AMPLIFICATION OF S.S.B. SIGNALS

When an s.s.b. signal is generated at some frequency other than the operating frequency, it is necessary to change frequency by heterodyne methods. These are exactly the same as those used in receivers, and any of the normal mixer or converter circuits can be used. One exception to this is the case where the heterodyning oscillator frequency is close to the desired output frequency. In this case, a balanced mixer should be used, to minimize the heterodyning oscillator frequency in the output.

To increase the power level of an s.s.b. signal, a **linear amplifier** must be used. A linear amplifier is one that operates with low distortion, and the low distortion is obtained by the proper choice of tube and operating conditions. Physically there is little or no difference between a linear amplifier and any other type of r.f. amplifier stage. The circuit diagram of a tetrode r.f. amplifier is shown in Fig. 9-6; it is no different basically than the similar ones in Chapter Six. The practical differences can be found in the supply voltages for the tube and their special requirements. The proper voltages for a number of suitable tubes can be found in Table 9-I; filament-type tubes will require the addition of the filament bypass capacitors C_9 and C_{10} and the completion of the filament circuit by grounding the filament-transformer center tap. The grid bias, E_1, is furnished through an r.f. choke, although a resistor can be used if the tube is operated in Class AB_1 (no grid current). The screen voltage, E_2, must be supplied from a "stiff" source (little or no voltage change with current change) which eliminates the use of a dropping resistor from the plate supply unless a voltage-regulator tube is used.

Any r.f. amplifier circuit can be adapted to linear operation through the proper selection of operating conditions. For example, the tetrode circuit in Fig. 9-6 might be modified by the use of another neutralizing scheme, but the resultant amplifier would still be linear if the proper operating conditions were observed. A triode or pentode amplifier circuit would differ only in detail; typical circuits can be found in Chapter Six.

The simplest linear amplifier is the Class-A amplifier, which is used almost without exception throughout receivers and low-level speech amplifiers. (See Chapter Three for an explanation of the classes of amplifier operation.) While its linearity can be made relatively good, it is inefficient. The theoretical limit of efficiency is 50 per cent, and most practical amplifiers run about 25 per cent at full output. At low levels this is not worth worrying about, but when the 2- to 10-watt level is exceeded the efficiency should be considered, in view of the tube, power-supply and operating costs.

Class-AB_1 operation provides excellent linear amplifiers if suitable tubes are used. Primary advantages of Class-AB_1 amplifiers are that they give greater output than straight Class-A amplifiers using the same tubes, and they too do not require any grid driving power (no grid current drawn at any time). Triodes can be used in Class AB_1 but tetrodes or pentodes are to be preferred. Class-AB_1 operation requires high peak plate current without grid current, which is easier to obtain with multigrid tubes (tetrodes and pentodes) than with triodes.

Maximum linear output is obtained from tetrodes, pentodes and most triodes when they are operated class AB_2. This operation, however, increases the driving-power requirements and,

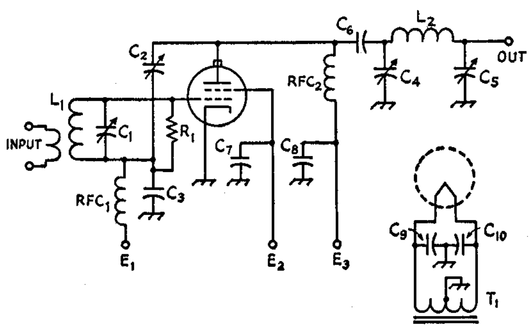

Fig. 9-6—Circuit diagram of a tetrode linear amplifier using link-coupled input tuning and pi network output coupling. The grid, screen and plate voltages (E_1 E_2 and E_3) are given in Table 9-1 for a number of tubes. Although the circuit is shown for an indirectly-heated cathode tube, the only change required when a filament type tube is used is the addition of the filament bypass capacitors C_9 and C_{10}.

Minimum voltage ratings for the capacitors are given in terms of the power supply voltages.

