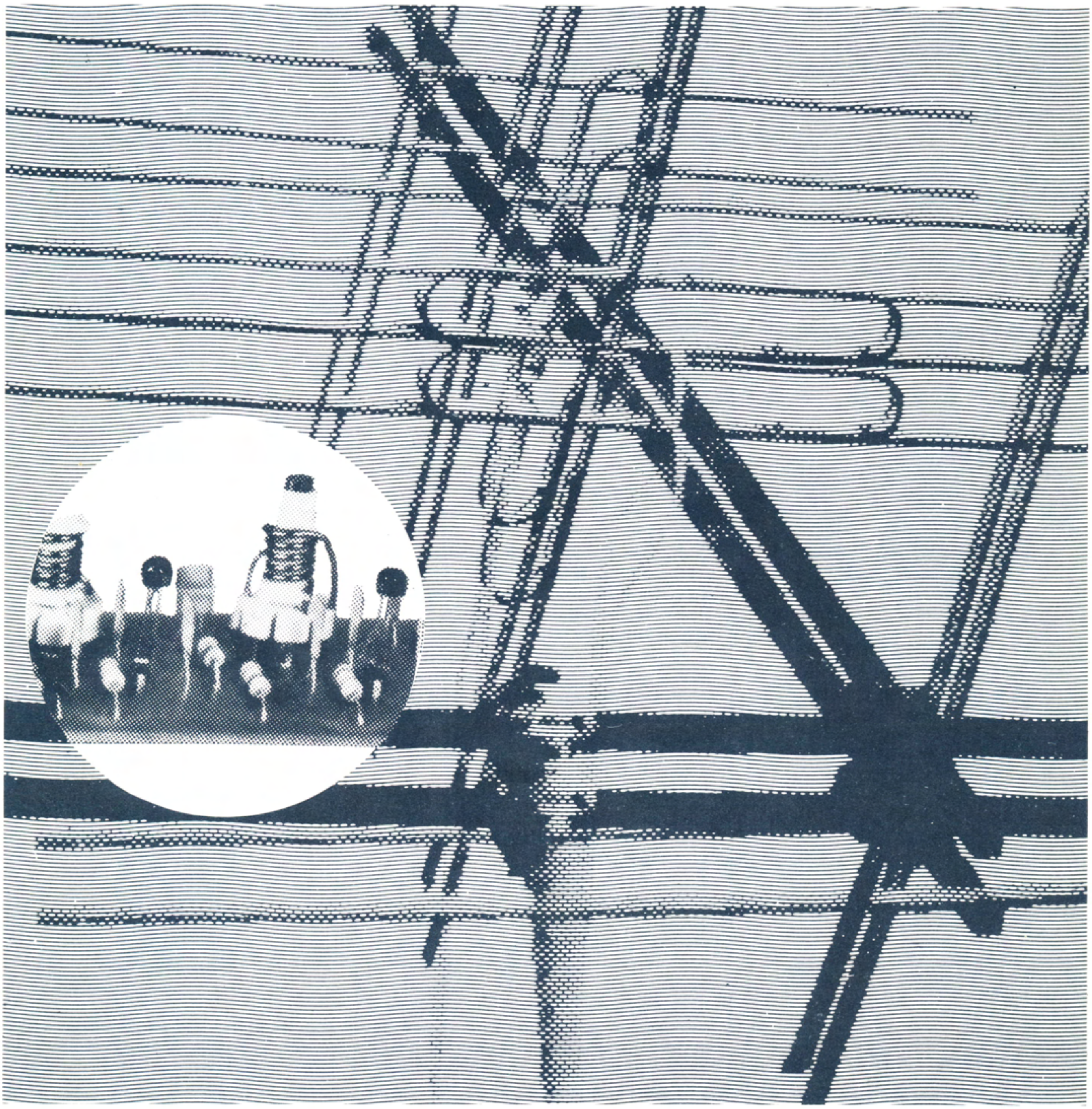
tunable aerial amplifier

The aerial amplifier described in this article is characterized, among other things, by its low noise level (1-2 dB), a voltage gain of 10-20 dB, and a wide tuning range (146-76 MHz).
It is designed for use as an FM-aerial amplifier, although it is relatively simple to modify it for application as a TV aerial amplifier.



