A Single-Sideband Transmitter for Amateur Operation

Circuit Details and Tuning Procedure for S.S.S.C. Transmission

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• Here is a down-to-earth description of the equipment used to generate the 14-Mc. single-sideband suppressed-carrier signal at WØTQK. While a few of the circuits and components may be new to you, you will find that the only real requirement to getting started on amateur s.s.s.c. is rolling up your sleeves and diving into the thing. This rig was built in five evenings, from scratch and with no previous experience, and is a superb example of the really progressive amateur's spirit and ability!

There are five main considerations in the design and construction of a single-sideband suppressed-carrier transmitter. They are (1) as nearly complete suppression as possible of the carrier, (2) elimination of the unwanted sideband, (3) linear operation of the entire transmitter, (4) a minimum of spurious-frequency radiations, and (5) excellent frequency stability.

The first two objectives are obtained by using a balanced modulator and an adequate filter system. Linear operation is obtained by using Class A amplifiers wherever feasible. Spurious frequencies are minimized by using balanced modulators for all frequency conversions, with traps further to reduce the local-oscillator signal that might leak through. The use of crystal-controlled oscillators for the high-frequency signals, running continuously, results in excellent frequency stability. The low-frequency oscillator (9 kc.) is self-controlled, but its power is supplied by a regulated source and, in any event, it takes a large-percentage change to affect the output frequency appreciably.

The block diagram of Fig. 1 shows the various stages required to obtain 14-Mc. output from the original s.s.s.c. at 9 kc. The first modulator, with a carrier frequency of 9 kc., produces the upper and lower sidebands but cancels out the carrier in the output circuit. The first filter passes only the upper sideband. The second and third modulators and filters perform similar functions but on different frequencies.

Circuit Details

If duplex operation is to be used in s.s.s.c. operation, the audio amplifier must have a low noise level, and the microphone must be insensitive to extraneous noise. Any noise or unwanted signal in the audio system will show up as modulation and hence as output, preventing full enjoyment of duplex operation. Further, poor response below 250 cycles in the audio end will make the job

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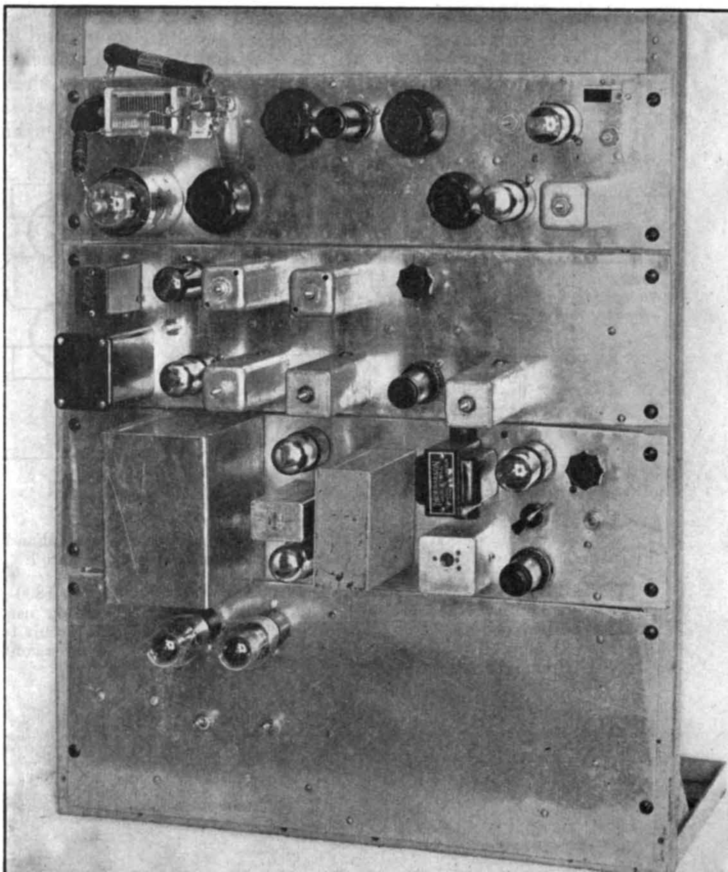


The s.s.s.c. exciter at WØTQK was built on four separate chassis. From the bottom up, they contain the power supply, the speech and first modulator, the second modulator, and the third modulator and output amplifier.

