c filament heating and battery plate supply results in steadier reception when receiving weak cw signals with an oscillating detector. This may possibly be due to the isolation of the two sources of power supply, or, perhaps, to the elimination of fluctuations in the plate supply voltage caused by minor variations in the line voltage or poor power unit design. Regardless of the exact reason, it must be admitted that battery plate supply is an improvement under some receiving conditions unless the really high grade pack especially designed for high frequency receiver operation is employed.

The life of the "B" batteries will be long, with the usual few milliamperes drain demanded by a three-tube set, and the first cost of the filament transformer and 135-volt block of batteries will be considerably lower than that of an efficient power supply designed for satisfactory high-frequency receiver work. There is also another advantage to the use of "B" battery plate supply — namely the elimination of the regeneration-control "detuning effect" almost invariably encountered in completely a-c operated ham receivers using improperly designed power packs. It is probably the superior regulation characteristic of "B" batteries or high quality pack that overcomes the trouble. In any event, the combination a-c filament supply "B" battery plate supply type of operation seems to be as free from such trouble as when the receiver is entirely battery operated.

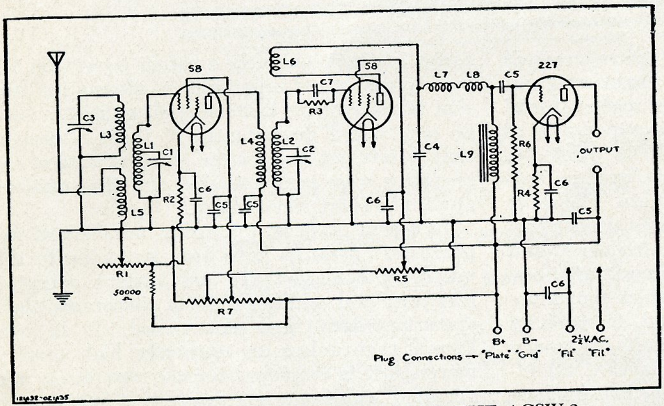


FIGURE 1 — CIRCUIT DIAGRAM OF THE ACSW-3

This receiver employs only a-c tubes, as indicated, and should be selected for complete a-c operation, or for partial a-c operation (using plate batteries) where a 2.5 a-c heater potential will always be available. The circuit constants are as follows —

L_1, L_2, L_3, L_4, L_5 and L_6 — R.F. Transformers.
L_7 — No. 100 Ultra High Frequency R.F. Choke.
L_8 — No. 92 Low Radio Frequency Choke.
L_9 — 700 Henry Choke — Part of S-101 Audio Coupler.
C_1 and C_2 — Ganged S.F.L. 270° Tuning Condensers with isolated rotors. 90-μμf per section.
C_3 — Midget Type Trimmer Condenser — 50-μμf.
C_4 — 250-μμf mica by-pass condenser.
C_5 — .01-μf non-inductive mica fixed condensers.
C_6 — .5-μf non-inductive paper by-pass condenser.
C_7 — 100-μμf small mica grid condenser. Incorporated in Detector R.F. transformer.
R_1 — 10,000 ohm potentiometer — special taper — used as gain control.
R_2 — 300 ohm cathode resistor, 2 watt type.
R_3 — 5 megohm detector grid leak.
R_4 — 2000 ohm cathode resistor, 2 watt type.
R_5 — 50,000 ohm potentiometer for regeneration control.
R_6 — 250,000 ohm audio grid resistor — part of S-101 Coupler.
R_7 — Voltage Divider-total resistance 12,000 ohms.

For complete battery operation the 6-volt d-c heater type tubes are far superior to any others previously available for such work. Gone are all the noises, microphonics, and other such troubles formerly associated with the use of battery tubes. Also, the heater being designed for 6-volt operation, restores to use the storage battery or "A" eliminator generally to be found in every amateur station. In the case of the 3-tube receiver described herewith, the total current consumption at six volts is under one ampere. Employing the new heater-type battery tubes, it is possible to design a battery receiver of similar characteristics to the a-c models. Thus the amateur in the rural districts, as well as those on exploration parties, expeditions, etc., may have essentially the same type of set as their brother operators located in the a-c districts.