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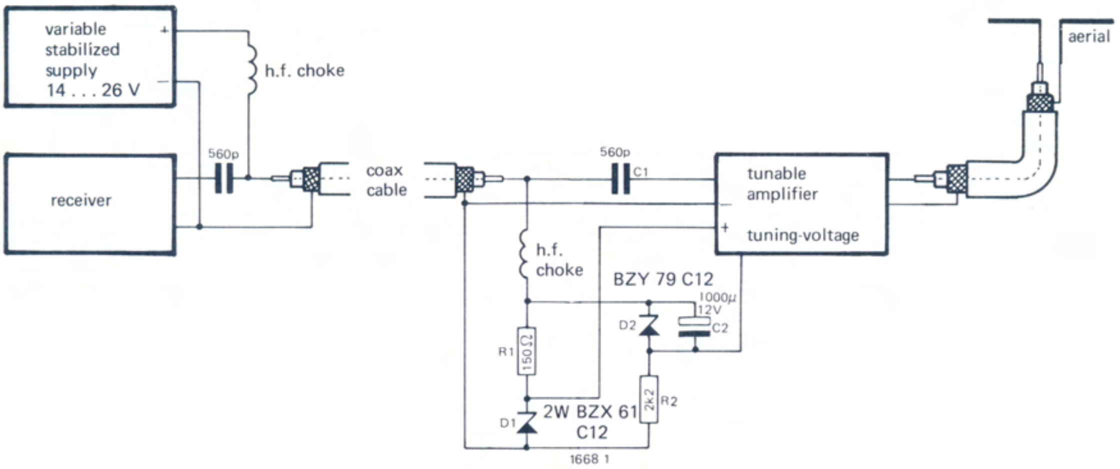

Figure 1. With simple means the coax cable can be used for the signal-, the supply- and the tuning voltages.

Aerial amplifiers can be divided roughly into two categories: wideband and tuned. The main advantage of wideband types is, of course, to be found in the fact that a frequency spectrum of several decades can be amplified without anything having to be switched over or readjusted. On the other hand, there are some drawbacks that count all the more if the amplifier is expected to provide maximum improvement in reception quality.

Using wideband amplifiers entails the following drawbacks:

1. Cross modulation soon occurs because the total amplitude offered can be fairly large. Furthermore, the entire amplified spectrum is fed to the receiver and this is another likely cause of cross modulation.
2. In most cases it is impossible to design a wideband amplifier for minimum noise contribution. This is because the cable impedance (usually 60 Ω) is not the optimum value for the amplifier. In addition, it is almost impossible to compensate fully for parasitic capacitances.

Comparison of the noise contributions of TV tuners and of wideband amplifiers shows that both are usually of the same order of magnitude for the UHF band. In the VHF-TV and the FM bands, the tuner often has an even lower noise figure than the wideband amplifier. If the wideband amplifier gives better reception, this is due mainly to the fact that when the amplifier is placed between the aerial and the cable, the cable losses become far less important.

Tunable amplifier

A drawback of a tunable amplifier is that an extra cable is usually needed for the tuning voltage. By means of a simple circuit, however, (figure 1) it is possible to use a tunable amplifier without an extra cable. The stabilized power supply provides the sum of the supply voltage and the tuning voltage, and within the amplifier the 12 V supply is obtained by stabilization with a voltage regulator diode.

By connecting a 12 V regulator diode in series with the supply voltage, the tuning voltage is 12 V lower than the supply voltage. If the variable stabilized supply is now adjusted from 14 to 26 V, the supply voltage for the amplifier remains 12 V, and a tuning voltage of 2 to 14 V becomes available.

It goes without saying that the variable supply must have a very low hum and noise level to avoid amplitude and phase modulation via the varicaps. Therefore a large electrolytic capacitor is placed in parallel with D2.

The circuit consumes about 100 mA, but offers the advantage that the amplifier always is at a higher temperature than ambient, so that water condensation and the resulting corrosion are avoided.

Design possibilities for tunable amplifiers

A FET-amplifier can be based on two main circuits, to wit: the common-gate and the common-source amplifiers. Since the amplifier is tuned, the input and output capacitances of the semiconductors usually present no problems. Not so, however, the feedback capacitance, because this may give rise to instability. Another important quantity is the input impedance. If we tabulate the necessary design data, we get something like table 1.