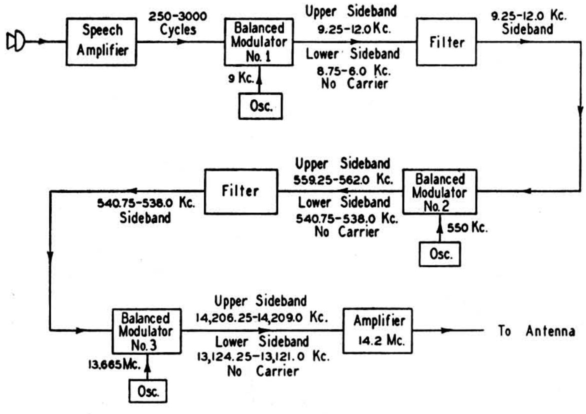


***Fig. 1* — A block diagram of the WØTQK s.s.s.c. transmitter. Two frequency conversions are required after the original single sideband is obtained at 9 kc.**

of the sideband-cutting filter easier. As shown in Fig. 2, a 6SL7 with the two sections in cascade was used in this rig, with a small coupling condenser to reduce the low-frequency response, and the amplifier has plenty of gain for working out of a crystal microphone. The 9-kc. oscillator coil was made by removing the iron from a p.p.-plates-to-voice-coil transformer and potting the windings in a small shield can filled with wax. Since transformers vary a great deal, the proper shunting capacitance to tune the circuit to 9 kc. must be found by trial. The 100-μμfd. variable condenser is used to set the oscillator frequency to the right point on the slope of the filter characteristic.

The "ring" modulator used in this first unit uses two 6SN7s connected as diodes. Both the carrier and modulating frequency are canceled out in the output of this arrangement, leaving only the sideband products of modulation and some harmonics. The cancellation is theoretically perfect in an exactly-balanced system, but stock tubes worked satisfactorily in this instance.

Selected 1N34-type crystals might also be used in this application, or the Sylvania V-306 "varistor" unit, which is made up of four selected crystals, could be substituted.

The special balanced output transformer, T_{202}, was wound specially (in the manner of the windings shown in Fig. 5) on a toroidal permalloy core. However, any high-grade transformer core should be satisfactory in this frequency range. In most cases a 1-to-1 turns ratio will be satisfactory.

The sideband filter is the one big headache in the production of single-sideband energy, and it is no small problem. The one used in this equipment was a surplus item and is very difficult to locate. It has a characteristic as shown in Fig. 3. However, with the information given in Terman's *Engineering Handbook* and many other texts, an excellent filter can be constructed. When designing one, the steepest possible attenuation slope should be set on the oscillator side, while the other side merely serves to limit the higher-frequency sidebands. A cut-off frequency of about 3 kc. above the oscillator frequency seems desirable. If there is not enough attenuation above this point, the speech amplifier may be designed to furnish additional reduction. In any event, the sideband filter must have high attenuation at all frequencies above twice the oscillator frequency minus the highest audio frequency, to eliminate the lower sideband of the oscillator harmonic and all other higher-frequency signals. The *frequency*

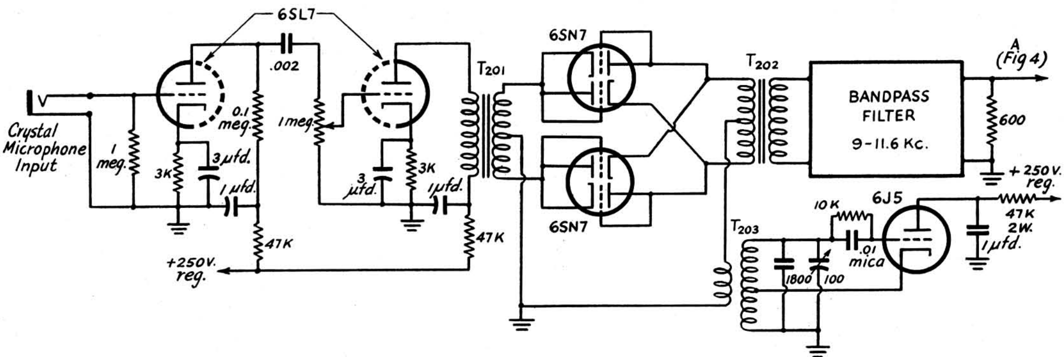


***Fig. 2* — The speech amplifier, first balanced modulator, and sideband filter of the s.s.s.c. system of WØTQK. Resistors are 1-watt and capacitances in μμfd. unless otherwise noted.**