C_1—Grid tuning capacitor, $3E_1$.
C_2—Neutralizing capacitor, $2E_3$.
C_3—Grid-circuit bypass capacitor, part of neutralizing circuit, $3E_1$.
C_4—Plate tuning capacitor, $1.5E_3$.
C_5—Output loading capacitor. 0.015 spacing for kilowatt peak.
C_6—Plate coupling capacitor, $2E_3$.
C_7—Screen bypass capacitor, $2E_2$.
C_8—H.v. bypass capacitor, $2E_3$.
C_9, C_{10}—Filament bypass capacitor.
L_1—Grid inductor.
L_2—Plate inductor.
R_1—Grid circuit swamping resistor, required for AB_2. See text.
RFC_1—Grid-circuit r.f. choke.
RFC_2—Plate r.f. choke.
T_1—Filament transformer.

TABLE 9-I—LINEAR-AMPLIFIER TUBE-OPERATION DATA FOR SINGLE SIDEBAND—GROUNDED-CATHODE CIRCUIT

Unless otherwise noted, ratings are manufacturers' for audio operation. Values given are for one tube. Driving powers represent tube losses only—circuit losses will increase the figures

Tube	Class	Plate Voltage	Screen Voltage	D.C. Grid Voltage[1]	Zero-Sig. D.C. Plate Current	Max.-Sig. D.C. Plate Current	Zero-Sig. D.C. Screen Current	Max.-Sig. D.C. Screen Current	Peak R.F. Grid Voltage	Max.-Sig. D.C. Grid Current	Max.-Sig. Driving Power	Max.-Rated Screen Dissipation	Max.-Rated Grid Dissipation	Avg. Plate Dissipation	Max.-Sig. Useful Power Output
2E26	AB_1	500	200	−25	9	45	—	10	25	0	0	2.5	—	—	15
6146	AB_1	600	200	−50	14	115	.5	14	50	0	0	3	—	25	47
6883		750	195	−50	12	110	.5	13	50	0	0	3	—	25	60
807		600	300	−34	18	70	.3	8	34	—	0	3.5	—	25	28
1625	AB_1	750	300	−35	15	70	.3	8	35	—	0	3.5	—	30	36
6550	AB_1	600	300	−31	57	135	2	20	31	0	0	6	—	35	50
8579[3]	AB_1	600	250	−50	100	325 (220)[4]	3	28 (14)[4]	50	0.5	2	7.5	—	75	110
811-A	B	1000	—	0	22	175	—	—	93	—	3.8	—	—	65	124
		1250	—	0	27	175	—	—	88	13	3.0	—	—	65	155
4-65A[2]	AB_1	1500	500	−90	30	83	—	5	70	—	—	10	—	—	60
		2000	500	−105	20	75	—	3	80	—	—	10	—	—	85
		2500	400	−85	15	66	—	3	77	—	—	10	—	—	100
		3000	400	−90	15	60	—	3	77	—	—	10	—	—	120
PL-177A[2]	AB_1	1500	600	−110	30	175	0	8	108	0	0	10	—	110	140
PL-177WA[2]		2000	600	−115	25	175	0	7	112	0	0	10	—	125	210
7094	AB_1	2000	400	−65	30	200	—	35	60	0	4[3]	20	—	—	250
813	AB_1	2500	750[5]	−95	25	145	—	27	90	0	0	—	—	—	245
	AB_2	2250	750[5]	−90	23	158	.8	29	115	—	.1	22	—	100	258
		2500	750[5]	−95	18	180	.6	28	118	—	.2	22	—	125	325
4-125A	AB_1	2000	615	−105	40	135 (100)[4]	—	14 (4.0)[4]	105	0	0	20	—	—	150
		2500	555	−100	35	120 (85)[4]	—	10 (3.0)[4]	100	0	0	20	—	—	180
		3000	510	−95	30	105 (75)[4]	—	6.0 (1.5)[4]	95	0	0	20	—	—	200
7034/ 4X150A	AB_1	1000	300	−50	50	225	0	11	50	0	0	12	—	—	115
		1500	300	−50	50	225	0	11	50	0	0	12	—	—	200
		1800	300	−50	50	225	0	11	50	0	0	12	—	—	250
4-250A	AB_1	2500	600	−115	65	230 (170)[4]	—	15 (3.5)[4]	115	0	0	35	—	—	335
		3000	600	−110	55	210 (150)[4]	—	12 (2.5)[4]	110	0	0	35	—	—	400
		3500	555	−105	45	185 (130)[4]	—	9.5 (2.0)[4]	105	0	0	35	—	—	425
		4000	510	−100	40	165 (115)[4]	—	7.5 (1.5)[4]	100	0	0	35	—	—	450
4-400A	AB_1	2500	750	−130	95	317	0	14	130	0	0	35	—	370	425
		3000	750	−137	80	317	0	13	137	0	0	35	—	400	555
		3500	750	−145	70	305	0	16	145	0	0	35	—	400	665
		4000	750	−150	60	292	0	20	150	0	0	35	—	400	770
PL-175A[2]	AB_1	2500	750	−143	100	350	1	35	143	0	0	25	—	265	570
		3000	750	−150	80	350	1	29	150	0	0	25	—	305	680
		3500	750	−160	75	350	1	24	160	0	0	25	—	345	790
5-500A	AB_1	2000	750[5]	−100	150	338 (252)[4]	—	31 (15)[4]	100	0	0	35	—	500	395
		3000	750[5]	−112	100	320 (221)[4]	—	26 (12)[4]	112	0	0	35	—	500	12
		4000	750[5]	−121	80	322 (212)[4]	—	24 (10)[4]	121	0	0	35	—	500	832
PL-8295/172	AB_1	2000	500[6]	−110	200	800	12	43	110	0	0	30	—	—	1040
PL-8432		2500	500[6]	−115	200	800	11	40	115	0	0	30	—	—	1260
		3000	500[6]	−115	220	800	11	39	115	0	0	30	—	—	1590
4CX1000A	AB_1	2000	325	−60	250	1000	−2	35	60	—	0	12	0	—	1020
		3000	325	−60	250	900	−2	35	60	—	0	12	0	—	1680

