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Editor, Radio Handbook

an Unusual SSB Modulator

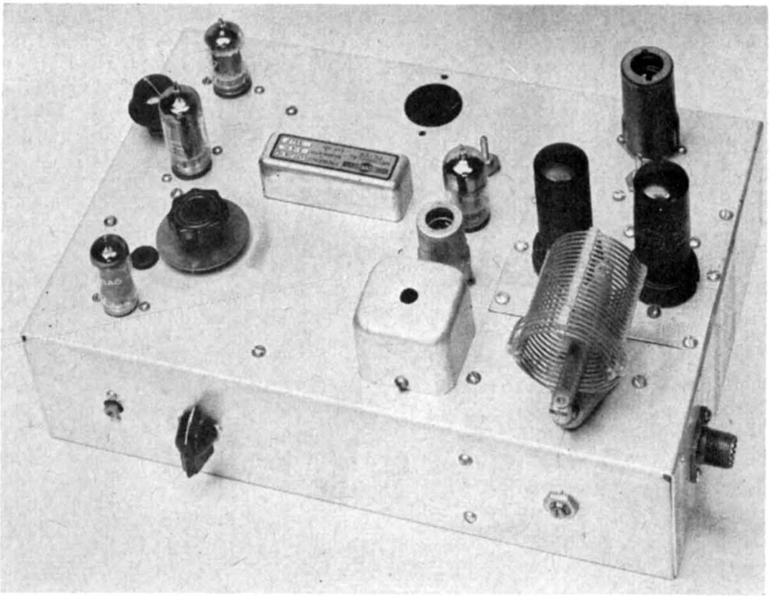
The balanced modulator is the heart of most single sideband transmitters. It is generally operated at relatively low radio frequencies, and may be used to modulate or "beat" voice frequencies against a carrier wave to produce double sidebands minus the carrier frequency. It may also be employed at higher radio frequencies to allow frequency conversion of the single sideband (SSB) signal, while providing substantial rejection of the mixing signal from the local oscillator.

The balanced modulator may be thought of as an electronic switch wherein the carrier frequency is switched on and off at the frequency of the modulating signal. Either vacuum tubes or metallic diodes may be used for such a switching circuit. A balanced modulator circuit employing two triode tubes is shown in *Figure 1*. The carrier frequency f(c) is applied to the grid circuit so that the impressed signal is in phase on both grids of the modulator, while the modulating frequency f(m) is applied to the grid circuit of the triodes so as to produce a phase reversal of the signal of 180° between the two grids.

When the signal in the plate circuit of the balanced modulator is examined, it will be found that the carrier frequency f(c) is absent. The pulses of plate current caused by the grid signal of f(c) cancel each other out, making the net result zero in the output plate circuit. Thus any variation in grid signal voltage that is applied to both tube grids in parallel and in the same phase will cancel out in the push-pull plate circuit.

The modulating frequency f(m) is applied to the grids of the balanced modulator in a push-pull manner. However, the modulating frequency is usually in the audio frequency range, and the tuned plate tank circuit offers little load impedance to such low frequencies. Thus, neither f(m) nor f(c) appear in the plate circuit of the balanced modulator. However, when both f(c) and f(m) are applied to the grid circuit of this stage, the plate circuit will contain signals that are grouped either side of the carrier frequency. These frequencies are equal to the carrier frequency plus and minus the modulating frequency, and may be termed a *double sideband suppressed carrier signal.*

Fig. 9. Low frequency stages are at the left of the chassis. The 6BA6 is in the foreground, with the 6AR8 balance potentiometer behind it. To the rear are the 6AR8, the audio level control and the 12AX7 speech amplifier. To the right of the Mechanical Filter are the 80 meter mixer and oscillator stages. The conversion crystal is inside the small shield can. At the right are the cascode buffer and parallel 6AG7 stages, with the 80 meter tank coil in the foreground.



The balanced modulator is acting as a switch tube, switching the carrier f(c) on and off at the modulating frequency f(m).

If the resulting two sidebands are passed through a suitable filter, one of the sidebands may be passed and the other rejected. A *single sideband suppressed carrier signal* will then be observed at the output of the filter.