Table 1.	common source	common gate
input impedances	specified by the manufacturer; can be anything between 1 and 20 k at 100 MHz	usually deviates no more than 20% from 1/S
output impedance	specified by the manufacturer and is usually of the same order as the input impedance at common source	
feedback capacitance	1-10 p	very low; usually 0.1-0.01 p

The drawback of the common-gate amplifier is that its maximum gain is less than that of the common-source circuit. On the other hand, however, the common-gate amplifier has greater reliability and stability. A secondary advantage is that the difference in matching for minimum noise or maximum gain is much less than for the common-source circuit, and is in some cases even negligible. Radio reception requires matching to minimum noise, TV reception requires matching to maximum power gain to eliminate cable reflection (picture 'ghosts').

The circuit (figure 2)

To obtain a wide matching range, the circuit is designed around discrete coils. This also offers greater freedom as regards using other types of FET. Often mistakes are made as regards the quality factor of such home-made coils; in this case a Q-factor of 100 or more can easily be achieved.

Although the diagram shows the amplifier with asymmetrical input and output, it can easily be adapted for application with symmetrical aerials by providing L1 and L3 with coupling windings. To eliminate the problem of the (wide) tolerance in the pinch-off voltage, the gates are connected to a positive voltage so that each of the FETs draws about 10 mA. For a 12 V supply voltage, the gate-drain voltage is about 6 V, and for most types of FET this produces the minimum noise contribution. The only limitation to using certain FETs is the slope, which should be greater than 4 mA/V. A larger number of types meet this requirement, as shown in table 2.

Table 2.

type	minimum slope mA/V	db noise contribution (typ) at 100 MHz
E300	4,5	1.5
E310	10	1.5
U1994E	4,5	1.5
2N4416	4	1.2
2N5397	6	1.8
U310	10	1.5
E304	4,5	1.7
SD201 (mos)	13	1.5

The fact that the circuits possess a high-Q-factor does not necessarily imply that the amplifier is a narrow-band type. The circuits are damped by the input and output impedances of the FETs. Suppose the no-load Q-factor is 100. The resonance impedance then found at 100 MHz is:

$$Z = Q\omega L = 15\ \text{k}.$$

The efficiency of a circuit is given by:

$$\eta = \frac{Q_O - Q_L}{Q_O}$$

where Q_O and Q_L represent the quality factor under no-load and load conditions, respectively.

So for a high efficiency it is necessary to load the circuit heavily, which also reduces the effect of the FET output impedance. For the case where $Q_O = \infty$, and the output impedance of the FETs is ∞, the gain is given by (figure 3):

$$A_V = n_2/n_1 \cdot S_1 \cdot (n_3/n_4)^2 \cdot n_4/n_3 \cdot (n_5/n_6)^2 \cdot n_6/n_5 \cdot Z_C =$$

$$= \frac{n_2 \cdot n_3 \cdot n_5}{n_1 \cdot n_4 \cdot n_6} \cdot S_1 \cdot Z_C \qquad (1)$$

If we take

$$Z_C = 50 \qquad n_2/n_1 = 1.2$$
$$n_3/n_4 = 2.5 \qquad n_5/n_6 = 5$$

(1) becomes:

$$A_V = 750 S_1 \qquad (2)$$

From the above formulae it appears that the gain is directly proportional to the slope of the first stage. This is only true, if the ideal condition ($Q_O = \infty$ and infinitely high output impedances) is sufficiently approached, and that is the case here if S2 is at least 4 mA/V.

It is logical, therefore, to use for T2 a cheap FET that meets this requirement, such as the U 1994 E or the E 300. Measurements where T1 = T2 = E 300 indeed showed a voltage gain of 3. When a type E 310 was used for T1 (S = 10 mA/V), the gain increased to about 8.

To investigate the effect of T2 on the gain, first a type E 310 was used, with the result that the gain increased to 10. Since the primary function of an aerial amplifier is to improve the signal-to-noise ratio at the amplifier input, it is pointless to measure the bandwidth at the 3 dB points. It is better to quote the bandwidth in which the noise contribution may deteriorate a certain

Note:
The FETs mentioned here are supplied by the following manufacturers:
Siliconix : E300, E310, U310, E304;
Teledyne : U1994E, 2N4416, 2N5397;
Signetics : SD201.

Figure 2. Although the supply voltage in the diagram is 13 V, the amplifier can be connected to any supply voltage between 10 and 20 V. At about 13 V the noise contribution is lowest.

Figure 3. This simplified diagram serves for a rough calculation of the gain.

Figure 4. The drawing shows how the coils should be wound.