[1] Approximate; adjust to give stated zero-signal plate current.
[2] Single-sideband suppressed-carrier ratings, voice signal.
[3] 60 Mc.
[4] Values in parentheses are with two-tone test signal.
[5] 0 v. suppressor grid
[6] +35 v. suppressor grid.

TABLE 9-II—CLASS-B LINEAR-AMPLIFIER TUBE-OPERATION DATA FOR SINGLE SIDEBAND—GROUNDED-GRID CIRCUIT

Tube	Plate Voltage	D.C. Grid Voltage	Zero-Sig. D.C. Plate Current	Max.-Sig. D.C. Plate Current	Peak R.F. Grid Voltage	Max.-Sig. D.C. Grid Current	Max.-Sig. Driving Power	Max.-Sig. Useful Power Output
811-A	1250	0	27	175	88	28	12	165
813[1]	2000	0	24	124	87	20	10	158
	2500	0	30	133	91	23	11	219
4-125A[1]	2500	0	15	110 (30)[2]	—	55	16	190
	3000	0	20	115 (30)[2]	—	55	16	240
4-400A[1]	2500	0	80	270 (55)[2]	—	100	39	435
	3000	0	90	280 (55)[2]	—	100	40	555
572B	2500	0	25	225	110	35	22[7]	400
3-400Z	2000	0	62	400 (265)[3]	—	148 (87)[3]	—	445[4]
	2500	0	73	400 (274)[3]	—	142 (82)[3]	—	560[5]
	3000	0	100	333	—	120	32	655
PL-6569	2500	−60[6]	40	300	180	80	70[7]	550
	3500	−90[6]	30	270	220	68	75[7]	760
	4000	−105[6]	24	250	205	42	60[7]	800
PL-6580	2500	−50	60	350	195	95	75[7]	610
	3500	−85	45	300	210	65	68[7]	765
	4000	−100	40	300	230	65	72[7]	910
3-1000Z	2500	0	162	800 (550)[3]	—	254 (147)[3]	—	1050[4]
	3000	0	240	670	—	300	65	1360
4-1000A[1]	3000	0	100	700	—	170(105)[2]	130	1475