Diode Modulators

The double triode tube may be eliminated, and the circuitry rearranged to allow the use of four metallic diodes connected as a shunt-quad modulator, as shown in *Figure 2*. When balanced diodes and transformers are used, the carrier pulses across diodes X1-X2 are balanced out by the equivalent pulses of opposite polarity that appear across diodes X3-X4. The carrier frequency f(c) therefore does not develop in the output circuit. Application of a modulating voltage to the quad alternately cuts off one pair of diodes, then the other pair

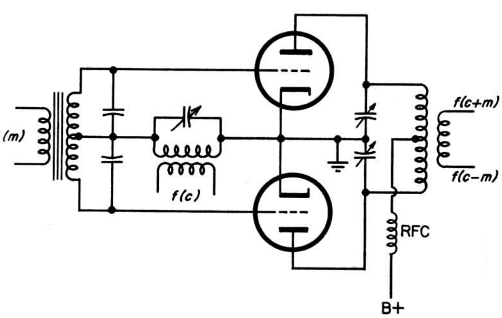


Fig. 1. Basic push-pull balanced Modulator. The output from a modulator (mixer) of this type consists of frequencies equal to the carrier frequency plus and minus the modulating frequency. Neither the carrier frequency or the modulating frequency appear in the output circuit.

as the polarity of the modulating signal reverses itself on each half-cycle. The shunt-quad may thus be thought of as a double-pole double-throw electronic switch, operating at the frequency of f(m).

For conditions of highest linearity, the diodes are to be preferred over the vacuum tube modulators. However, the cost of improvement in linearity is obtained only at circuit complexity. It is necessary for conditions of good linearity to have low impedance input and output circuits to such a quad. The varying load imposed by the quad upon the carrier frequency generator can often lead to instability of the oscillator, or perhaps to frequency modulation of the oscillator. Coupling of the carrier oscillator to such a low impedance quad is best done through some type of isolating stage, such as a cathode follower. This entails the use of an additional tube. In like

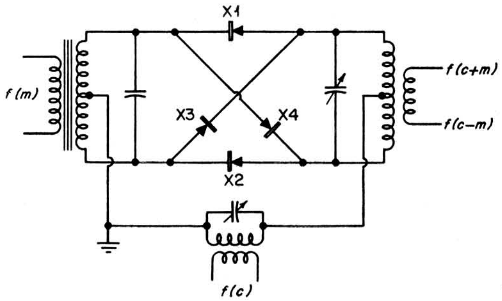


Fig. 2. The "ring" or shunt-quad Modulator. Employing four metallic diodes, this modulator is capable of low distortion performance if the input and output circuit impedances are held at a low level.

manner, it is necessary to provide a low impedance source for the modulating signal, f(m). The use of a cathode follower or an impedance matching transformer between the audio driver and the quad modulator is a necessity. If it would be possible to obtain the excellent linear operation of the diode modulator in a circuit of high input and output impedance, the design of a simple balanced modulator would be greatly simplified.

The 6AR8 Switch Tube

The thought that the balanced modulator operates as an electronic switch offers interesting and novel applications of one of the new tubes that has recently been released for color television purposes. Such a tube is the General Electric 6AR8 Sheet Beam tube, whose general characteristics are listed in *Figure 3*.

The 6AR8 is a minature double plate sheet-beam tube which incorporates a pair of balanced deflectors to direct the electron beam to either of the two plates, and a control grid to vary the intensity of the beam. The tube is designed to be used as a synchronous detector in color television receivers, and as an electronic switch in the burst gate circuit of such receivers. When the 6AR8 is employed as a synchronous detector, it is used as shown in *Figure 4*. The focussing electrodes of the tube form the electron stream into a sheet beam which is attracted to the plates of the 6AR8 tube by virtue of the positive potential applied thereto. Between the electron gun and the plates, the electron beam passes between two deflecting electrodes. Depending upon the voltages applied to the deflectors, the beam will be directed entirely to either one or the other of the two plates, or be proportioned between them. The frequency of the signal applied to the deflectors determines the rate at which the plate current is switched between the two plates. The magnitude of the plate current is determined by the negative voltage that is ap-

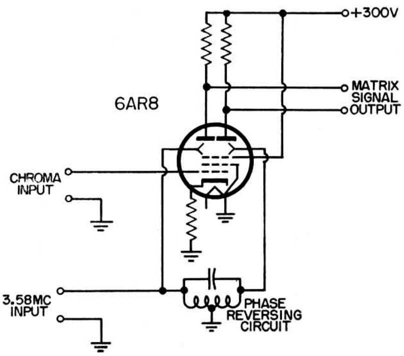


Fig. 4. The 6AR8 tube as employed for TV service as a synchronous detector.

plied to the #1 control grid. The 6AR8 tube may be considered as equivalent to a voltage controlled single pole double-throw switch through which a current, the magnitude of which is also voltage-controlled, flows. The transfer characteristics of this interesting tube are shown in *Figure 5.*

In color TV service, the deflecting electrodes are switched at a frequency of 3.58-Mc., the push-pull switching voltage being obtained from a balanced resonant circuit connected between the deflecting electrodes, as shown in *Figure 4.* The Chroma input is applied to the control grid of the 6AR8, and the resulting output signal for the Matrix is taken across the two plate load resistors of the tube.