General Design

In a receiver designed with the peculiar requirements of amateur operation in mind, there is little necessity for audio amplification of loud-speaker magnitude. The concentration desirable for communication reception, particularly of weak signals through interference and QRN, is achieved with less effort when ear 'phones are used — a general practice in amateur and commercial stations. The power amplifying stage has therefore been omitted in the design of the SW-3.

This omission is still further justified in consideration of the actual gain secured in the radio frequency circuit, even at 30 mc, in consequence of the new tubes and highly efficient r-f design to which reference has already been made. The high amplification factor, high transconductance and the plate impedance characterizing the new tubes have enabled the engineer to achieve a degree of sensitivity and selectivity that have heretofore been little more than experimental ideals. The use of these tubes has necessitated the redesign of the plug-in inductors in the antenna-radio-frequency and detector circuits.

The tubes employed as indicated in the wiring diagrams (Figures 1 and 2) function, from left to right, as radio-frequency amplifier, beat-frequency-oscillator-detector and one stage audio amplifier. This arrangement is comparable in many ways to the more elaborate short wave superheterodyne receivers, and has the advantage of a definitely better signal to noise ratio.

Aside from the gain achieved in the audio frequency circuit, this tube also serves as a very essential coupling medium between the output of the detector and the headphones (or additional amplification if employed). In this function, it promotes smooth regeneration, freedom from fringe howl and back-lash, and, with other elements in the circuit, eliminates the feedback from the 'phone cord to the input circuit of the receiver.

Shielding

The required stability of a communications short wave circuit presents special problems in view of the peculiar characteristics of very high frequencies and the maintenance of a stable oscillating condition during beat-note reception. A large part of the burden of stability is placed on the shielding — which must perform a double function in providing adequate circuit isolation with the minimum reduction of high radio-frequency efficiency.

While it would seem that the single stage of r.f. and regenerative detector type of circuit is about as simple an arrangement to build as can be imagined, such has been found far from true where more than mediocre performance is demanded. For instance, if inadequately shielded, the r-f tube will oscillate whenever the detector regeneration control is advanced. This condition exists to a surprising extent in both homemade and commercial receivers in use today. Such receivers are tolerated, it would seem, simply because the owners have never operated a receiver employing the same circuit properly shielded. There just isn't any comparison.

The mere fact that the r-f stage is apparently stable when the detector is approaching an oscillating condition, is not necessarily an indication of perfect shielding, as interlocking still may be present to an obnoxious degree.

Consideration of the receiver being described will demonstrate that there is far more to shielding than the mere boxing off of the different parts of the circuit. Offhand, the arrangement shown in Figure 3A would appear satisfactory. However, this seemingly ideal arrangement, with the coils, tubes and condensers of the two circuits completely shielded from each other, is far from perfect. It was found that with a watertight joint between the shield and the base there was no oscillation trouble with the r-f amplifier, although there was an annoying amount of interlocking. As soon as the chassis was placed in a metal cabinet, however, and the cover closed, the r-f stage oscillated violently!

Next tried was the arrangement shown at B in Figure 3, with even less satisfactory results. Furthermore, the lack of symmetry of the shielding made it very difficult to gang the r-f and detector tuning condensers.

The next experiment comprised the shielding system shown at C in Figure 3. This arrangement worked fairly well in comparison with its predecessors, but here, too, there was still excessive interaction. The compartments were probably too large, for the isolating effect of the coil compartments decreases very rapidly as the compartment size increases. Another disadvantage of this arrangement was the requirement of tube shields. There was, however, no perceptible change in the shielding effect when the chassis was placed in a metal cabinet.

