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LAZY LINEAR

Final Amplifier for AM, NBFM, CW or SSB Using GL-811-A Triodes

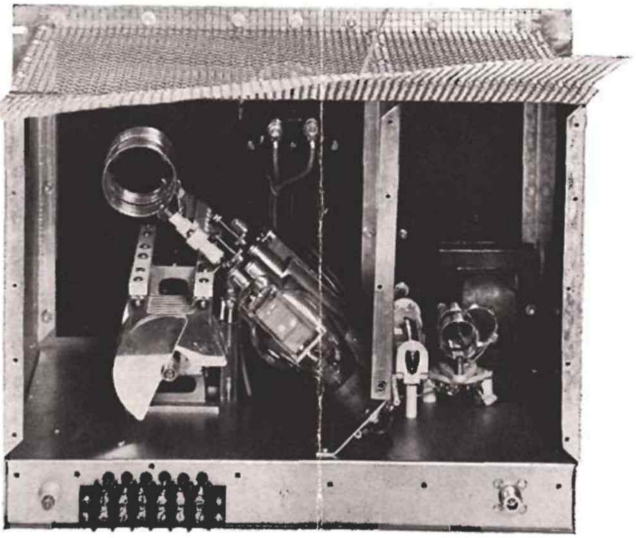

Fig. 1. Rear View of Lazy Linear with Shielding Mesh Raised to Show Detail

High power linear amplifiers are very rarely used in amateur stations, although the average amateur uses linear amplifiers all the time, and may not realize it fully. All distortion-free audio amplifiers, as well as RF and IF amplifiers, in superheterodyne receivers are linear amplifiers (the limiter in an FM receiver is an exception).

Perhaps the amateur has kept away from high-power linear amplifiers because of their reputation for poor efficiency. This reputation is perhaps deserved only when AM signals are considered, as a check of Fig. 12 will show. However, a linear amplifier is ideally suited for single-sideband transmission where the peak efficiency is about 70 percent. The Lazy Linear was designed with this type of operation in mind, although data is given for operation on AM phone, NBFM phone, and CW.

The Lazy Linear is a final amplifier capable of 400 watts peak output on SSB, 400 watts peak output using a keyed carrier (CW), 180 watts peak output on NBFM phone, and 180 watts peak output (45 watts carrier power output) on AM phone. A complete comparison of these various types of emission is given in Fig. 12. In addition, the Lazy Linear has been designed to be practically TVI-proof. Complete shielding and filtering of power leads is employed in the Lazy Linear.

GENERAL LINEAR CONSIDERATIONS

A linear amplifier is by definition an amplifier in which the output signal is directly proportional to the input signal. Since this is the case, the input and output signals are very much interdependent upon one another. This is emphasized because the average amateur is familiar with Class C amplifiers, and his experience with this type of amplifier will have to be forgotten temporarily when adjusting linear amplifiers. The adjustment is not difficult but the amateur must remember that the grid current, driving power, plate current dip, etc., as applied to his experience with Class C amplifiers may mean something entirely different when working with linear amplifiers.

A linear amplifier has several very important advantages over Class C amplifiers. Because the driving power is materially lower with linear amplifiers there is far less probability of generating and radiating harmonics. This means that television interference caused by harmonics of the intended signal is much less likely. Further, the harmonic output of a linear amplifier of a given output rating is lower than is experienced with Class C amplifiers. This cuts down the amount of trouble that can be caused by harmonics and makes TVI elimination a simpler job.

For single-sideband transmission a linear amplifier is practically essential. The practical efficiency in this type of service is in the order of 70 percent on peaks. NBFM transmission could well employ a linear amplifier to take advantage of the low driving power requirements and the reduced harmonic output as compared with "Class C" amplifier operation.

In CW use, a linear amplifier opens the way to the solution of key-click elimination and bandwidth reduction. As before, of course, the driving power requirements are very low and the harmonic distortion is low. For CW work the keying and shaping may be done at a low power level point in the exciter

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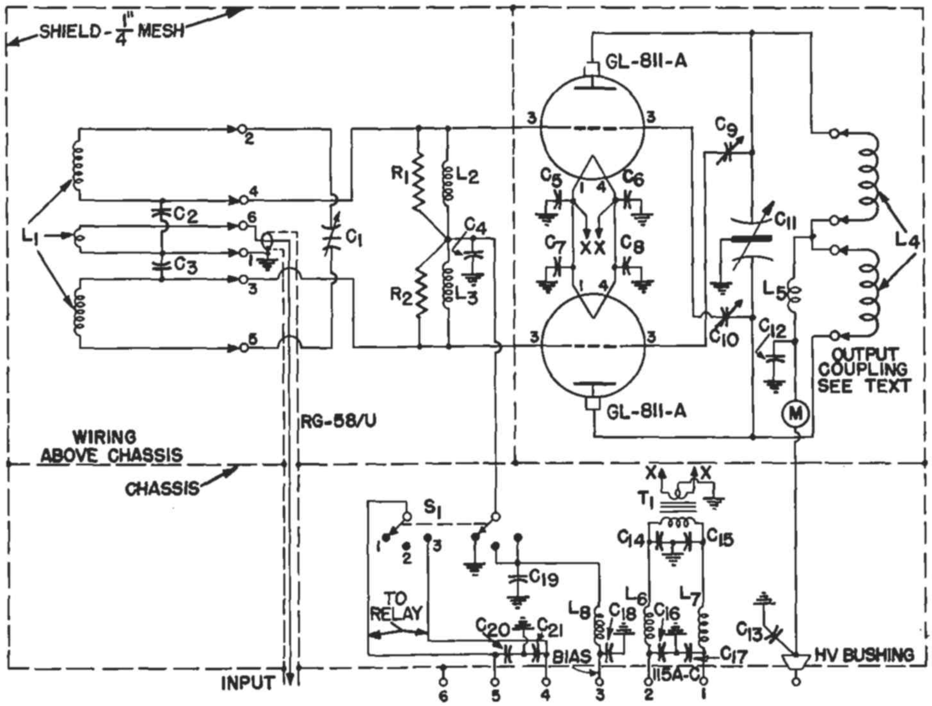