T_{201} — Single plate to 200-ohm line, center-tapped (Thordarson 55A15).
T_{202} — Balanced line-to-line, special (see text).
T_{203} — Push-pull plates to voice coil, with iron core removed.

The 1800-μμfd. shunting capacitor will vary with the winding used, and a capacitance necessary to tune the circuit to 9 kc. should be employed. The 100-μμfd. variable condenser gives a tuning range of about ± 125 cycles.

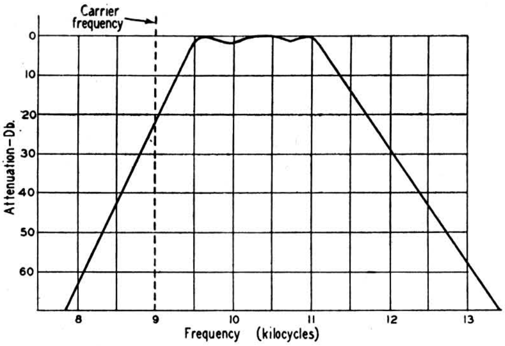


Fig. 3 — **Transmission characteristic of the 9- to 11.6-kc. bandpass filter shown in Fig. 2. The rapid attenuation in the region between 9.5 and 8.5 kc. is the secret of the suppression of the lower sideband.**

of this first filter is not at all critical and may be as high as 50 kc., but it must be remembered that we are after a steep slope in cycles and not in per cent. If too low a frequency is used, trouble will be encountered in the second filter when it tries to separate the upper and lower sidebands at that point. Since condensers are cheap and coils are hard to wind, a low design impedance of around 500 ohms makes construction easier. It goes without saying that high-*Q* coils are extremely desirable.

Second Modulator

The second-modulator-and-filter unit operates on 540 kc. and is the simplest to build since, foı the most part, conventional receiver i.f. technique is used. The wiring diagram is shown in Fig. 4. Coils were obtained from junked i.f. transformers, with turns removed to permit them to resonate around 540 kc. It is desirable to have a tuning range in these transformers of a little more than twice the first-oscillator frequency (9 kc.) so that either sideband can be selected. A crystal oscillator was used in this section mainly because one was available in the junk box, but a good self-controlled oscillator, running continuously from a regulated power supply, should serve just as well. Injection voltage from this oscillator to the modulator was set at 2 volts, as was the case in the other two modulators, although this value is not very critical.

The output coil for the modulator gave a great deal of trouble in the original design stages, and the final design was hit upon only after filling the shack with what seemed like miles of No. 32 wire. This turned out to be a bifilar winding for the primary with a single scramble-wound secondary, as shown in Fig. 5, and it gives excellent balance. It is simple to construct, and is also used in the third-modulator grid circuit. Because of variations in construction, the necessary amount of shunting capacitance may have to be found by cut-and-try.

As in the first modulator, the selection of frequency for this section is not critical, but there are several factors to be considered. The frequency must be high enough so that the sidebands generated in the next modulator will be far enough apart to be readily separated by a filter. But the frequency of the oscillator in this second section must be low enough so that its following filter will not have to be *too* selective. Then, too, the procurement of components is always a