Figure 5. The method for coil mounting shown here saves considerable time. Overall performance does not suffer, but the appearance is not so neat.

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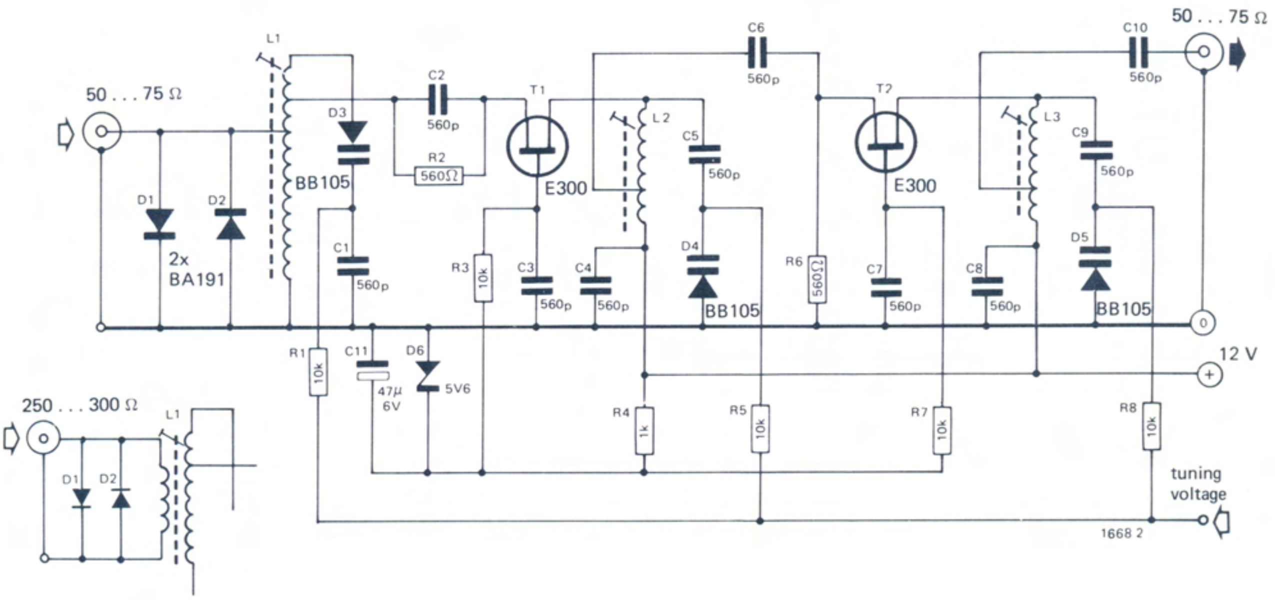

amount, say 0.5 or 1 dB. If this standard is used, the bandwidth of the amplifier is about 3 MHz at 100 MHz, but this could not be measured exactly because the elektor laboratories are not equipped with the (extremely) expensive equipment needed to take accurate noise measurements.

The ratio n_2/n_1 given in the example above, and which is lower than might be expected, was determined empirically for a minimum noise contribution, and this adaption proved to be the most favourable one for both the E 300 and E 310. If the coils are made of silver-plated copper wire, it is quite a simple matter to determine the best tap.

Mounting, construction and adjustment

An important requirement is that all connections must be as short as possible. Photograph 1 gives a clear picture of the mounting. The FETs should have much shorter connecting leads than shown in the photograph (about 6 mm); long leads have distinctly unfavourable effects on stability and the signal-to-noise ratio; this was being verified when this photograph was taken.

All capacitors, except for C11, are of the low-loss ceramic disc type. Current types of Schottky diodes can be used for D1 and D2, and types BB105A, BB105B and BB105G are suitable for D3 to D5. The coils are wound on Kaschke coil formers type KH 5/22, 7-560-8A, with a ferrite core, type K 3/12/100. Several other types of coil formers might be suitable as well, if the diameter is about ¼ in (6 mm). The ferrite core has to be a VHF-type! The winding data are given in table 3.