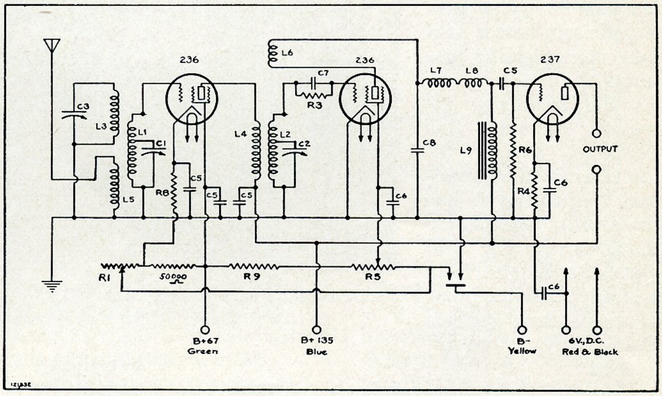


FIGURE 2 — CIRCUIT DIAGRAM OF THE DCSW-3

This is the combination circuit which should always be selected when battery operation may be required. It can, however, readily be converted to a-c operation using the standard 235 and 227 tubes. The circuit constants are identical with those indicated in Figure 1, with the following exceptions —

R8 — 350 ohm resistor.

R9 — 20,000 ohm 2-watt type resistor.

SW — Regeneration control and cathode circuit switch.

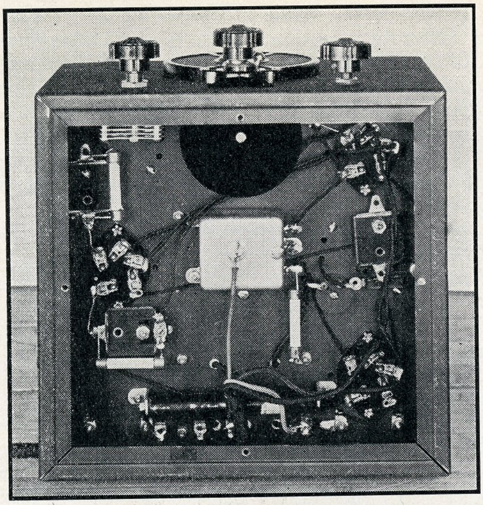
With the experience gained with models A, B and C, we arrive at the arrangement illustrated at D. Here the compartments are small enough to shield properly, and yet large enough not to increase the coil losses appreciably. Furthermore, there is no common partition between the coil compartments as exists in designs A and B, which, in all probability, was responsible for the "cover" effect. The r-f tube shield was found essential in order to shield the plate lead from the coil and prevent oscillation.

In the model finally adopted in the SW-3, it was found advantageous to make the vertical parts of the shielding integral with the metal cabinet rather than to weld them directly to the chassis. It is also desirable to insulate the vertical parts of the shielding compartments from the chassis itself with a ⅛" air gap and to weld them to the sides of the metal cabinet. The chassis, in turn, is grounded to the cabinet by mounting screws on each side. Such an arrangement completed the shielding job by reducing interlocking to a negligible degree.

A further indication of the trouble to be experienced in attempting to use a common partition between the coils in a shortwave receiver is illustrated at E and F in Figure 3. This problem was recently encountered in the design of another receiver employing the same circuit. The separate compartments completely eliminated the r-f oscillation and interlocking difficulties.

Steel vs. Aluminum

A word regarding the relative merits of steel and aluminum shielding is of interest at this point. It is well known that on the extremely low frequencies, say for instance 60 cycles, iron is definitely better as a magnetic shielding material than aluminum. As the frequency increases, however, this difference rapidly diminishes, until at broadcast frequencies it has practically completely disappeared. On still higher frequencies, from a purely shielding point of view, there appears little, if any, actual difference.



THE UNDERSIDE OF THE A.C. MODEL WITH ITS BASE-PLATE REMOVED

However, there are several other aspects to be considered in addition to the pure shielding effect, such as the introduction of losses when shielding is placed close to a coil. It is for this reason that in the design of the receiver care has been taken to keep the steel shielding partitions everywhere separated from the r.f. transformers by distances at least equal to the coil diameters. At this, or greater distances, there is no noticeable difference in the resistance of the r-f transformers whether the shielding be aluminum or steel. In the design of receivers where it is necessary to place the shield closer than the diameter of the coil at any point, then there is a marked advantage in using aluminum or some other non-ferrous material.