Fig. 2. Circuit Diagram of Lazy Linear

CIRCUIT CONSTANTS

C_1	Split-stator 140 mmf variable (Hammarlund *HFD-140*)
C_2, C_3	See Grid Coil Table
C_4, C_5, C_6, C_7, C_8, C_{14}, C_{15}, C_{16}, C_{17}, C_{18}, C_{20}, C_{21}	0.005 mf ceramicon or mica
C_9, C_{10}	Neutralizing condenser, 3–9 mmf, 6000 volt (Millen 15006)
C_{11}	200 mmf per section split-stator variable, 0.077 inch air-gap (Millen 14200)
C_{12}, C_{13}	0.002 mf, 2500 volt (working) mica
C_{19}	1.0 mf, 200 volt paper or oil-filled
L_1	National AR-17 swinging-link coils, modified as per text and coil table
L_2, L_3, L_8	500 microhenry r-f choke (Millen 34300–500)
L_4	Millen 44000 series "150 watt" coils, modified as per text
L_5	1.0 millihenry, 300 ma r-f choke (*Millen 34107*)
L_6, L_7	R-F chokes, one layer of No. 26 enamelled wire wound on new-style one watt, one megohm resistor
M	0–500 ma meter (G.E. DO-40)
R_1, R_2	1000 ohm, 10 watt non-inductive resistor (Sprague NIT)
S_1	Two-pole, three-position, non-shorting switch (Mallory 3223-J)
T_1	6.3 v, 10 ampere filament transformer (Thordarson T-21F12 or T-19F99)

without amplifier distortion undoing the job done at the low level point.

It is recommended that the prospective builder or user of the Lazy Linear read and digest the article "Linear R.F. Amplifiers" by S. G. Reque, which appeared in the May, 1949 QST. This article reviews the high points in the design and adjustment of linear amplifiers and will furnish good background material on the subject.

ELECTRICAL DETAILS—GRID CIRCUIT

Fig. 1 will explain one reason for the name Lazy Linear. The name also applies because the tubes seem to loaf along when providing 400 watts of peak power output on SSB.

The circuit diagram for the Lazy Linear is given in Fig. 2.

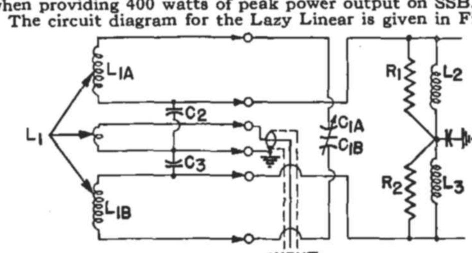

Fig. 3. Lazy Linear Grid Circuit

It will be seen that the diagram is that of the usual push-pull final with the exception of the grid circuit. In linear amplifier circuits the grid circuit is extremely important because it is necessary to provide a signal of good regulation to the tube grids. The choice of the GL-811-A tube simplifies the grid circuit design. Incidentally, the GL-811 tube will also work in the Lazy Linear, but the newer tube with its greater plate dissipation will permit a larger factor of safety in operation. The GL-811-A tubes are inexpensive and lend themselves readily to the requirements of linear amplifier operation at a power output level that is surprisingly high.

The input circuit is a combination transformer/resonant circuit/pi-matching network. Referring to the special grid circuit schematic in Fig. 3, the driving signal is coupled by means of an adjustable swinging link into a resonant circuit comprising L_{1A}, L_{1B}, C_{1A}, C_{1B}, C_2 and C_3. If the inductance of L_{1A} and L_{1B} in series be considered as having a value of L_T, and the capacity of the four condensers C_{1A}, C_{1B}, C_2 and C_3 in series be considered as having a resultant value of C_T, resonance will be achieved when the inductive reactance of L_T equals the capacitive reactance of C_T. Further, if C_{1A} is equal to C_{1B} and C_2 equals C_3, this relationship may be expressed in the formula:

$$C_T = \frac{C_{1A} C_2}{2(C_{1A} + C_2)}$$

Also, since C_2 will be equal to C_{1A} times a constant, K, we find that the resultant capacitance will then be expressed in the formula:

$$C_T = \frac{1}{2} K \frac{C_{1A}}{(1 + K)}$$

In the design of the Lazy Linear K is equal to approximately

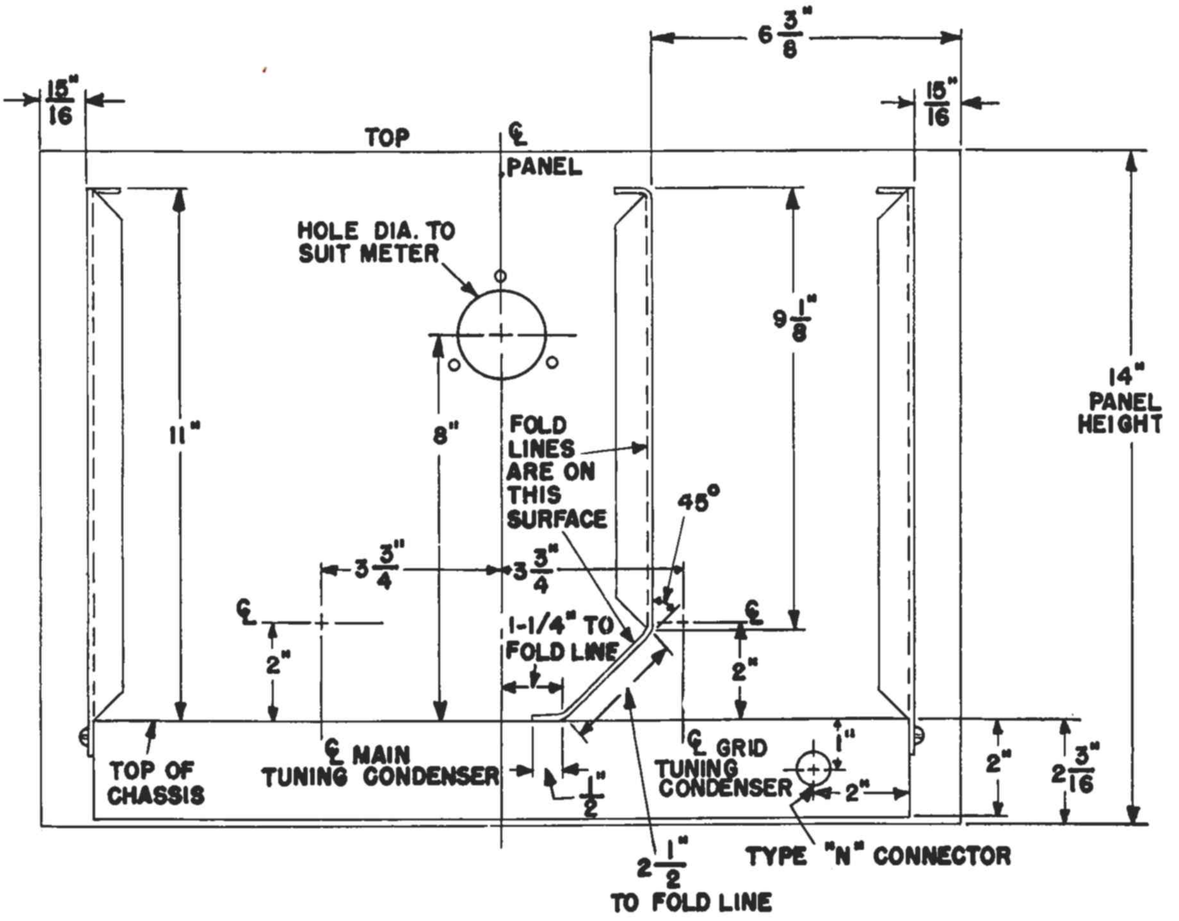

Fig. 4. Detail of Chassis and Panel Assembly (Rear View)

2.5, which calculates out to give the answer that C_2 (which is equal to C_3) equals 7 times C_T. It will be seen therefore that the choice of a coil fixes the values of the four condensers for any given frequency. Since C_{1A} and C_{1B} are variable (but equal) the ratio K will change somewhat over any given amateur band. Center-band frequencies were used in the calculations.

The foregoing information on the design of the grid circuit has been given mainly for one reason, and that is to point out the importance of the following statement. *It is absolutely necessary to use coils having the correct value of inductance in order to fulfill the combined requirements of tuning, coupling and matching in this circuit.*

The total operating Q of the circuit into which the exciter driving tube operates is approximately 20. This value of Q gives a reasonable amount of room for maladjustment without the danger of ending up with too low a Q for the driver. By the same token, the load on the grid circuit provided by the driver lowers the source impedance of the matching circuit and improves the voltage regulation of the driving system. Good grid circuit regulation is essential in order to provide the amplifier itself with a signal reasonably free from distortion.

It was found necessary to use a fixed source of grid bias in some cases. The amount of bias required (zero to −3 volts depending upon the plate voltage used) is most conveniently provided by a small 4½ volt battery. This battery should give at least "shelf life" but must be in good condition if distortion is to be held to a satisfactory point. While discussing distortion it might be well to point out that, contrary to a commonly held belief, a linear amplifier must be made as linear as possible for SSB work. Amplifier distortion evidences itself as unwanted sideband components and cross products on either side of the carrier frequency despite the fact that the load into which the amplifier operates is a tuned load.

Resistors R_1 and R_2 and chokes L_2 and L_3 were not taken into account when making calculations on the grid circuit, but this approximation will not cause any serious error. The two resistors are loading or "swamping" resistors which serve to fix the source impedance and the operating Q of the grid circuit. Note, the rotor of C_1 is insulated from ground.

From the above discussion of the grid circuit of the Lazy Linear the average amateur may form the opinion that the unit is extremely complicated to build and adjust. The fact is that the design work has been carefully done so that, if the parts specified are used, the average amateur should not have any difficulties in building and using the Lazy Linear. The emphasis placed upon the design of the grid circuit has been deliberate in order to show why the circuit constants and the tune-up procedures should be followed exactly.

ELECTRICAL DETAILS—PLATE CIRCUIT

Push-pull operation of the GL-811-A tubes requires the use of a balanced plate tank condenser. The rotor of this condenser (C_{11}) is grounded securely to the chassis to provide a good return path to the filaments. Harmonic currents must flow through the condenser back to the filaments, and they need all the encouragement, that is, low impedance, that can be provided.

The remainder of the circuit is quite usual. Note that the high voltage required should be un-modulated d-c. No attempt should be made to employ high-level plate modulation.

No output coupling arrangement will be seen in Fig. 1. This does not mean that the Lazy Linear has not been tested on the air. As a matter of fact, the Lazy Linear was thoroughly tested on the air and some of you reading this may have had a QSO with W2KUJ while the unit was undergoing tests at his shack.

Output coupling may be by means of an adjustable link arranged to swing between the two halves of the plate tank coil. Or, a balanced pi-matching network with grounded neutral may be used. In any case, provision for adjustment of the coupling (or at least the reflected load) must be made. Ample space is available for mounting a swinging link on the chassis next to the tuning condenser. If a pi-network is used this should be connected to the stator plates of the tuning condenser by means of blocking condensers of ample voltage rating (0.001 mf at 2500 volts working should be suitable).