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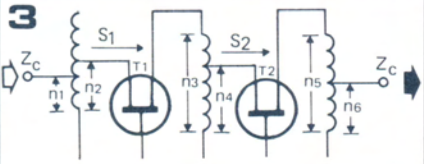

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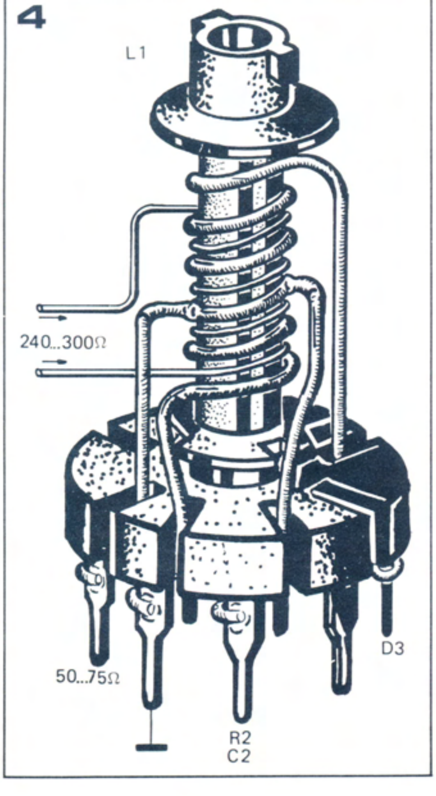

coil	tap with respect to + or $-V_b$	total number of turns
L1	aerial 50/75Ω2	
	240/300Ω4 (coupling winding)	5
	source 2.5	
L2	source 2	5
L3	output 50/75Ω1	
	240/300Ω2 (coupling coil)	5

The wire should preferably be silver-plated copper wire with a diameter of 1.2 mm. The spacing between the turns is 0.8 mm and is obtained simply by winding a so-called 'blind wire' of a diameter equal to the spacing, i.e. 0.8 mm, together with the coil wire.

Once the coil has been mounted, this blind wire is, of course, removed unless the 240/300 Ω connections are to be used. In that case the blind wire is 0.8 mm enamelled copper wire, and after mounting of the coil, this blind wire is wound off again until the above number of turns is left.

As the coupling coils must be placed at

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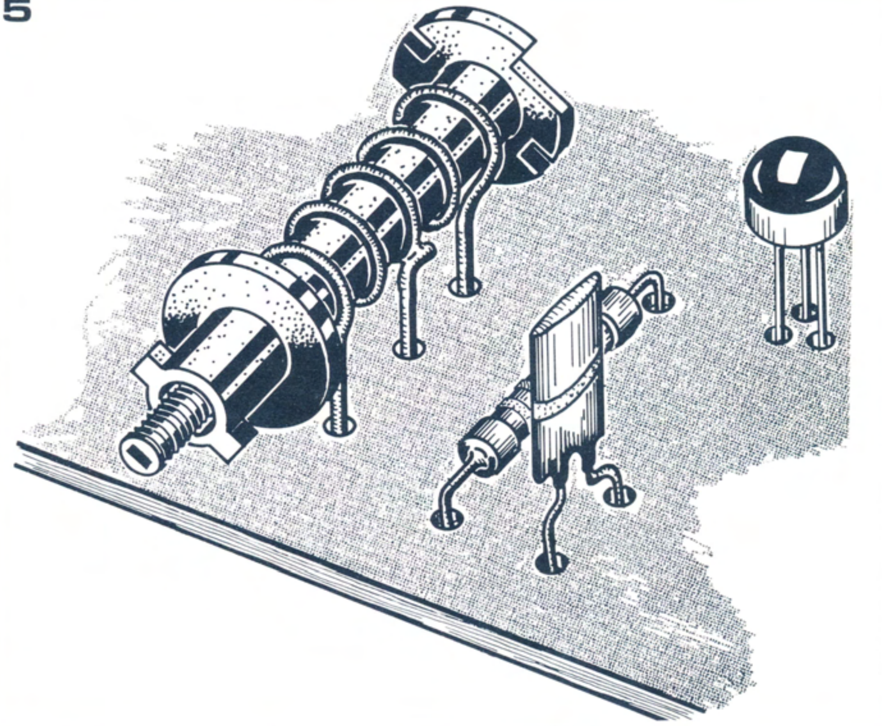