The 6AR8 as a SSB Balanced Modulator

The 6AR8 may be divorced from its color TV applications and used as a balanced modulator for SSB work. The linearity of the transfer characteristic shown in *Figure 5* would indicate that the linearity of this tube when used in a suitable balanced modulator circuit would be excellent. A simplified circuit suitable for SSB work is shown in *Figure 6.* The r.f. carrier is applied to the control grid of the 6AR8, modulating the electron beam at the frequency of the applied signal. In the exciter to be described, this frequency is 455 k.c. The electron stream then passes through the deflection plates towards the collecting plates. A push-pull audio signal is applied to the deflection electrodes, switching the electron beam back and forth between the two collector plates at an audio frequency rate. The exciting r.f. signal is applied in "single-ended" fashion to the 6AR8 circuit, and is balanced out in the push-pull plate circuit configuration. To obtain maximum conditions of balance, the plate potential of the 6AR8 is applied through the arm of a potentiometer, the ends of which are attached to the two plates of the tube. By adjusting this control for maximum rejection at the carrier frequency, more than 40 db. of plate circuit carrier rejection may be obtained.

The main advantage of the 6AR8 when used as a balanced modulator is that it works well when the input and output circuits are of relatively high impedance. One-half of a 12AX7 may be employed as an audio phase inverter to supply push-pull audio signals to the deflection plates. Usual values of plate and cathode load resistors may be employed in the phase inverter circuit, without fear of excessive circuit loading by the balanced modulator stage. It is not necessary to use a low-mu triode with the accompanying low values of plate and cathode load resistance, such as is necessary when driving a metallic diode modulator.

In addition, there is very little reaction between the mixing oscillator and the balanced modulator. Many balanced modulators impose a non-linear load upon the mixing oscillator. If this oscillator is a variable frequency device, frequency modulation will occur during the mixing process. This action produces a peculiar low frequency "growl" on the SSB signal which is most annoying, and difficult to cure. This effect is entirely absent when the mixing oscillator is coupled to the 6AR8 modulator. The high impedance circuits of this stage allow the use of simple input circuits, and also allow the use of the Collins Mechanical Filter to separate the wanted and unwanted sidebands.

Simple precautions must be taken to prevent the 455 k.c. energy from being coupled into the audio system, and into the rest of the SSB equipment. Each deflection plate of the 6AR8 is bypassed to ground with a 100 uufd. mica condenser, and 10,000 ohm series isolating resistors are placed between the 12AX7 phase inverter and the balanced modulator. This

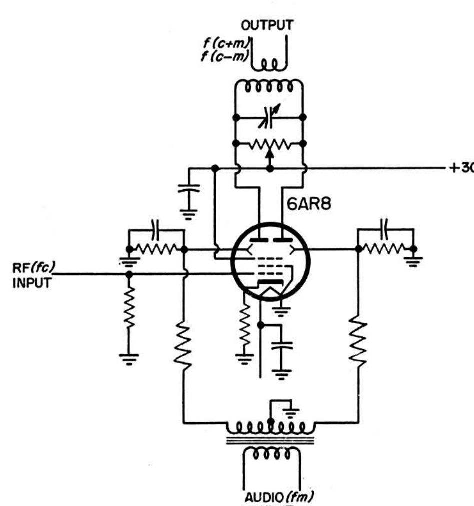


Fig. 6. The 6AR8 used as a balanced Modulator R.F. input is applied to the control grid, and push-pull audio to the deflection plates. The output circuit contains a double-sideband suppressed carrier signal.