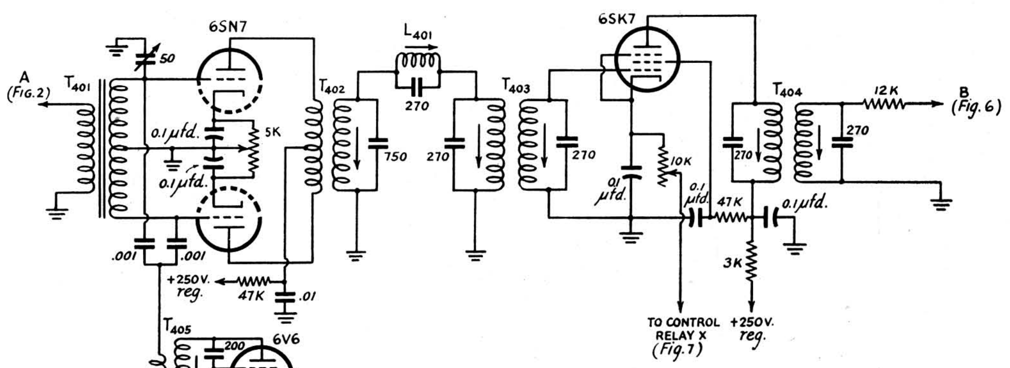


Fig. 4 — **The circuit of balanced modulator No. 2 and the 540-kc. filter.**

T_{401} — Single plate to p.p. grids (UTC HA-104).
T_{402} — Special balanced-modulator plates to unbalanced load. (See text and Fig. 5.)
T_{403}, T_{404} — 465-kc. i.f. transformer with enough turns removed to resonate at 540 kc.
T_{405} — Same as T_{403} but with one condenser removed.
L_{401} — Single winding from 465-kc. i.f. transformer, with turns removed. Resonated at 550 kc.

problem, particularly if they must be special, and so a frequency somewhere in the i.f. range of present-day receivers seems indicated. It is also a great help to be able to listen to the output of this stage in a receiver, and so the low-frequency end of the broadcast band seems to be a logical spot.

Third Modulator

The frequency of the third section, and consequently the selection of components, depends entirely on which amateur band is to be used, and the preceding frequencies. Since only 14-Mc. operation was planned in this instance, an oscillator frequency around 13,600 kc. was needed, and a crystal ground for working in the 11-meter band filled the bill nicely. The wiring diagram of the third-modulator section and the following amplifiers is shown in Fig. 6. A 6SL7 in an oscillator-doubler combination gave the required 2-volt signal, and the coils in these stages were shielded to prevent any strays from getting into the output amplifiers and causing out-of-band radiations. The output of the third modulator is low, as in the other modulator stages, but a single 6SG7 operating Class A brought the signal up to about 15 volts, ample to drive an 807 as a second Class A amplifier. Since the over-all gain of these two stages is very high, it is essential to use complete shielding as well as parasitic suppressors in the 807 stage. If the stage driven by the 807 does not operate as a zero-bias Class B stage (and hence load the 807 at all times), it is necessary to use a loading resistor across the 807 tank. In our case the 807 stage was loaded by a 4000-ohm resistor, since the 807 is used to drive a pair of 813s. The peak output power of the 807 stage appears to be about 10 watts, and it is ample to drive the 813s to 1-kilowatt peak input.

Power Supply

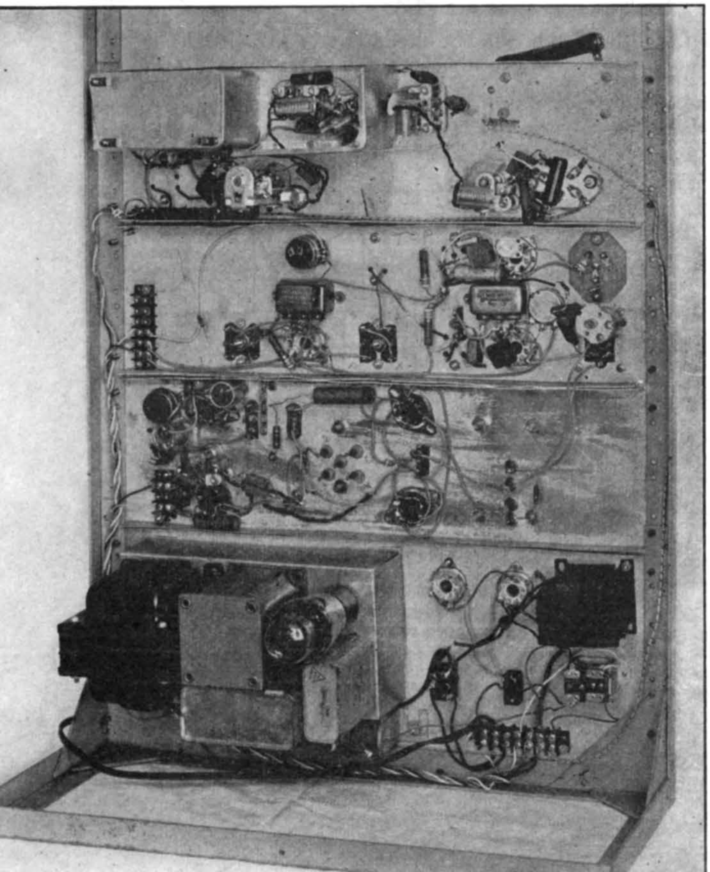
There is little to be said about the power supply, since it is conventional in every way. However, the wiring diagram is shown in Fig. 7, since the control circuits are also included in this unit. The control circuit is a d.p.s.t. relay that opens the cathode circuit of the 6SK7 540-kc. amplifier and the plate power to the 807 stage. The oscillators are allowed to run continuously, to minimize frequency drift.