In high frequency work, our present concern, the real advantage of the use of steel over aluminum lies in its shielding of the receiver as a whole from the low frequency (60-cycle) magnetic field which often completely envelops the ham operating table and results in a strong a-c hum in connection with aluminum shielded battery type receivers. There is also the consideration of perfect shield joints, which are difficult to obtain with aluminum but readily achieved with steel by welding.

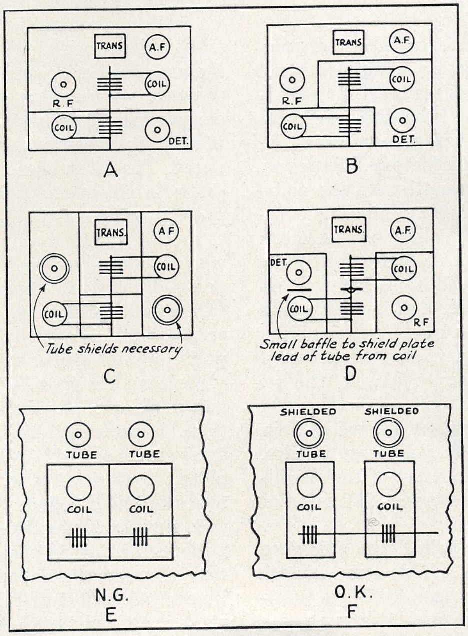


FIG. 3—TYPES OF R-F SHIELDS SHOWING THE EVOLUTION OF THE HIGHLY EFFICIENT SYSTEM EMPLOYED IN THE SW-3

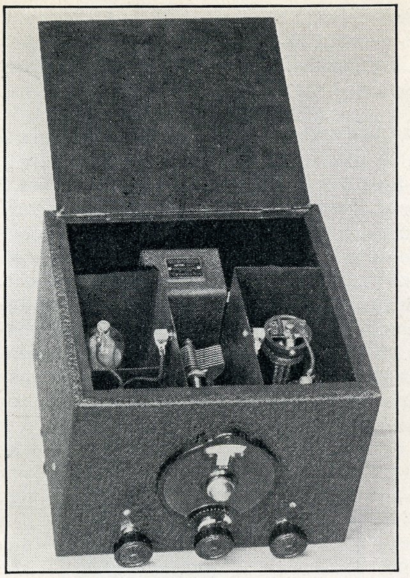
Elimination of Stray Coupling

While shielding is undoubtedly the most effective single medium employed in circuit isolation, the highest degree of short wave efficiency can only be obtained when shielding is supplemented by circuit refinements designed to reduce intercoupling effects to an imperceptible minimum.

The radio frequency filter in the detector plate circuit of the SW-3 is the result of careful study of the problems involved. Highly undesirable operating conditions result when excessive r.f. is permitted to invade the a-f channels. The predominant characteristic of such a condition is the presence of hand capacity effects on all parts of the audio frequency system, including the headphones, cords and even the metal receiver cabinet. Another symptom is the exasperating fringe howl as the detector approaches oscillation. A sticky regeneration control — an apparently excessive amount of lost motion — is directly traceable, in many instances, to inadequate filtering in the detector output circuit.

The use of a detector tube having a high plate impedance precludes the employment of a fairly large bypass condenser which would necessarily attenuate the higher audio frequencies when it occasionally happens, even in amateur operation, that high quality 'phone reception is desirable. The matter resolves itself into the familiar high radio-frequency problem of efficient choke design. The inductance of the short wave choke in the SW-3 is only 2.5 millihenries, but what is more important the distributed capacity has been reduced to 1 mmf!

A low-radio-frequency choke is placed in series with the h-f reactor to permit effective regeneration control on wavelengths over 100 meters, thus permitting the efficient range of the receiver to be extended into the broadcast band, and above, by means of larger plug-in coils. On long wavelengths the choking action is the sum total of the individual inductances of the two chokes, affected by a negligible quantity of mutual inductance. On high frequencies, the reactance of the larger choke coil is negative — the windings are bypassed by its distributed capacity — and only the smaller choke coil functions.