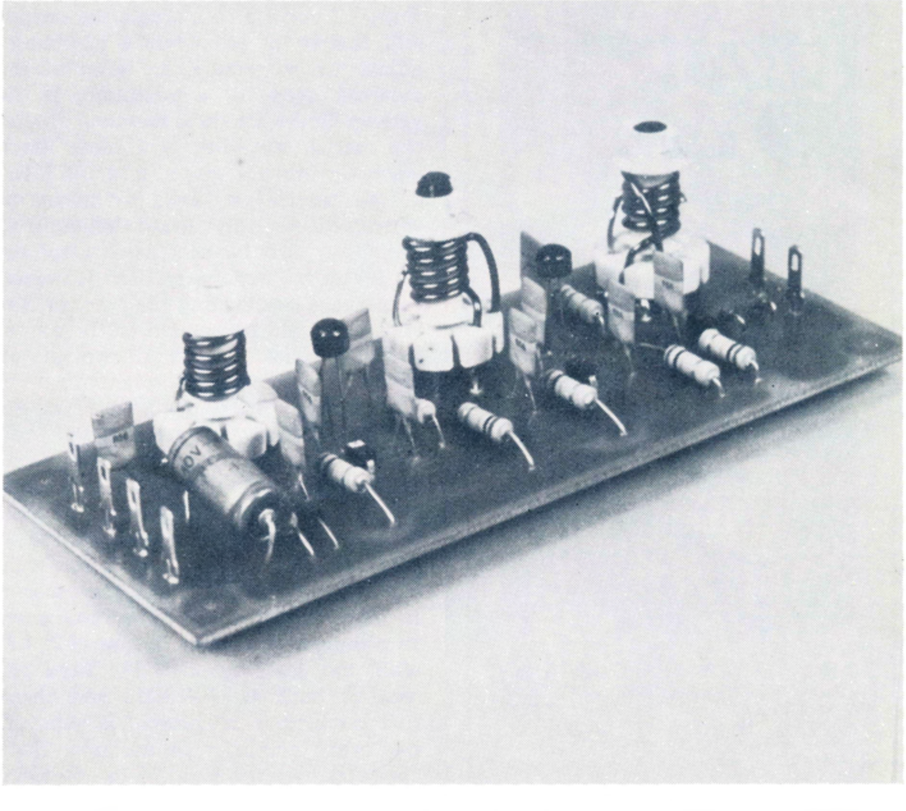

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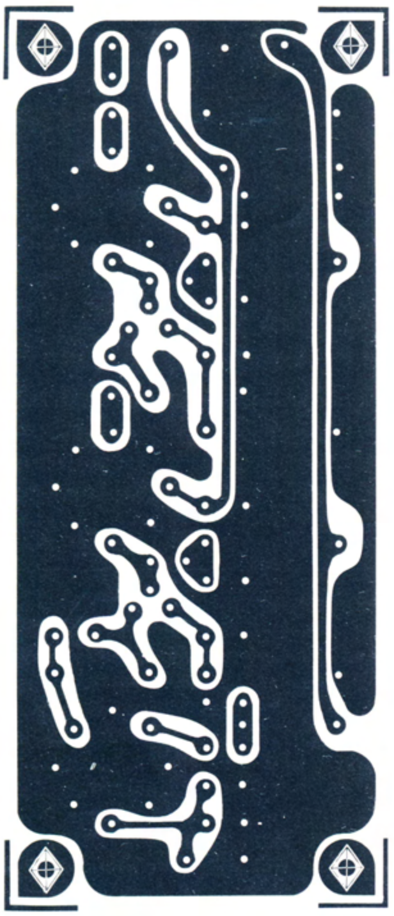

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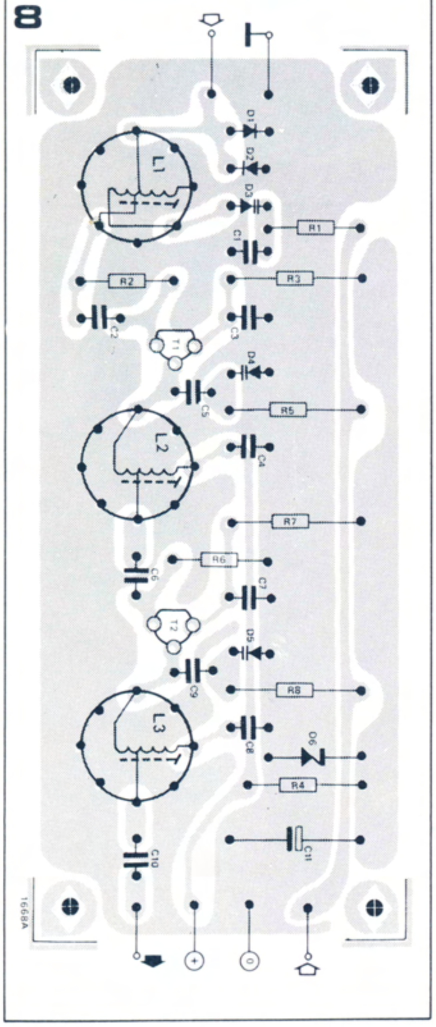

Figure 6. To obtain the tuning voltage for the amplifier from a tuner with a high-impedance tuning voltage, such as tap presets for instance, an emitter follower is required. If a low-impedance tuner voltage is used, the tuning voltage for the amplifier can be obtained directly via the 47 k adjustment potentiometer.