[1]Grid and screen connected together.
[2]Screen current.
[3]Two-tone signal.
[4]Minimum distortion products.
[5]Minimum distortion products at 1 k.w. p.e.p. input.
[6]Approximate; adjust to give stated zero-signal plate current.
[7]Includes bias loss, grid dissipation, and feed-through power.

what is more important, requires that driver regulation (ability to maintain wave form under varying load) be good or excellent. This is not an easy requirement to meet, and the current trend is to use tetrodes or pentodes in AB_1 or zero-bias Class-B triodes.

Class-B amplifiers are theoretically capable of 78.5 per cent efficiency at full output, and practical amplifiers run at 60–70 per cent efficiency at full output. Triodes normally designed for Class-B audio work can be used in r.f. linear amplifiers and will operate at the same power rating and efficiency provided, of course, that the tube is capable of operation at the radio frequency. The operating conditions for r.f. are substantially the same as for audio work — the only difference is that the input and output transformers are replaced by suitable r.f. tank circuits. Further, in r.f. circuits it is readily possible to operate only one tube if only half the power is wanted — push-pull is not a necessity in Class-B r.f. work.

For proper operation of grounded-cathode Class-B amplifiers, and to reduce harmonics and facilitate coupling, the input and output circuits should not have a low *C*-to-*L* ratio. A good guide to the proper size of tuning capacitor will be found in Chapter Six; use the voltage-to-current ratio of p.e.p. conditions. It is essential that the amplifier be so constructed, wired and neutralized that no trace of regeneration or parasitic instability remains. Needless to say, this also applies to the preceding stages.

In a Class-AB_1 amplifier, the control-grid bias supply can be anything. However, the screen supply should have good regulation; its voltage should remain constant under the varying current demands. If the maximum screen current does not exceed 30 or 35 ma., a string of VR tubes in series can be used to regulate the screen voltage. If the current demand is higher, it may be necessary to use an electronically regulated power supply or a heavily bled power supply with a current capacity of several times the current demand of the screen circuit.

Where VR tubes are used to regulate the screen supply, they should be selected to give a regulated voltage as close as possible to the tube's rated voltage, but it does not have to be exact. Minor differences in idling plate current can be made up by readjusting the grid bias.

The plate voltage applied to the linear amplifier should be held as constant as possible under the varying current-demand conditions. This condition can be met by using low-resistance transformers and inductors and by using a large value of output capacitor in the power-supply filter. An output capacitor value three or four times the minimum required for normal filtering is reasonable.

Grounded-grid operation of zero-bias triodes is finding increasing popularity among s.s.b. operators. A zero-bias triode that requires 10 or 15 watts driving power in a grounded-cathode circuit will need several times this for full output in the grounded-grid configuration. This is not because the grid losses increase—they don't

—but in grounded-grid operation a large portion of the input signal finds its way to the output. Since many of the sideband-exciter designs that one starts with are in the 50- to 100-watt output class, a grounded-grid amplifier makes better use of the exciter output than would a Class-AB_1 amplifier.

It is not necessary to use indirectly-heated cathode type tubes in grounded-grid circuits; filament-type tubes can be used just as effectively. However, it is necessary to raise the filament above r.f. ground with filament chokes between the filament transformer and the tube socket. The inductance of the r.f. chokes does not have to be very high, and 5 to 10 μh. will usually suffice from 80 meters on down. The current-carrying capacities of the r.f. chokes must be adequate for the tube or tubes in use, and if the resistance of the chokes is too high the filament voltage *at the tube socket* may be too low and the tube life will be endangered. In such a case, a higher-voltage filament transformer can be used, with its primary voltage cut down until the voltage at the tube socket is within the proper limits.