Approximately 8000 ohms plate-to-plate loading is correct, although the exact value depends upon the plate voltage used and the class of service employed. As was true in the grid circuit, coils of the proper value of inductance are necessary in order to preserve suitable L-C ratios on each band. Plate coil specifications are as follows: The Millen 44000 series coils are used. For example, 44010 is the 10 meter coil, 44020 is the 20

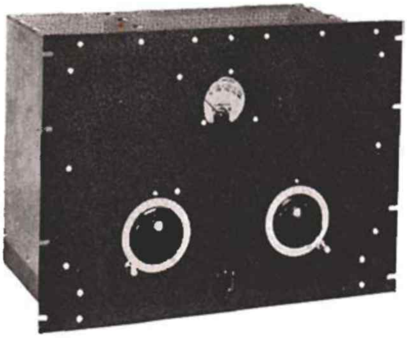

Fig. 5. Front Panel View of Lazy Linear

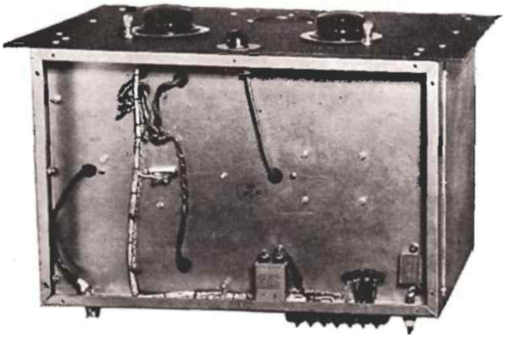

Fig. 6. Underside View of Lazy Linear

meter coil, etc. These coils are used without change with the following exceptions. Coil 44080 is used for 160 meters and extra padding capacitance is required in parallel with C_{11}. Two 200 mmf condensers should be used, one in parallel with each stator section of C_{11}. These capacitors may be fixed air condensers or vacuum condensers, or even a variable condenser from the junk-box set at the proper capacitance.

Coils 44010, 44020 and 44040 will work without alteration on 10, 20 and 40 meters. Coil 44080 must be altered by removing 6 turns from each half of the coil. (This means that two 44080 coils are required, one for 80 and one for 160.)

For those who desire to make their own coils, the desired *inductance for the 160—10 meter coils, respectively, is 40, 20,* 10, 5 and 2 microhenrys.

MECHANICAL DETAILS

The Lazy Linear is constructed on a 11 by 17 by 2 inch *plated* chassis and uses a 19 by 14 inch front panel. The entire unit must be shielded to minimize TVI. Figs. 4, 10, and 11 show the constructional details of the metal pieces which act to support the shielding mesh and also to shield the input circuit from the plate circuit. Two pieces of galvanized quarter-inch mesh hardware cloth are cut to size to provide the top shield and the rear shield. They are best cut to size when the other metal pieces are mounted in position and properly aligned. In addition to all this shielding, a cover plate is used on the bottom of the chassis.

To make the shielding effective, remove the paint around the edges of the rear side of the front panel so that good electrical contact can be made between the front panel and the end plates, between the front panel and the quarter-inch mesh, between the front panel and the chassis, and between the front panel and the rack on which it mounts. The paint must also be removed from around the meter hole, on the rear face of the panel, so that the copper screen which covers the meter hole may be soldered to the panel. The meter itself is mounted on standoff posts to prevent breakdown between the meter and the panel. If the meter case is metal, insulated standoff posts must be used.

The rear shield of quarter-inch mesh is hinged to the top quarter-inch mesh by means of a length of flat half-inch wide copper braid. The braid should be soldered to the galvanized mesh at every point along the joint.

Detail photographs are given of the grid section and the plate section. The plate section detail, Fig. 8, shows how the Millen coil base is mounted on the Millen condenser. Two pieces of 1/16 inch brass, one inch by one inch, must be made. A half-way point fold is placed in these pieces at a 45 degree angle. When the 6–32 screw is removed from the tuning condenser in order to mount the brass plate it will be seen that the threaded area is too small to allow re-use of the same machine screw. A longer screw must be provided. However, take care that it is not too long, as it may strike the threaded rod on which the stator plates are mounted. It may be necessary to file the machine screw used to the proper length.

It will also be necessary to cut off approximately one inch of the stud which forms the top part of the neutralizing condenser so that it will fit in the space provided.

By following the photographs and the sketches, no difficulty should be encountered in the construction of the Lazy Linear. Make sure that you do a good job on the bypassing, especially where the power leads enter the rear of the chassis. Use as short leads as possible.

The dials shown in the front-panel view, Fig. 5, are Millen 10008 with Millen 10050 dial locks.

Grid coils required are the National AR-17 swinging link series. Because the input circuit is a pi network changes must be made on each of these coils. As received the coils have a center-tapped link and only one connection from the center point of the two main coils. Further, it is necessary to add C_2 and C_3 on each coil, and in the case of the 160 and 80 meter coil additional padding must be added so that it is effectively in parallel with C_1.

The changes should be made as follows: Cut the wire which connects pin 3 to the center-tap of the link about ⅜ of an inch below where it connects to the link. The two main coils are joined by a wire which is molded into the center piece of insulating material. Find the point on this wire where the connection to pin number 4 is made and cut the joining wire just below this point. The wire just cut now connects to the wire going to pin number 3. Add condensers C_2 and C_3, and the padding condenser if required, and the job is done. It will be necessary to match C_2 and C_3 within 5 percent in all cases. Repeat for all grid coils. (See Grid Coil Table for proper values to add.)