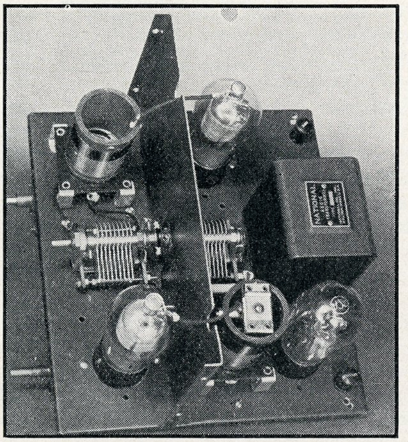


WITH THE COVER OPENED

The plan of the internal arrangement is the same as that shown at D in Fig. 1. With the band-spreading coils in place, the normal control-grid clips fasten to the dummy insulating plugs mounted on the compartment walls. The partitions are welded to the sides of the cabinet but are insulated from the base by an air gap.

At the present stage of the radio art, there is no excuse for a two condenser type of receiver that is not single dial control in the fullest sense of the term — even on short wavelengths. Careful engineering in the SW-3 has resulted in highly efficient uni-control, but here, too, the problem of stray coupling elimination had to be solved. This is the coupling through those portions of the tuned circuits which happen to be common in parts of the gang condenser frame in the conventional multi-section tuning capacitor. While the paths involved are very short, an inch or two represents an appreciable part of the total conductor length at frequencies above 15 megacycles, and is sufficient to cause instability and circuit interlocking.

To overcome this trouble a special tuning condenser was developed in which both rotors are entirely insulated from the condenser frame and from each other. This design makes it possible to isolate completely the input and output circuits of the radio-frequency stage, resulting in a perfectly stable system, even at the highest frequencies to which the receiver will tune.



A GOOD EXAMPLE OF HOW NOT TO SHIELD

A study of shielding in the development of the receiver described brought out some surprising points. The example illustrated looks good but isn't, as explained in the text. This arrangement is the same one shown at A in Fig. 1.

Volume Control

It has heretofore been considered that the simple regeneration control in the detector circuit — assisted, perhaps, by an a-f attenuator for headphone reception — provided adequate volume control. Such an arrangement, however, results in several forms of distortion. The radio-frequency tube is necessarily operating at maximum amplification at all times, resulting in considerable overload of both that tube and the detector on strong signals. Backing up the regeneration control to reduce the signal strength results in additional distortion, due to the fact that the detector tube is then being operated with a decreased plate or screen voltage. The obvious solution is to employ a supplementary control at the input to the r-f stage.

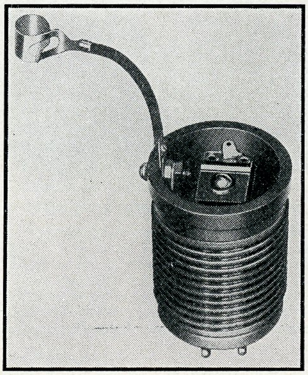
Under actual reception conditions, this volume control contributes several other advantages. The detector can always be operated on that portion of its characteristic curve at which best rectification is obtained, with a resulting improvement in tone quality and detecting efficiency. The receiver can also be operated in a condition of maximum selectivity on 'phone signals by setting the regeneration control close to the point of oscillation and controlling volume altogether at the r-f input. This latter feature is of particular utility in consideration of the congestion existing in the amateur telephone bands.

The volume control on

the SW-3 is arbitrarily calibrated from R-1 to R-9 — making possible accurate comparisons of signal strength in amateur and experimental reception.