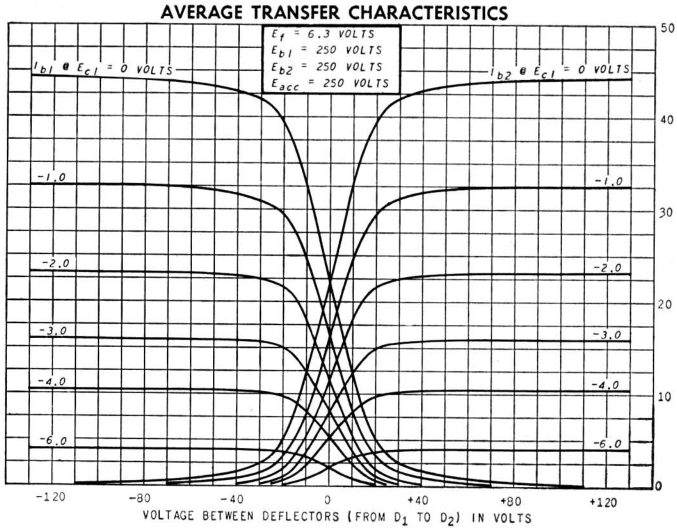


Fig. 5. Transfer characteristic of 6AR8 Sheet Beam Tube. Note the linear transfer characteristic over the deflection voltage range of −15 to +15 volts.

simple filter provides sufficient isolation between the circuits.

Pin #5 of the 6AR8 is a common connection to one leg of the filament and to the suppressor electrode and shield within the tube. It is necessary to ground this pin for proper operation of the tube. The other filament pin (#4) is bypassed to ground with an .01 ufd. ceramic condenser to prevent energy leakage via the filament line. For best plate circuit balance, the cathode of the 6AR8 is unbypassed.

The Sideband Filter

The Collins F455D-31 Mechanical Filter is used to provide rejection to the carrier frequency and to the unwanted sideband. This unit is an electromechanical bandpass filter consisting of an input transducer, a resonant mechanical section comprised of a number of metal discs, and an output transducer. The input and output transducers serve as electrical-to-mechanical and mechanical-to-electrical coupling devices and do not affect the selectivity characteristics of the filter, which are determined by the metal discs. An electrical signal applied to the input terminals is converted into a mechanical vibration at the input transducer by means of magnetostriction. This mechanical vibration travels through the resonant mechanical section to the output transducer, where it is converted by magnetostriction to an electrical signal which appears at the output terminals of the filter.

For voice operation, a passband of approximately 2500 cycles is needed. Accordingly, the 3.1 k.c. bandwidth Mechanical Filter is used, having a passband as shown in *Figure 7*. The shape factor of this passband (ratio of bandwidth at 60 db. to bandwidth at 6 db.) is less than 2.25 to 1. The frequency of the beating oscillator is set so that the carrier is placed at one of the "20 db. points" on the filter curve. The oscillator frequencies for these points are approximately 453.5 k.c. and 456.6 k.c. By moving the oscillator from one frequency to the other either one of the two sidebands may be placed outside the passband of the filter and rejected.

The SSB signal appearing at the output of the filter may be converted to the frequency of use and amplified to the desired level.

A Practical SSB Exciter using the 6AR8

A 12AX7, 6AR8 and 6BA6 form the framework of a simple filter-type exciter as shown in *Figure 8*. A maximum audio signal of 0.10 volts, r.m.s. is required at the input grid of the 12AX7 audio amplifier for 5 watts of peak SSB output on 80 meters. The 12AX7 tube serves as a voltage amplifier and phase inverter, while the 6AR8 acts as the balanced modulator. The beating oscillator is a 6AU6 whose frequency is variable over the range of 450 to 460 k.c. A double sideband suppressed carrier is generated by the 6AR8 tube, and one sideband is rejected by the Collins Mechanical Filter which follows the modulator stage. The output of the filter is at a frequency of 455 k.c. A 12AT7 double triode mixer stage follows the filter, beating the SSB signal against a 3355 k.c. crystal conversion oscillator. The resulting SSB signal is on 3810 k.c. The SSB signal is amplified by a 12AU7 connected as a cascode amplifier, driving in turn a parallel connected pair of 6AG7's operating class AB1. These tubes deliver a SSB signal of about 5 watts peak power with negligible high order distortion products.

An audio signal of 0.10 volts r.m.s. (easily obtained from the usual variety of crystal microphone) is amplified in the two 12AX7 stages, producing a peak audio voltage of 22 volts to ground between each deflection plate of the 6AR8 (measured at pins 1 and 2). This is sufficient for complete electron beam swing at plate and accelerator potential of 300 volts. Approximately 5 volts of negative bias is applied to the 6AR8, resulting in a quiescent plate current of 6 ma. per section and a deflector current of less than 1 ma.

A peak-to-peak r.f. voltage of 3 volts is required from the 6BA6 electron coupled oscillator. The circuit shown is a modification of the standard Clapp arrangement, wherein the cathode r.f. choke has been replaced by a 1600 ohm composition resistor. This eliminates a bulky r.f. choke, and at the same time provides better waveform from the oscillator. Poor waveform in the low frequency beating oscillator can degrade the performance of the balanced modulator to a great degree. The output from the oscillator is taken from the cathode, since only a small mixing voltage is required.