Figure 7. Layout of the printed circuit board. (EPS 1668).

Figure 8. Component layout on the PC board in figure 7.

the 'cold end', winding back takes place from the coil end that is connected to the varicap. This is illustrated in figure 4. Soldering the wires to the former pins is a time consuming job, particularly for the wire diameter quoted here. If more value is set upon efficient mounting than on appearances, the coils are mounted directly in the circuit, as shown in figure 5. The coil formers will fit only after clipping, as can be seen in this figure. In this case the coils are wound on a drill with a slightly smaller diameter (about 0.1 mm) than the outer diameter of the coil former.

If the receiver used is not tuned by means of varicap diodes, the aerial amplifier should be adjusted as follows. Set the ferrite cores half way in the formers. Tune the receiver to a weak station with a frequency of about 95 MHz and adjust the tuning voltage – the voltage applied to the varicap diodes – to obtain a maximum output. Tune L2 and L3 to increase the output still further or to obtain a maximum; adjust L1 to reduce the noise of the received signal to a minimum. If the varicap diodes are three matched diodes, the aerial amplifier will now track correctly over the range 76 to 146 MHz. If the receiver is tuned by means of varicap diodes, the voltage that controls them can also be used to control the diodes in the aerial amplifier. However, to prevent overloading the receiver, the voltage should be applied to the diodes in the aerial amplifier through an emitter follower as shown in figure 6. The tuning procedure now is as described above, except that a weak station with a frequency of about 88 MHz should be used and P1 is set to give a maximum tuning voltage. Next turn the receiver to a weak station at 100 MHz, and again adjust P1 to obtain a maximum output. Tune the receiver to 88 MHz and readjust the three cores to obtain a maximum output (L2, L3) with the least noise (L1). Tune the receiver back to 100 MHz and check that no further adjustment is required; the aerial amplifier should now track correctly over the band 76 to 146 MHz.

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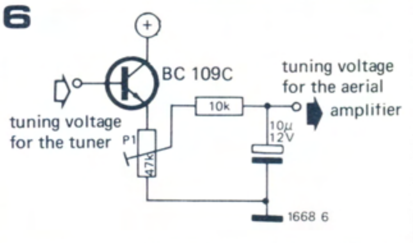

Parts list

resistors:
R1,R3,R5,R7,R8 = 10 k
R2,R6 = 560 Ω
R4 = 1 k

capacitors:
C1 . . . C10 = 560 p ceramic disc.
C11 = 47 µ, 6 V

semiconductors:
D6 = 5V6 regulator diode

other semiconductors: see text!

If further adjustment is needed, then repeat the whole procedure until it is not.

Results and application in the 2 m amateur band

The sensitivity of FM tuners can be limited by:

1. the signal-to-noise ratio at the input, and
2. insufficient amplification of the intermediate frequency.

Most factory-made receivers are designed so that a combination of these two factors is operative. Although it is difficult to give an exact rule for the improvement obtained by using the amplifier, it may be expected that the sensitivity of the receiver will improve by about a factor of 3 for the same signal-to-noise ratio. If still greater amplification is required, the amplifiers can be cascaded. An amplification factor of more than 10, however, will usually give rise to cross modulation in the receiver; the same amplification can also be obtained by means of one amplifier equipped with FETs that have a steep slope. The coils described can be used in the two-meter band, but the varicaps must then be replaced by ceramic trimmers of 1-9 pF. The bandwidth is more than sufficient to cover the entire band.

Conclusions

The aerial amplifier discussed in this article is suitable for many applications and has such a low noise figure that it will improve reception in all cases. Apart from the 76-146 MHz range, the amplifier, with modified coils, can also be used to great advantage in the following bands:

14, 21 and 28 MHz amateur band, channel 2-4 TV, channel 5-12 TV, and perhaps the UHF band.

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