R-F Transformers and Band Spreading

Following the policy of careful attention to all details of a simplified circuit in order to secure maximum performance, a special molding material was selected for the transformer forms. The use of this low-loss material permits the winding of the coil turns into grooves turned into the solid walls of the forms, resulting in a rigid transformer that will stand up under rough handling. This special molding material, known as "R-39," differs from the ordinary compositions in that it contains no wood flour or other moisture absorbing filler, the presence of which has been discovered by the Radio Frequency Laboratories to be the cause of the losses and variations in dielectric qualities of molded bakelite when placed in high frequency fields. As a result of the practical elimination of dielectric losses in the transformer field, not only is the sensitivity increased, particularly in the r-f stage where no appreciable amount of regeneration exists, but the selectivity is also improved due to the substantial reduction of the r-f resistance in the tuned circuits. In the case of transformers developed for the 33 to 20 mc range, it was found that the detector refused to oscillate when these coils were wound on forms molded of ordinary bakelite, whereas no difficulty was encountered when the special NATIONAL "R-39" low-loss material was used.



THE 7000-KC. BAND-SPREADING DETECTOR TRANSFORMER

A special six-prong form is used with the turns of the plate coil for the r.f. tube wound between the turns of the detector grid coil. The adjustment screw of the trimmer condenser is readily accessible from the top. The tickler winding is in a slot at the lower end of the form and the grid condenser and leak are inside, beneath the trimmer condenser.

While this receiver is so designed as to employ coil sets covering from 9 to 2000 meters, special band-spread coils have been developed in recognition of the SW-3's adaptability to amateur requirements. These coils are available for the 28, 14, 7, 3.5 mc as well as the 1.75 mc amateur bands.

In general appearance (as will be seen from the accompanying photographs) the new band-spread coils differ from the conventional coils only in that a lead comes out of the top which clips directly to the caps of the screen grid tubes, in place of the leads built into the receiver. In order that the clips in the receiver may not dangle about and short circuit on the metal chassis or cabinet, dummy insulating terminals are furnished for securing them safely.

Inside each detector coil form there is a small grid leak and grid condenser, as well as an adjustable low-capacity trimmer condenser. The schematic diagrams (Figures 1 and 2) show how the band-spreading is accomplished. Here it will be seen that C, the usual variable tuning condenser, now shunts only a portion of the total inductance, while the grid leak R and the condenser C connect directly to the top of the coil. Finally, the trimmer condenser C shunts this whole arrangement and is in parallel with the tube capacity, connecting directly from the grid to the filament. Figure 4 shows a sketch of the coil, indicating how the prongs of the coil are connected and the disposition of the screen grid lead which comes out of the top of the coil. The particular L/C ratio in this arrangement results in a circuit of a high order of sensitivity sufficiently superior to the conventional arrangement as to be readily detectable in listening tests.

Slightly different types of coils are used in the a-c and d-c models of the SW-3. Both types, in band-spread and standard designs, are described in detail, with wave ranges and identifications, in the catalog section of this booklet.

The advantages gained throughout the receiver by perfection of design have been conserved through the employment of low-loss dielectrics in the radio frequency circuits aside from the coil forms. The coil and tube sockets as well as the supporting bars for the variable condenser plates are of isolantite, an insulating medium that is consistently used wherever experimental research has indicated the advisability.

The Audio System

The output of the detector tube is impedance coupled to the single audio stage by means of a plate choke coil of very high inductive value. It was found that the use of a choke having a much higher inductance than the primary of a conventional transformer resulted in increased coupling efficiency, and the reduction of any tendency toward howling, roughness or backlash in the regeneration control. These difficulties were encountered to a highly objectionable degree when straight resistance coupling was employed.

Operation

As mentioned previously, an arrangement finding particular favor with many experienced amateur operators at this time is the use of a-c on only the heaters of the a-c tubes, so as to take advantage of economical operating costs, "B" batteries being used for plate supply in preference to the so-called "B-eliminator." The operating advantage of such a combination shows up mainly on weak cw signals where a higher order of detector stability is obtained, due probably to the elimination of plate supply variations caused by line voltage fluctuations. It would also seem that there exists a slight increase in freedom from detuning effects of the regeneration control when using batteries in place of a simple power supply. The extent of this improvement, of course, depends upon the type of power pack involved and is much more noticeable when using the conventional type "B-eliminator" than when using a special type of power unit designed strictly for high frequency receiver operation.