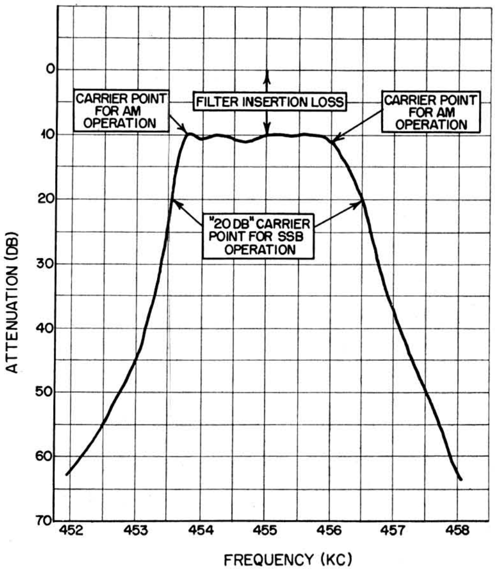


Fig. 7. Passband of Mechanical Filter

It is interesting to note that in the usual balanced modulator circuit the ratio of r.f. voltage to audio voltage is of the order of 10/1, or 20/1. That is, the carrier voltage must be 10 to 20 times the amplitude of the modulating signal for best linearity. Here, the situation is reversed. The modulating signal is just about 20 times greater than the carrier signal. Since the two signals are applied to different electrodes of the modulator tube, the old 10/1 or 20/1 ratio does not hold true.

Sufficient isolation must be provided in the power leads to prevent signal leakage between various stages. Since both the 6BA6 low frequency oscillator and the 6AR8 modulator are

Parts List for Figure 8

C1—100 μμfd variable ceramic padder Centralab 823-DN
C2—30 μμfd variable. Bud LC-1642
C3-C4—.002 μfd silver mica
C5-C6—250 μμfd mica. Series tuning capacitors for mechanical filter
C7—130 μμfd mica. Parallel tuning capacitor for mechanical filter
C8—Output tuning capacitor. 150 μμf Bud MC-1856
L1—2½ mh r.f. choke. National R-100
L2, L3—National XR-50 form, 22 turns #18e. ½" diam, ¾" long
L4—Bud 40-JEL (for 80 meter operation)
RFC-1 — 4 microhenry. J. W. Miller 5221
RFC-2, RFC-3—2½" millihenry. National R-100
PC—50 ohm, 1 watt resistor, wound with 10 turns #22e. wire
MF—Collins 455 Kc mechanical filter, type 455-D31
R1—Audio level control, 0.5 meg
R2—Modulator balance control, 3000 ohms
All .01 condensers are centralab ceramic type DD

"hot cathode" circuits, it is imperative that the filament line supplying these tubes be close to ground potential at the carrier frequency of 455 k.c. A 0.1 ufd. condenser is placed across the filament leads of the 6BA6 oscillator, and a 0.01 ufd. ceramic condenser is placed across the filament pins of the 6AR8 socket. In addition a small r.f. choke is placed in the filament line between these two tubes and the high frequency portion of the exciter. As a final step, the B-plus line is bypassed with a 0.5 ufd. condenser, and is decoupled from the rest of the exciter with a 1,000 ohm decoupling resistor.

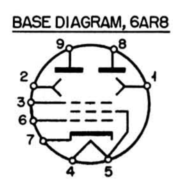
The Low Frequency Oscillator

The 6BA6 oscillator is variable over a range of about 10 kilocycles at 455 k.c. This allows the operator to change sidebands by moving the oscillator frequency from one side of the passband of the mechanical filter to the opposite side. It is possible to transmit an amplitude modulated signal consisting of the carrier and either the upper or lower sideband by placing the carrier at one edge of the filter passband. For normal SSB operation, the oscillator is placed on the slope of the passband, close to the 20 db. attenuation point, as shown in *Figure 7.*

Fig. 3. The 6AR8 Sheet Beam Tube. Designed for TV synchronous detector service, the 6AR8 may also be employed as a balanced modulator for SSB service.