Construction

The entire exciter, including the power supply and control circuits, is mounted on a 30-inch relay rack. In the interest of economy and ease of construction, panels were made of 0.050-inch aluminum (bought in surplus) with the top and bottom edges turned back to strengthen the panel. In spite of the thin material there is ample strength to support the heaviest components, and a great deal of time and labor was saved by working in aluminum instead of steel. All tube sockets are mounted on these panels, which puts all of the tubes on the fronts of the panels, and the wiring becomes a simple matter. Although this type of construction does not conserve space, it is invaluable in testing and development. The author had never seen another single-sideband rig, and so all sorts of serious difficulties were anticipated. Fortunately, they weren't encountered.

The power supply, borrowed from another rig in the station, was bolted on the back of the lower panel.

Since three frequency conversions are used, and the signal is at



A rear view of the s.s.s.c. exciter shows the relatively simple lash-up required to get going. The entire unit was built from scratch in less than a week, with no attempt to make the thing beautiful. Most of the parts will be readily identified by comparison with the several wiring diagrams.

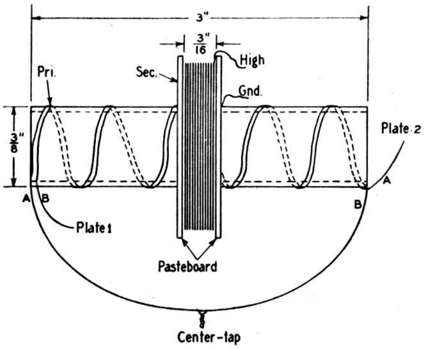


Fig. 5 — **Winding details of the T_{402} of Fig. 4. The primary consists of two strands of No. 32 d.s.c., closewound parallel for a winding length of 2 inches. The secondary is 50 turns of No. 32 d.s.c., scramble-wound between two pasteboard rings. Several layers of writing paper are wound over the primary before starting the secondary. The coil is tuned with a 1-inch powdered-iron slug.**

a low level most of the time, shielding is not necessary on the first two modulator units, other than the usual shield cans around the i.f. coils. The third-modulator assembly deals with frequencies near the output frequency and signals of a higher level, and so shielding between stages is essential. The high-frequency oscillator and multiplier are completely enclosed, and the 807 has its plate circuit on the front of the panel, and obviously not for aesthetic reasons!

Additional Amplifiers

It is to be assumed that more than the 10 watts of s.s.s.c. energy furnished by this exciter will be wanted at the average station, although this exciter will compete very well with conventional rigs having about 10 times the output.

The mere mention of a Class B r.f. amplifier seems to put the damper on the enthusiasm of most amateurs, but it shouldn't be so. Very few hesitate to use a Class B *audio* amplifier as a modulator, and they seldom run into trouble. Any amplifier following this exciter should operate in the same manner as a Class B audio amplifier, since the carrier has been completely suppressed. Any tube that is suitable for r.f. applications will work well, provided it is properly neutralized and the operating voltages set as for Class B audio work. The ratio of peak to average power in speech being about 10 to 1 (depending upon the voice and microphone), quite high peak output can be obtained with low plate dissipation. Although the theoretical maximum efficiency of this type of amplifier is 78 per cent at full output, even the actual peak operating efficiency of 50 to 65 per cent will compare favorably with any Class C amplifier. As in all Class B amplifiers, the efficiency is proportional to the exciting grid voltage, within the range of linearity.