GRID COIL TABLE

160 meters: (No National AR-17 series coil was available at time of writing.) A suitable coil can be made as follows:

Each half to be 50 turns, 1 inch in diameter, 32 TPI spacing. (B & W Miniductor No. 3016 cut in half.) Space two halves one-half inch apart. Make link also 32 TPI, 1 inch in diameter, 12 turns. Pad (pin 2 to 5) with 100 mmf. C_2 equals C_3 equals 1000 mmf.

80 meters: Use National AR-17-80S. C_2 equals C_3 equals 470 mmf. Use a 20 mmf mica padding condenser from pin 2 to pin 5.

40 meters: Use National AR-17-80S and remove 8 turns from each coil half. C_2 equals C_3 equals 250 mmf. Remove 5 turns from link.

20 meters: Use National AR-17-40S. C_2 equals C_3 equals 100 mmf.

10 meters: Use National AR-17-20S. C_2 equals C_3 equals 50 mmf.

Desired inductance, for those who wish to make their own, for the 160—10 meter coils, is, respectively, 65, 32, 16, 9 and 3 microhenrys.

EXCITER REQUIREMENTS

The table of Fig. 12 indicates various modes of operation and gives information on driving power, plate operating conditions, etc. In general the driving power requirements are very low. Any exciter which ends up in an 807 or a tube of similar power should be suitable to drive the Lazy Linear for any mode of operation, provided that the exciter itself provides the proper type of emission. The exciter described by W2KUJ in the March and April 1949 *CQ* will provide an adequate driving signal for all types of emission (SSB, AM, NBFM).

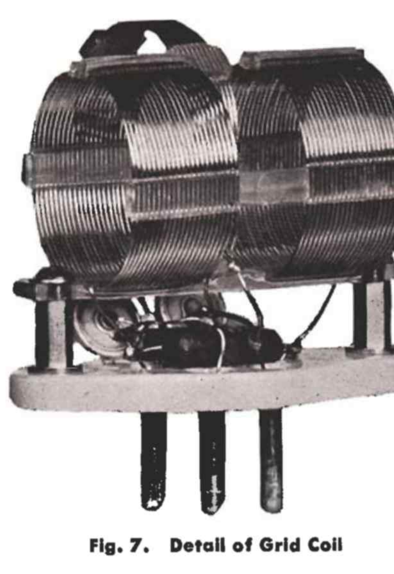

Fig. 7. Detail of Grid Coil

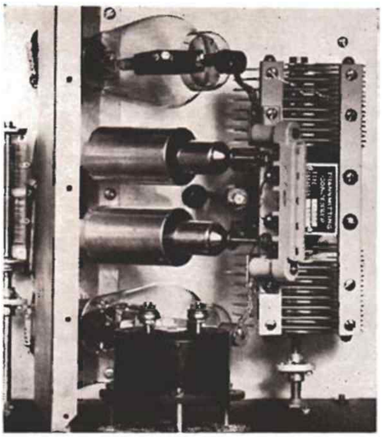

Fig. 8. Detail of Lazy Linear Plate Circuit

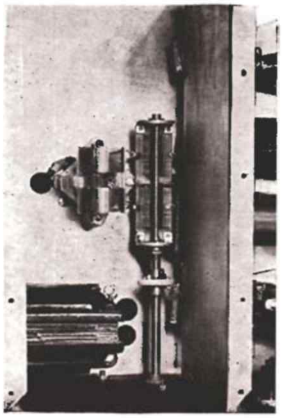

Fig. 9. Detail of Lazy Linear Grid Circuit

POWER SUPPLY REQUIREMENTS

The rating table, Fig. 12, gives plate current requirements for various modes of operation, where the type of emission allows this information to be given. The voltage required will depend upon the builder's personal choice of the types of operation desired. If only AM and NBFM operation is contemplated, the power supply may be of conventional design.

For CW and SSB operation the heavy bleeder normally used to achieve good regulation may be replaced by a high resistance bleeder which will serve to discharge the filter condensers. The stand-by current drain taken by the Lazy Linear takes the place of the heavy bleeder current. Because of the intermittent current drain which typifies CW and SSB speech transmission, special care must be taken in the power supply design to avoid power supply filter resonance. A practical means of achieving this is to use a 10 to 20 mf output condenser.

TUNE-UP ADJUSTMENTS

Before attempting to get the transmitter operating properly, re-read Reque's article on linear amplifiers, as the two-tone test described therein will not be described here.

Select your band and insert the proper coils. Couple an exciter to the grid so that an un-modulated signal drives the Lazy Linear. Tune for maximum grid current (measured by an external meter in the bias supply when switch S_1 is in position 2 or 3). The filaments must be on, and the plate supply disconnected from the rear high-voltage bushing. Any grid current from 50 to 100 mils will be satisfactory now.

Neutralize the final in the usual manner. Make sure the plate tank condenser is tuned to resonance during the neutralizing process. If opportune, neutralize on the highest frequency band you intend to use.

The next step is to match the grid and plate circuits. Couple the final to a dummy load. Arrange an oscilloscope with the vertical connections connected across the dummy load so that the plate output may be observed. Apply a small input signal to the grid circuit, making sure that the grid link is loosely coupled. Now apply plate voltage (not over 1000 volts) and resonate the plate tank for maximum output as shown by the scope. The plate current should be approximately 50 to 100 mils, depending on the excitation. This may be reached by 1) making a crude adjustment of the plate loading with the dummy load, or 2) detuning the plate tank slightly to get the desired plate current. Strive for approximately 75 mils.