Heater Voltage:
6.3 volts, 0.3 amp.
Envelope—T6½

Pin Connections
1—Deflector #2
2—Deflector #1
3—Accelerator grid
4—Heater
5—Heater, shield, focus electrode
6—Control grid #1
7—Cathode
8—Plate #2
9—Plate #1



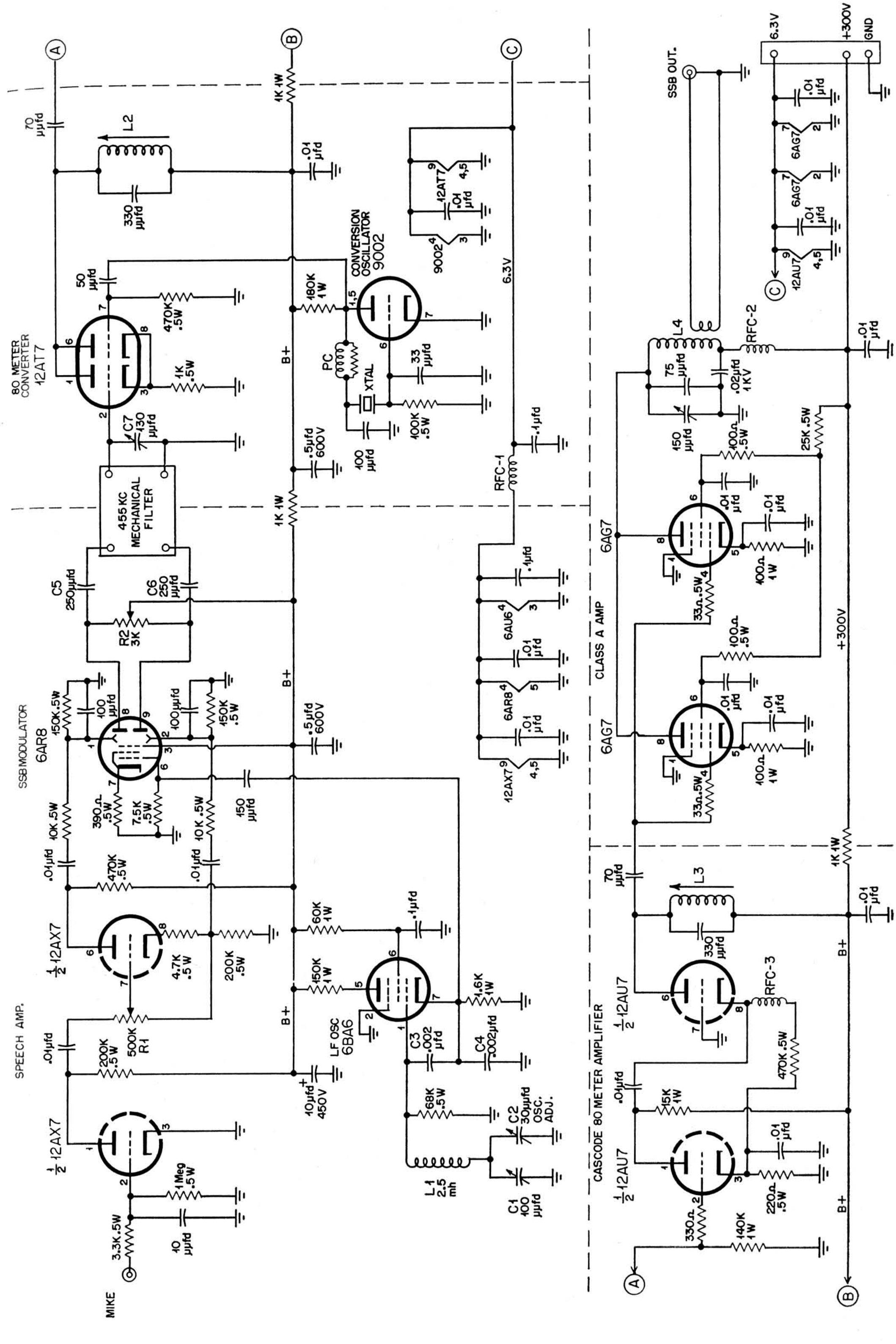


Fig. 8. Schematic, SSB 80 Meter exciter.

The Q of the inductance used in the oscillator grid circuit determines the value of the silver mica padding condensers that are connected from grid to cathode and from cathode to ground of the 6BA6 oscillator tube. With a low-Q coil, these condensers may have to be decreased from the indicated value to .001 ufd. apiece to maintain oscillation of the stage. The effect of these condensers upon the frequency of oscillation is minor, since the frequency determining elements are placed between the coil and chassis ground. The larger the capacity of the padding condensers, the better will be the stability of the oscillator. A good quality 2½ millihenry r.f. choke (National R-100) used in this circuit will allow .002 ufd. padding condensers to be used across the tube elements.