Although filament chokes can be wound on wooden or ceramic forms (e.g., large cylindrical ceramic antenna insulators), they can be made more compact and with lower resistance (less voltage drop) by winding them on ferrite rods. Individual chokes for each side of the filament are desirable if they must be wound on wood or ceramic, but when wound on ferrite a dual winding is satisfactory. The single winding choke(s) should be wound with heavy wire spaced (with string) one-half to one wire diameter. In the ferrite-cored choke the two parallel enameled wires are treated as one wire; see Chapter Six for two examples of homemade filament chokes.

When considerable power is available for driving the grounded-grid stage, the matching between driver stage and the amplifier is not too important. However, when the driving power is marginal or when the driver and amplifier are to be connected by a long length of coaxial cable, a matching circuit can be used in the input of the grounded-grid amplifier. The input impedance of a grounded-grid amplifier is in the range of 50 to 400 ohms, depending upon the tube or tubes and their operating conditions. When data for grounded-grid operation is available (see Table 9-II), the input impedance can be computed from

$$Z = \frac{(\textit{peak r.f. driving voltage})^2}{2 \times \textit{driving power}}$$

From this and the equations for a pi or L network, a suitable matching circuit can be devised. It should have a low Q, about 3 or 4.

Tables 9-I and 9-II list a few of the more popular tubes commonly used for s.s.b. linear-amplifier operation. Except where otherwise noted, these ratings are those given by the manufacturer for audio work and as such are based on a sine-wave signal. These ratings are adequate ones for use in s.s.b. amplifier design, but they are conservative for such work and hence do not necessarily represent the maximum powers that can be obtained from the tubes in voice-signal s.s.b. service. In no case should the *average* plate dissipation be exceeded for any considerable length of time, but the nature of a s.s.b. signal is such that the average plate dissipation of the tube will run well below the peak plate dissipation.

Getting the most out of a linear amplifier is done by increasing the peak power without exceeding the average plate dissipation over any appreciable length of time. This can be done by raising the plate voltage or the peak current (or both), provided the tube can withstand the increase. However, the manufacturers have not released any data on such operation, and any extrapolation of the audio ratings is at the risk of the amateur. A 35- to 50-per cent increase above plate-voltage ratings should be perfectly safe in most cases. In a tetrode or pentode, the peak plate current can be boosted some by raising the screen voltage. In all instances there will be an optimum set of driving and loading conditions for any given set of plate and grid (and screen) voltages, but the tube manufacturer can obviously give only a few (and they are likely to be conservative). The *only* dependable approach to determining the proper conditions for an "unknown" linear (one operating at other than manufacturer's ratings) is by using an oscilloscope and dummy load.

When running a linear amplifier at considerably higher than the audio ratings, the "two-tone test signal" should never be applied at full amplitude for more than a few seconds at any one time. The above statements about working tubes above ratings apply only when a voice signal is used—a prolonged whistle or two-tone test signal may damage the tube. It is possible, however, to "key" or "pulse" the two-tone test signal so that the linearity of an amplifier can be checked at high peak-to-average plate dissipation ratios. For example, an electronic "bug" key can be used to switch the two-tone test signal on and off at a rapid rate (a string of "dots"). This will reduce the average-to-peak plate-dissipation ratio to a low figure. (For another method of adjusting linear amplifiers safely at high input, see Goodman, "Linear Amplifiers and Power Ratings," *QST*, August, 1957.)

Linear amplifiers are rated in "p.e.p. input" or "p.e.p. output." The "p.e.p." stands for **peak envelope power**. P.e.p. input is not indicated by the maximum reading the plate milliammeter kicks to; it is the input that would be indicated by the plate milliammeter and voltmeter *if* the amplifier were driven continuously by a single r.f. signal of the peak amplitude the amplifier can handle within its allowable distortion limits. In other words, it is the "key-down input" within the allowable distortion limits. The p.e.p. output is the r.f. output under these same conditions. As implied in the preceding paragraph, it may be impossible to measure the p.e.p. input or output directly without injuring the tube or tubes.