Under these conditions you should now match the exciter to the grid circuit. The objective here is to present the right load to the exciter so that the exciter works properly. In other words, you are familiar with the operation of your exciter, its plate current when running properly, etc. Adjust the coupling between the exciter and the grid circuit, by means of the link, (while adjusting C_1)until the exciter is working as it should. If the exciter you chose supplies sufficient power output, then there should be sufficient drive to the Lazy Linear. (See the table in Fig. 12 for approximate driving powers required.) While making these coupling adjustments by adjusting the link, work from a lightly loaded condition toward heavier loading, making sure that the grid condenser is in tune at all times. The grid current will be significantly lower with plate voltage applied than it is with plate voltage off, so do not become concerned about the apparent loss of grid drive. An oscilloscope lightly coupled to the grid circuit can be a valuable adjustment aid.

No figure can be put on the grid current to be expected, as it may vary by a factor of perhaps five to one, depending on the plate loading, which has not yet been adjusted. However, do not exceed the maximum grid current rating of 100 mils for two tubes.

The amplifier has now been adjusted in a preliminary sort of way, and we are ready to proceed with the two-tone test as described in Reque's article, which has been referred to before. Apply a two-tone test signal to the grid circuit of the Lazy Linear. No more than 1000 volts d-c should be applied to the Lazy Linear plate circuit at this time. The envelope observed on the scope should now be as indicated in Fig. 4 of Reque's article, at least for low level inputs driving the final.

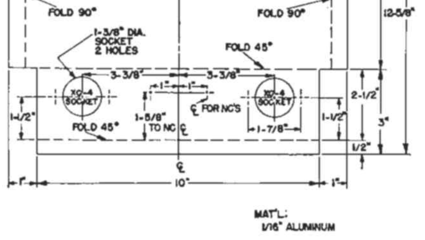

Fig. 10. Detail of Interstage Shield

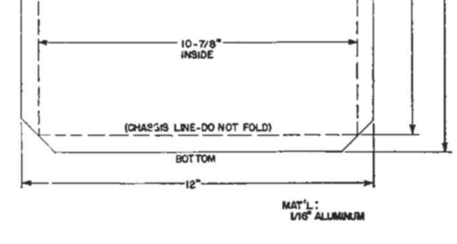

Fig. 11. Detail of Side Shields

Now, with the plate load lightly coupled and C_{11} at resonance increase the input signal until the envelope flattens on peaks. The scope should be coupled to the output circuit for this test. (Note that this is *not* the distortion shown in Fig. 5 of Reque's article.) The envelope flattening may be caused by one or both of the following two conditions. 1) The driver may be improperly coupled or loaded, or it may be at the limit of its output capability, or, 2) the loading on the plate circuit may be too light, which means that the reflected load impedance is too high.

To check for point 1, couple the oscilloscope to the grid circuit of the Lazy Linear. If the envelope shows an undistorted signal (Fig. 4, Reque's article) then point 2 is causing the trouble. However, if the peaks are flattened, then the driver is supplying a distorted signal.

To check for point 2, couple the scope to the dummy load again, and watch the distorted pattern as the final tank condenser is detuned toward a higher capacity. If the plate current goes up more than 20 percent and the flattening effect seems to disappear, then the load should be coupled more tightly to the final. If this is the case, retune to resonance, couple tighter, and again check the pattern on the scope. Take care not to overload the tubes during this adjustment. Any more than a very slight indication of color in the tube anodes should be avoided.

At 1000 volts plate supply and with the two-tone signal to the grid circuit, the plate current will be in the order of 160 mils, although this value is governed by the signal strength coming from the driving stage. Optimum plate loading is that which causes a flattening of the peaks of the scope pattern as the drive is slightly increased (assuming that the driver itself is not limiting). Very little dip in plate current will be noted when tuning through resonance with the plate condenser when the amplifier is properly loaded.

With conditions as just previously described, that is, 1000 volts on the plate, two-tone test signal coming in, the average power input to the final will be 160 watts, and the peak input 1.57 times this figure or 250 watts, and the peak output will be approximately 175 watts, with a realizable 70 percent overall plate efficiency.

With the loading adjustment unchanged, the plate voltage may be increased to 1500 volts, and the bias changed to minus 3.0 volts. This is the reason that switch S_1 was incorporated in the Lazy Linear. In position 1 the grid bias is zero and the external plate voltage relay is not energized. In position 2 external bias is switched into the circuit and the plate voltage stays the same. In position 3 the external bias is unchanged but a relay may be actuated to change the voltage from 1000 to some higher voltage.

When operating with 1500 volts on the Lazy Linear several precautions must be observed. First, the two-tone test signal will cause over-heating of the final tubes if applied for more than 5 seconds at a time. Also, the *1500* volt condition can be used only when the final is driven by an exciter which puts out a single-sideband speech signal, or driven by a keyed exciter.

When testing at 1500 volts, apply a SSB signal from the exciter and talk into the mike (use no prolonged whistles or other steady tones). Increase the drive until the voice peaks reach a definite saturation point as seen by the scope connected across the output. Assuming that the driver itself is not limiting, then this point represents the maximum peak output signal consistent with the loading and plate supply voltage used. It will be approximately 400 watts peak output. The loading of the output circuit will be the same as used with the 1000 volt tests.

Never attempt to operate the final beyond the saturation point just discussed. If desired, distortion may be checked by means of the two-tone test signal, when using 1500 volts, if the signal is left on for only a second or two (long enough for the plate current meter to settle down so that it may be read.) When making this test, the bias should be minus 3.0 volts and the average plate current as seen on the meter will be 240 mils, approximately. Make this test only after the tuning procedure and performance has been thoroughly checked at lower voltages. Even then, do not leave the two-tone test on for more than a second or two. This is important if you wish to use the very same tubes in the future!

After one is satisfied with the tune-up procedure, then the dummy antenna may be replaced with the radiating antenna and the coupling checked, at 1000 volts, with the two-tone test signal for a quick on-the-air test. Always monitor the output signal with an oscilloscope when you are on the air. This is the most reliable method for monitoring a phone signal.