The resonant frequency of the 6BA6 grid circuit is determined by the series padding condenser connected across the oscillator tuning condenser. Too little capacity at this point in the circuit will cause the 6BA6 stage to stop oscillating. The remedy for this is to remove a few turns from the oscillator coil and to add sufficient padding capacity to restore oscillation.

Sideband Filter and 80 Meter Stages

The 6AR8 modulator stage is coupled to the mechanical filter which is series tuned to provide proper impedance match to the modulator. The value of the series tuning capacity will vary with the type and model of filter used. The series capacity removes the d.c. plate voltage from the filter coils. As stated earlier, the carrier balance of the 6AR8 stage is set by a potentiometer control in the plate circuit.

The output circuit of the mechanical filter is parallel tuned to 455 k.c. A SSB signal of about 0.2 volts peak is obtained at this point. A 12AT7 double triode is employed as a conversion mixer to the 80 meter band. The SSB signal and the 3-Mc. mixing carrier are applied to individual grids of the triode sections, and the two signals are mixed in the common plate circuit which is tuned to the sum frequency, which falls within the 80 meter phone band. A 12AU7 cascode stage follows the mixer and amplifies the SSB signal to a level suitable to drive the parallel 6AG7 tubes to a peak power of about 5 watts.

The 12AU7 cascode stage provides a voltage gain of about 90 without the need for parasitic suppression and/or stabilizing circuits that are usually needed in high gain pentode circuits. The plate circuit of the cascode stage is high-C, which helps to further reject the fundamental signal of the crystal controlled conversion oscillator.

The parallel connected 6AG7 output stage employs screen parasitic suppression and series grid resistors to insure stable operation. The stage is not neutralized and tends to be slightly regenerative, raising the intermodulation figure of the transmitter by a measurable amount. The high order products of the transmitter are about 30 db. down from the peak output, which compares favorably with the majority of good amateur SSB signals, and which sets a shining example for some of the mediocre SSB signals that can be heard on the amateur bands from time to time.

Exciter Construction

The SSB exciter is built upon a 8″x12″x3″ aluminum chassis which is divided into compartments to insure that various signals and r.f. voltages stay where they belong. A top view of the exciter is shown in *Figure 9* and a bottom view in *Figure 10*. The 12AT7 speech amplifier, 6AR8 modulator and 6BA6 low frequency oscillator are in one compartment. The center compartment contains the 9002 conversion oscillator and the 12AT7 80 meter mixer. The remaining compartment is divided in two. The smaller section contains the 12AU7 cascode stage, and the larger half contains the parallel 6AG7 amplifier stage. All filament and plate leads to these last two stages pass through bulkhead-type condensers which are mounted in the shield partitions, insuring that the shields are not "short circuited" by power lead coupling loops. When a bottom plate is placed under the chassis, the stage isolation is of a high order.

It is necessary to shield the 9002 conversion oscillator and the 12AT7 mixer tubes, or there will be undesirable coupling around the mechanical filter between the low frequency stages and the 80 meter stages. This coupling will tend to mask the excellent skirt selectivity of the filter. A shield over the 80 meter conversion crystal is also needed. A minute amount of stray coupling existed between the conversion crystal and the 6BA6 low frequency oscillator tube, even though they were located six inches apart on the chassis. After the unit had been run for a time, tube shields were placed on all tubes with the exception of the 6AG7's, with a measurable improvement in sideband suppression and skirt selectivity of the filter. When a filter provides some 80 db. of unwanted sideband rejection, as does the mechanical filter, it does not take much stray leakage around the filter to ruin the passband of the unit. Careful attention to details will reduce this unwanted coupling to a minimum.

Exciter Adjustment

Adjustment of the exciter is relatively simple. The 6BA6 oscillator is so tuned that 455 k.c. falls at mid-scale on its tuning control, which may be labelled "Upper-Lower Sideband selector". The SSB signal at the output of the mechanical filter may be introduced into the i.f. section of a monitor receiver by a short length of coaxial line. The oscillator may then be heard as it is tuned across the passband of the mechanical filter. The 80 meter conversion oscillator may now be monitored for operation, and the low frequency oscillator may be heard on 80 meters as it passes across the filter "window".

The next step is to adjust the balance potentiometer in the plate circuit of the 6AR8 stage for minimum 80 meter carrier at the SSB frequency. The sideband oscillator is then tuned just outside the filter passband, and an audio signal is applied to the exciter. If available, a sine wave of about 2000 cycles should be used, at a level of less than 0.1 volt, r.m.s.