The minor variations between the a-c and d-c models are indicated in the wiring diagrams, Figures 1 and 2. For a-c heater operation the circuit and tubes indicated in Figure 1 are used, with the plate supply furnished by a highly efficient eliminator. "B" batteries are not recommended because of the drain imposed by the voltage divider. When complete a-c operation is employed, it is most essential that the plate supply be well regulated and filtered. Where hum, instability or low sensitivity cast any suspicion on the available power source, it is recommended that a National Company, type 5880 AB unit be employed. This A-B power source is especially designed to supply heater and plate potentials for completely a-c operated short wave receivers. (A complete description of these units, for different line voltages and frequencies, will be found in the catalog section of this booklet.)

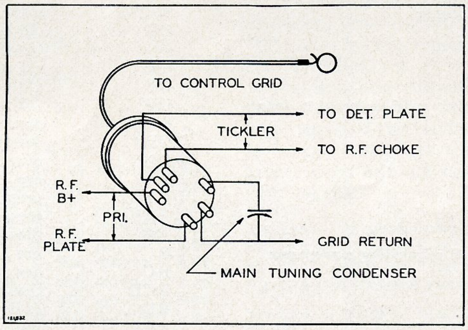


FIG. 4 — DIAGRAMMATIC EXPLANATION OF THE BAND-SPREAD COIL CONSTRUCTION

Band-spreading makes tuning and logging much easier, but does not affect the electrical separation of stations. Selectivity remains the same, except in so far as the more accurate tuning made possible by band-spreading, facilitates station discrimination.

The battery model, Figure 2 is designed to use either battery or a-c type tubes. When operated purely as a d-c receiver, the 6-volt 5-prong heater Type '36 and '37 tubes are recommended so as to permit operation from the standard 6-volt storage battery or "A" eliminator. As will be seen from the circuit diagram, a separate "B-minus" lead is brought out in the battery model. Thus the standard a-c tubes, also being of the 5-prong UY-base variety, may be plugged in at any time in place of the heater-type battery tubes and the receiver adapted to a-c operation.

When using the battery model of the receiver with the combination a-c & d-c power supply, a common center-tap resistor should be connected across the heaters inside the base of the chassis. It has been found that erratic operation will result on some frequencies unless this center tap resistor is placed across the heater terminals of one of the sockets, preferably the detector. If the receiver is to be used alternatively with a-c and d-c type tubes, provision should be made for removing this resistor from the circuit when operating with a filament battery so as not to impose a parasitic load on the batteries.

For complete battery operation, the 6-volt heater tubes were selected not only because of the convenient 5-prong base making them interchangeable with the a-c tubes and because of the general availability of 6-volt storage batteries, but also because of their freedom from the microphonic howls that occasionally cause trouble where the 2-volt type d-c tubes are employed.

There is of course no reason why the first audio stage of the SW-3 cannot be connected to a power amplifier for loudspeaker operation. Where an adequate amplifier is available, this receiver provides the most economical and efficient short wave receiving equipment. It can also be used in conjunction with the power supply and last stage channel of a high grade broadcasting receiver, and in such instances functions as a short wave "adapter."

The left hand control is the antenna trimmer, and the right hand control the regeneration-oscillation adjustment. The calibrated volume control is located just under the tuning knob.

For most effective results, the SW-3 should be operated in conjunction with a high grade short wave antenna, such as described in the National Company booklet "World Wide Short Wave Reception." (Sent for 10¢ in stamps, or free to the owner of any National short wave receiver.)

The compact size of the SW-3, measuring only 9¾" by 9" by 7", recommends it for portable, aircraft and other services where space and weight are important considerations.

WE ARE indebted to QST Magazine for permission to republish much of the material contained in this Second Edition, describing the 1933 SW-3 receiver.

This is one of a series of pamphlets concerned with outstanding developments in the field of transmitting, high-frequency and broadcast receivers, frequency measuring apparatus and other equipment of interest to the radio and communications engineer.

James Millen

THE NATIONAL COMPANY

Malden, Mass. U. S. A.