#	EMISSION TYPE	INPUT SIGNAL REQ'D	PLATE VOLTAGE	PLATE CURRENT MA.	PLATE INPUT W.	CARR. OUT. W.	PEAK OUT. W.	NOTES
1	AM	100 % MOD. 2 WATTS	1000	CONSTANT 150	CONSTANT 150	45	180	A. PLATE TO PLATE IMPED. FOR ALL CONDITIONS IS 8000 OHMS. DETERMINE LOADING AT ONE KV. WITH TWO TONE TEST OR EQUIV.
2	NBFM	NBFM 8 WATTS	1000	CONSTANT 250	CONSTANT 250	175	180	B. CONDITIONS 1, 2, 3 AND 5 BIAS IS ZERO.
3	CW	CW 8 WATTS	1000	KEYDOWN 250	KEYDOWN 250	175	180	C. CONDITION 4 BIAS - 3 V. D. CONDITION 6 BIAS - 3 V.
4	CW	KEYED CARRIER ONLY-20 W.	1500	380	570 SEE NOTE F	400	400	E. RECOMMENDED CONDITION WHERE AM, NBFM, CW AND SSB USED INTERCHANGEABLY.
5	SSB	SSB 8 W. PEAK	1000	VARIABLE BUT STATIC PLATE CURRENT WILL BE 35 APPROX.	VARIABLE	SEE NOTE E	180	F. CONDITION 4 FOR KEYED SIGNALS ONLY.
6	SSB	SSB 20 W. PEAK	1500			SEE NOTE G	400	G. CONDITIONS 6 FOR SPEECH ONLY.

Fig. 12. Performance Table for Lazy Linear

TECHNICAL TIDBITS

RESTRICTING SPEECH RANGE IN SPEECH AMPLIFIERS

Note: The following article was prepared for publication before the April 27 FCC proposals regarding restricted bandwidth were made public. The attenuation of unwanted audio frequencies as discussed in this article is in the order of 12 db per octave. Because the FCC has given no details of the attenuation they consider necessary, there is no way of knowing whether 12 db per octave will be considered adequate.

This is a case of where you can get something for nothing, or at least, close to nothing. Before giving the punch line, though, let's examine the situation from the beginning.

Phone stations on the ham bands seem to fall into three categories regarding their speech quality. The first are the stations that will have no audio equipment in the shack unless it is capable of a flat response from 20 cycles to 15,000 cycles. Their quality is superb, and your ears would tell you so if it were possible to have a receiver and a reproducing system capable of handling this audio range at a time when propagation conditions allowed undistorted reception. These amateurs are taking up needless space in the limited ham spectrum by their activities, but as long as their carrier is inside the band edge by twenty to twenty-five kilocycles (in order to keep those wide sidebands inside the band) then, the FCC will not bother them, at least not yet.

On the other extreme is the second group, small though it be. These amateurs wish to have a transmitter that is as effective, communication-wise, as possible. Those who are on AM phone tailor their speech amplifier equipment until it transmits the narrowest possible audio range, leaving only enough audio range for complete understandability. A more rabid group goes even further, by partially eliminating the carrier and then transmitting only one sideband. These amateurs deserve a lot of applause, but we needn't bother to applaud them, because they did this not for applause but because they want their money's worth out of their equipment.

Which brings us to the third group, which must certainly include the majority of the world's phone men. This group is made up almost entirely of Mr. Average Phone Man and others of his ilk. Mr. Average Phone Man has a speech amplifier and a modulator which he copied faithfully from some handbook or some radio magazine. When he finished the audio end, he connected it to his c-w rig, got on the air, and asked the first ham he contacted the age-old question "How's my modulation?" Aside from the fact that Mr. Average Phone Man should have checked his modulation with a scope, while transmitting into a dummy load, instead of depending on the advice of another Mr. A. P. M., this situation is quite normal and is to be expected.

All right, you say, this is old stuff, so where's the pitch? Here it is. Why continue to waste power by transmitting certain audio frequencies if these audio frequencies are unable to help the other fellow hear you, especially when you can almost get rid of these unwanted high and low frequencies at practically no cost? To be specific about cost, the change can be made by the use of four 600 volt paper or mica condensers.

Before explaining how and where to put which condensers, let's make certain that another point is clear. This article has nothing to do with speech compressors, speech clippers, or sharp cutoff low-pass filters. The latter will do an excellent job of tailoring the speech range, but these filters may be rather elaborate. Speech compressors and speech clippers, on the other hand, do not affect in any way the band-pass characteristics of an amplifier unit. They may, however, affect the fidelity from a distortion standpoint. This is especially true of speech clippers.

One other point might also be explained here. The changes to be described are suitable for practically any type of speech amplifier. However, a restricted bandwidth is not assured if these changes are made in an amplifier which is used for NBFM. If the swing is not carefully adjusted the bandwidth may still be excessive. In other words, it is worthwhile to make these changes in an NBFM speech amplifier, but the effect will be nullified if the signal is permitted to swing too far frequency-wise, due to improper adjustment.

Here, then, is what you may do to restrict the audio range of your speech amplifier in an economical way. First, attenuate the low audio frequencies by changing the value of two of the interstage coupling condensers and second, attenuate the high audio frequencies by adding a condenser from plate to ground on two of the audio stages.

The calculations to determine the proper size of condenser for each point are not difficult. It is first necessary to decide on the audio range you wish to cover. Let us assume that you want an audio characteristic which is down somewhat at 300 cycles on the low end and 3500 cycles on the high end. To be more exact, this is one which will be down 6 db at 300 and 3500 cycles, when changes are made to two of the stages. These two frequencies—300 and 3500 cycles—will be used in the calculations.