The signal heard at the 80 meter SSB frequency should be a steady carrier with little trace of the 2000 cycle tone. Any tone that may be heard is a result of the sideband beating with the residual carrier and with high order distortion products. When received on a superhetrodyne receiver with no beat oscillator, the SSB test signal with pure tone modulation should sound like a carrier, with perhaps just a trace of light tone modulation.

The output circuit of the mechanical filter should be tuned for maximum SSB signal, as should the plate circuit of the 12AT7 mixer. The 12AU7 cascode amplifier is next plugged in, and the plate circuit of this stage adjusted for maximum SSB signal. The same step is followed for the 6AG7 stage. The 6AG7's may be loaded with an automobile headlight lamp which will serve as a dummy load. The bulb will light to about one half brilliance under full SSB output. When voice modulation is applied to the exciter, the signal should be completely unintelligible until the receiver BFO is turned on and properly adjusted. The speech should be clear and crisp, and no "buckshot" should appear in the spectrum where the rejected sideband lies. Care must be taken to make sure that the amplifier stages are not tuned to the frequency of the 9002 conversion oscillator, since these tuned circuits offer the only rejection to this signal.

When modulation is removed from the SSB exciter, the lamp load should go out. Any residual glow is an indication of carrier leakage, or of leakage of the conversion oscillator signal through the amplifier stages.

By pushing the exciter, almost 10 watts of output may be obtained, but the higher order distortion products increase sharply in value and the SSB signal is adorned with undesired products falling in the unwanted sideband, and outside the limits of the wanted sideband. At a conservative level of 4 or 5 watts, the signal is clean and sharp.

Conclusion

The exciter is a simple unit to get working, the important adjustments being the setting of the carrier-null potentiometer in the 6AR8 stage. The exciter may be tuned up with the S-meter of the station receiver. If a good audio oscillator is at hand, the null control may be adjusted by merely tuning it for minimum intermodulation on the 80 meter signal, or minimum 80 meter carrier when the 6BA6 oscillator stage is in the center of the passband. A little experience will show the best position of the oscillator on the filter slope.

The output of the exciter is sufficient to drive a pair of 807 or 6146 tubes to 100 watts or so. It has also been used to drive a Class AB1 4-400A to about 500 watts on 80 meters.

The author wishes to thank Chandos Rypinski, W6RDR, of *Electronic Industries, Inc.*, Burbank, Calif. for his original suggestion of this application of the 6AR8 tube and for his subsequent design suggestions, and the Tube Division of the *General Electric Co.* for supplying pre-production samples of the 6AR8 tube. ■

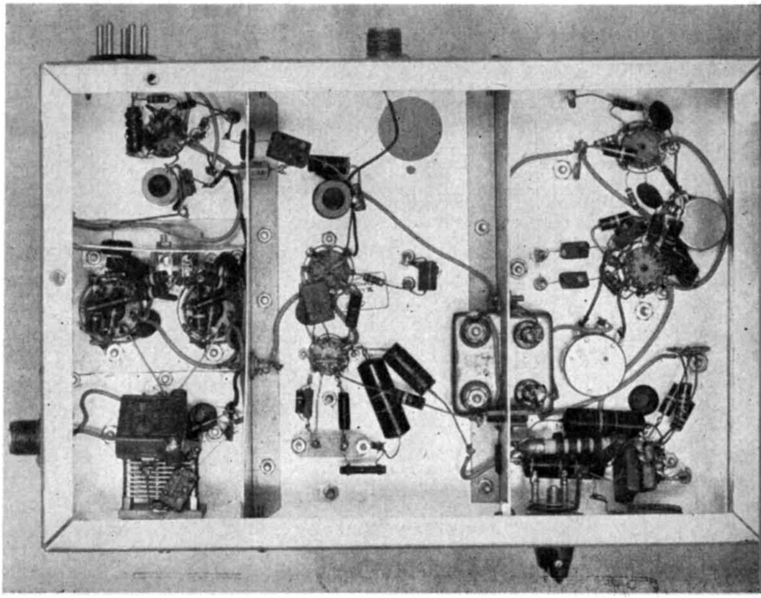


Fig. 10. The output amplifier and cascode stages are in the left hand compartments. The center compartment contains the mixer and oscillator stages. At the right are the low frequency and audio stages. The mechanical filter (atop the chassis) bridges the right hand compartment shield. The input circuit of the filter falls in the low frequency compartment, while the output circuit falls in the mixer compartment.