A pair of 811s or 805s would make an excellent final amplifier, although a single tube is just as satisfactory. The use of zero-bias tubes eliminates

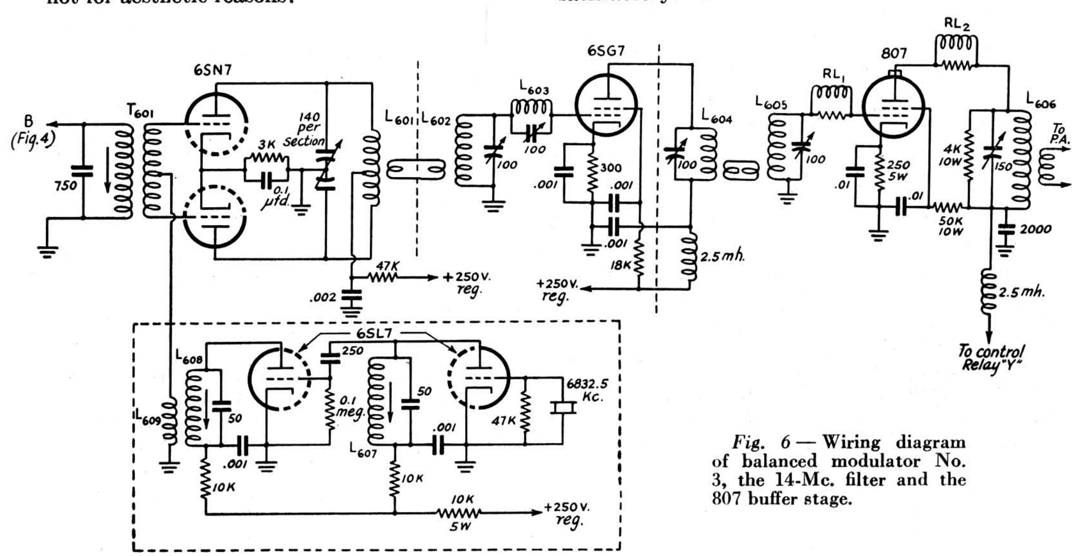


Fig. 6 — Wiring diagram of balanced modulator No. 3, the 14-Mc. filter and the 807 buffer stage.

L_{601} through L_{606} — 14 turns air-wound, ¾-inch diameter, 0.85 inch long (B & W Miniductors). Link windings are 2 turns at ground ends of coils.
L_{603} — Tuned to 13,665 kc. with mica compression trimmer.
L_{607} — 18 turns No. 18 s.c.e., close-wound on ½-inch diam. tubing.
L_{608} — 9 turns No. 18 s.c.e., close-wound on ½-inch diameter tubing.
L_{609} — 8 turns No. 18 s.c.e., close-wound on same tubing as L_{308}, spaced ⅜ inch.
RL_1, RL_2 — 6 turns No. 18 wound over 100-ohm 2-watt resistor.
T_{601} — Same as T_{402}, Figs. 4 and 5.

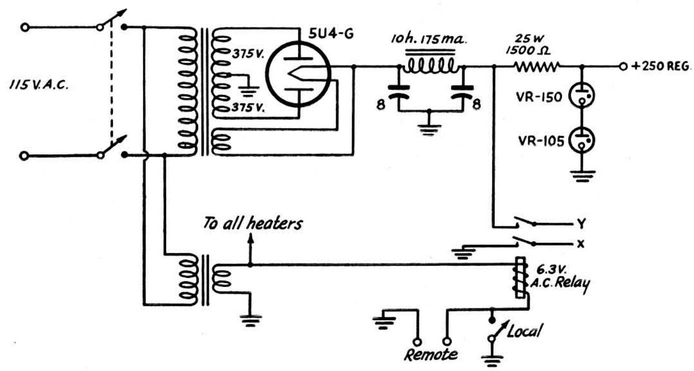


Fig. 7 — The power supply and control circuit for the s.s.s.c. exciter.

the need for a fixed-bias supply and its rigid requirement of constant voltage (necessary if the amplifier is to remain linear throughout its range.)