The next step is to examine the circuit diagram of your speech amplifier. Most amplifiers consist of a pentode preamplifier, driving a triode or pentode amplifier, driving a phase inverter or transformer coupled amplifier which in turn drives the output stage. We are interested only in the first two tubes. We want to put a condenser from the plate of the first tube to ground, and one from the plate of the second tube to ground. Also, we wish to change the values of the condensers which are between the plate of the first tube and the grid of the second tube, and between the plate of the second tube and the grid of the third tube.

If the third tube is a phase inverter, it is best not to attempt to change the coupling condenser between the second and third tubes. The reason is beyond the scope of this article but it might be necessary to change the grid circuit of the phase inverter in order to get the proper effect from the changed coupling condenser. In this case, the coupling condenser can be changed between the microphone and the input tube. This is completely satisfactory if a dynamic microphone is used. If a crystal microphone is used, a different approach is necessary. Again this is not within the scope of this article, so that you will have to be satisfied with changes on only one tube, instead of two.

The final step before starting the calculations is to check the value of the grid resistor to which the new coupling condenser will connect. This will be the grid resistor for the second and third tubes unless, as stated above, it is necessary to put one coupling condenser between microphone and grid, in which case examine the grid resistors for the first and second tubes. These resistors should be no greater than 250,000 ohms. If they are of a greater value, decrease them so they are 250,000 ohms or less. Incidentally, the grid resistor for the second tube is usually the gain control.

The proper value of coupling condenser will now be one whose capacitive reactance, at 300 cycles, is equal to the grid resistance in the grid circuit of the stage to which it connects. These words mean, simply, that the condenser value in micro-farads is equal to: $\frac{1{,}000{,}000}{(1884)\ (R_G)}$ where R_G is the value of the grid resistor in ohms. This assumes that the low frequency point selected was 300 cycles. The figure of 1884 is 300 times 2 times π. As an example, if the grid resistor is 250,000 ohms, the condenser should be 0.0021, so use a 0.002 mf condenser. Make this calculation for both stages, and replace your present coupling condenser with the calculated value of condenser if it is not already that value. The low frequency audio tones are now taken care of.

Before starting the calculation of the plate to ground condensers, find out the plate resistance (R_P) of the two tubes involved. Most handbooks have this figure. Next, check the circuit diagram and get the value of the plate load resistor which you are using. This is the resistor which connects directly to the plate at one end and is bypassed to ground (and connects to B plus) at the other end. Next, get the value of grid resistor on the tube which follows the tube whose value of R_P you just looked up. Now, calculate the effective parallel resistance of these three factors, that is, of R_P, the plate resistance, of R_L, the plate load resistance, and R_G, the grid resistance, by the formula:

$$\frac{1}{R_T}=\frac{1}{R_P}+\frac{1}{R_L}+\frac{1}{R_G}$$

For example, assume that a 6J5 tube uses a plate load resistor of 50,000 ohms. The plate resistance of a 6J5 is approximately 7000 ohms. Assume also that the grid resistance of the next stage is 250,000 ohms. The effective resistance of these three in parallel is 5990 ohms. Call this R_T for the 6J5 stage. Incidentally, the R_P for triodes is low, as shown above. For pentodes, R_P will be very high.

The proper value of shunt condenser to connect from plate to ground is one whose capacitive reactance, at 3500 cycles, is equal to R_T. Stated again simply, the value in micro-farads is:

$$\frac{1{,}000{,}000}{(22{,}000)\ (R_T)}$$

This assumes that the high frequency point selected was 3500 cycles. The figure of 22,000 is 3500 times 2 times π. As an example, if R_T is 5990 ohms, then the plate to ground condenser calculates out to be 0.0076 mf so use a 0.0075 mf condenser. Connect it to the plate of the tube and to a convenient ground point. Make this calculation for both stages. This takes care of the higher frequency audio tones.

Let us now examine the change we have brought about in the speech amplifier and also examine what we have gained from this change. To do this, we shall have to assume that the response of the speech amplifier, before the change, was fairly uniform from 150 to 6000 cycles. This is the sort of response which might be expected in a speech amplifier following general circuit practice. In addition, the response was probably only five or six db down at 100 and 10,000 cycles.

When you used your speech amplifier, before the change, you were modulating your carrier with all the complex audio tones that existed in the microphone output, over the 100 to 10,000 cycle range. Your sideband power, which is all that the other ham is using to hear your signal, was therefore spread over a wide frequency range. It so happens that it takes a fair amount of modulator power to transmit the lower and higher frequency audio components which are not necessary for intelligibility.

By making the change in your speech amplifier, you now still have the same power in your sidebands, assuming that the percentage of modulation is the same, but you now have a great deal more power available to transmit the range of frequencies that really count, those between 300 and 3500 cycles. Effectively, therefore, you have a "louder" signal, because you have increased power at the audio frequencies to which the other ham listens. In round numbers, the increase in signal strength is about 6 db, which is the same as a four to one increase in carrier power, or the same as putting up an antenna with a 6 db gain over the one you were using.

To get an idea of the response curve which is obtainable, let us look at a speech amplifier which uses, for example, a 6SL7 dual triode for the first two stages, driving a third stage which has a 250,000 ohm grid leak. Assume that the aforementioned changes have been made. Now let us apply a pure tone at 1000 cycles, the midband frequency, and measure the output of the speech amplifier. Next, apply a pure tone of 300 cycles. The output will be down 6 db, or four to one in power. The same thing is true for a 3500 cycle tone. A pure tone at 150 cycles (and at 7000 cycles) will be down 14 db, or twenty-five to one in power.

Thus, while the curve obtained is not of the sharp cutoff variety, it will give essentially the same results, and will certainly sound the same to the ear. Further, it was obtained at practically no cost.

—*Lighthouse Larry.*

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