The second rig in this station used a pair of 813s in a neutralized push-pull final, so all that was necessary was to run a link from the s.s.s.c. exciter over to their grids and to short out the resistor bias in the 813 amplifier. The tubes are run with 600 volts on the screens, 2000 volts on the plates, and the bias is adjusted to give a zero-signal plate current of 40 ma. With full signal the plate current rises to 470 ma. The tubes show no color during normal voice modulation. To attest to the completeness of the carrier suppression, when there is no audio signal a small 2.5-volt dial lamp can be coupled to the output tank of the 813s and it will show no sign of any r.f. But the experiment should be tried with the microphone circuit closed, because it doesn't take much to burn out the bulb in a hurry!

Transmitter Tuning Procedure

The tuning of an s.s.s.c. rig is very straightforward and, incidentally, quite interesting. The first thing to remember is that nothing can be done without an audio signal! After the frequency of the first oscillator (9 kc. approximately) has been set well down on the slope of the sideband filter, a tone signal of about 1000 cycles is fed into the speech amplifier. For this tone we use the c.w. beat-note obtained by tuning the station receiver to the 18th harmonic of a 100-kc. frequency standard. (The 1800-kc. signal is convenient; the receiver is stable at that frequency, and there is no QRM.)

A vacuum-tube voltmeter would be very handy for tuning, but there is none in our shack so a 1N34 crystal and a 20,000-ohms-per-volt meter do very well. If everything is correct, a reading should be obtained at the second-modulator plate coil, T_{402}, under modulation. This coil is tuned for maximum output on the desired sideband, as are all of the coils in the second stage (T_{403}, T_{404}). Of course the crystal-oscillator stage must be checked first for operation, because an audio signal is used. The 1N34 voltmeter across the secondary of T_{405} will indicate output when the oscillator is working.

The third, or output, section is tuned in the same manner by peaking each circuit for maximum output. When all circuits have been tuned, with the exception of the traps, L_{401} and L_{603}, the second modulator (Fig. 4) must be balanced. The controls for doing this are the 5000-ohm potentiometer in the cathode circuit of the 6SN7 modulator and the 50-μμfd. variable from one grid to ground. A receiver tuned to 550 kc. should be coupled to the output (point *B*) and the 5000-ohm potentiometer adjusted for minimum signal. The 50-μμfd. condenser is to compensate for capacitive unbalance in the secondary of T_{401}, and it may have to be increased in capacitance or connected to the other grid, depending upon the construction of the transformer. When minimum reading has been obtained with these two controls, the 550-kc. trap should be tuned to eliminate the last of the oscillator signal. The high-frequency trap in the grid circuit of the 6SG7 (L_{603}) is tuned by listening to the 13.6-Mc. signal and tuning for minimum. As a final check on the carrier suppression, it should be possible to couple a flashlight bulb to the output tank and have no indication of r.f. when there is no audio signal.

Operation

Until such a time as this type of transmission is either in greater use on the amateur bands or more operators are aware of its existence, the problem of establishing contact will remain a large one, but with interest shown it is not insurmountable. Three systems have been tried at this station with varying degrees of success. The first is to contact the station with the main 1-kw. rig set on the same frequency and then, after informing the receiver station of the proper tuning procedure, to switch rigs. This has worked in almost all cases, but occasionally we will get the report that the *f.m.* is not working! The second method is to call CQ, or another station, on single sideband and hope for the best. Surprising as it may seem, many contacts have been secured this way. The third system, which incidentally places the transmitter in a queer mode of operation, is to feed a small amount of 9-kc. signal around the first modulator and filter unit and use this as a carrier. Plate dissipation on the final-stage runs high this way, and the allowable power output is cut down.

(*Continued on page 28*)

DX on s.s.s.c. (no special effort made at DX work):

October 9th —	VK4KS	Fragmentary contact. VK4KS in contest.
October 25th —	KH6MQ/J9	Kwajalein, Marshall Islands. Got us distinctly through bad QRM.
	ZS6GF	Pretoria, South Africa. Had 40-minute solid QSO. Reported s.s.s.c. easily readable but hard to tune. Had AR-88 receiver.

On November 3, 1947, worked WØTQK at 8:55 P.M. PST, for the first two-way single-sideband QSO. Our first contact with WØTQK was on October 21st, and he had built up his entire rig in the meantime! On November 8th, worked WØTQK for first duplex s.s.s.c. QSO; very nearly solid circuit for one-and-one-half hours.

Thanks are due the following members of the Stanford Radio Club for their assistance in connection with the single-sideband tests: Dave Thompson, W6VQB, Rob Beaudette, W7FXI, and Chet Carr, W6NVH.

Single-Sideband Transmitter

(*Continued from page 24*)

In all cases where the receiving station has been able to tune in the s.s.s.c. signal correctly, the results have been very gratifying. The most apparent effect is the terrific reduction in QRM compared to double-sideband transmission.

When one tunes in a single-sideband signal, it sounds like — and is! — a sideband that has lost its carrier. No amount of tuning will restore its readability. The essential thing to remember is that this very narrow band of frequencies being transmitted must be centered in the passband of the receiver i.f. amplifier. This is most easily done by using sharp i.f. selectivity, crystal in first or second position, and tuning for maximum signal. Once centered in the i.f. channel, the receiver is set up for c.w. reception, audio gain on full and r.f. gain reduced, and the b.f.o. set to the frequency of the missing carrier. In order to set the b.f.o. a very careful adjustment is required, since the exact frequency may be passed over during periods of no modulation. If the oscillator is set on the wrong side, the speech will appear inverted and unreadable. As most receivers will drift during stand-by, the high-frequency oscillator (main tuning) should be corrected since most of the drift is in this oscillator. Changing the b.f.o. will set the signal out of the i.f. passband. If sufficient selectivity is available in the i.f. amplifier, it can easily be seen that two stations can use the same carrier frequency with no interference. A recent test with a dual-conversion amateur receiver showed that no retuning was necessary over a period of more than half an hour. S.s.s.c. communication places a severe stability requirement

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on the receiver, but the present trend appears to be toward this end.

In spite of its apparent complexity of construction, only five evenings were consumed in building this equipment. The saving in large modulator and r.f. driver tubes and their power supplies more than overcomes the few additional receiving components needed, and it is hoped that adequate filters will soon be offered for less than the cost of a modulation transformer. This is the first stab at reducing QRM on the amateur 'phone bands since the modulated oscillator was outlawed. It's up to *you!*

Any DX Today?

(*Continued from page 31*)

If 50-Mc. WAC is to be achieved it will call for consistent daily operation by all concerned, with good antennas and receivers, using the methods of m.u.f. observation outlined above.

In carrying out observations such as described in the foregoing many interesting problems needing explanation, with plenty of food for thought for those with inquiring minds, present themselves. What, for instance, causes an ionosphere storm and its associated auroral effects? Why are there no ionosphere storms in mid-December, when the North Pole is in darkness (possibly because this is an ultraviolet-light effect)? Why does the F_2 m.u.f. drop so much in midsummer giving a general effect very similar to ionosphere-storm days in October–November or February–March? What causes the very high F_2 m.u.f. of winter days at sunspot maximum — is it purely ultraviolet radiation, the angle at which it strikes the upper atmosphere being of importance, or is some other factor involved? What causes sporadic-E ionization in both this and the other regions? How important and interdependent are actual *weather* variations in the stratosphere and above? . . . And so on! !

There is now a great deal of evidence — it remains to be analyzed and interpreted!

Conclusion

The examples of various records accompanying this article represent only a few of those made at G6DH over a number of years. Further details of these are available for anyone who has a genuine use for same.

25 Years Ago

(*Continued from page 39*)

9AUS, 9DTM and 9ZAF rendering splendid public service. . . . At the Seattle Radio Show the public was given a demonstration of the "Radio Hound" radio-controlled car built by 15-year-old Kenneth G. Field, 7QB. . . . For a second year the Department of Commerce gives recognition and encouragement to amateurs, with the announcement of a Hoover Cup for 1922.

Gracing the pages of the "Who's Who in Ama-

(*Continued on page 132*)