

# VHF Transistor Power Amplifiers, Dragoslav Dobricic, YU1AW

**The purpose of this article is to describe how to assemble several VHF power amplifiers, examples are given for the 50 and 144 MHz bands. Two types of amplifiers will be considered, amplifiers with one and with two transistors. Assembly instructions are given as well as explanations of some general issues with regard to the construction of VHF power amplifiers.**

## Introduction

The first step is to choose a transistor, this ultimately dictates what will be achieved. The quality of an amplifier is defined by several parameters that define its quality. An amplifier can be deemed to be a high quality amplifier if it has the following characteristics:

- High efficiency level
- High power amplification
- Good suppression of harmonics and low level of IMD products
- Good electric and thermal stability
- Simple design and adaptability

Some of these are contradictory and often have to be solved by various compromises, while others are compatible and by creating the first we automatically create the other. High efficiency is the most important, maximising this ensures that the majority of the other parameters approach their optimum. Beside an arbitrarily chosen working point or class in which the transistor will operate, the matching as well as the circuit losses influence the efficiency. For highest efficiency it is necessary to:

- Strictly respect AC and DC current and voltage recommendations by the manufacturer for the class of operation.
- Match the transistor to the output conditions recommended by the manufacturer for maximum efficiency. Also the losses in the matching circuits should be minimal.
- Keep the temperature of the transistors under the maximum allowed temperature, which is achieved by adequate cooling.

By fulfilling these conditions a high degree of efficiency is obtained, as well as highest output

power, relatively low operating temperatures and slight harmonic and IMD distortions.

The second condition, high power amplification, is achieved by matching the input to ensure stable operation. Losses in the matching circuits directly influence the power amplification. Another extremely important condition that has to be fulfilled for high amplification is extremely good grounding of the emitter or source in FET transistors. These should be extremely short therefore of extremely low resistance!

Stability of the amplifier depends on the transistor itself, but also in a large measure on other factors such as: matching, mechanical construction and separation of electric paths in the input and output circuits. This will eliminate unwanted feedback between input and output. The most important issue for the stability of any amplifier concerns the low frequency performance where the transistors have enormous gain. It is important to make sure that the base and collector “see” several dozens ohms. If a collector or base “sees” a short circuit via a large capacitor or open circuit via a high inductance at low frequencies, an amplifier oscillates very easily.

The third condition, good suppression of higher harmonics and low level of generated inter-modular products (IMD) also depends on many factors. We will list just a few:

- choice of the optimal value of efficiency (Q) of output circuit
- linearity of a transistor’s chosen operating point
- output matching
- small output resistance of the base bias circuit
- value of excitation power

By correct design, the unwanted secondary products generated by the amplifier could be reduced to a minimum. Output filtering can reduce these even further. Filtering cannot reduce some of the odd order inter-modulation products because they are very close to the operating frequency. They can only be influenced by correct design of the amplifier, making it linear generates a very small level of these unwanted products. Even harmonics and even series of inter-modulation products can be efficiently decreased by push-

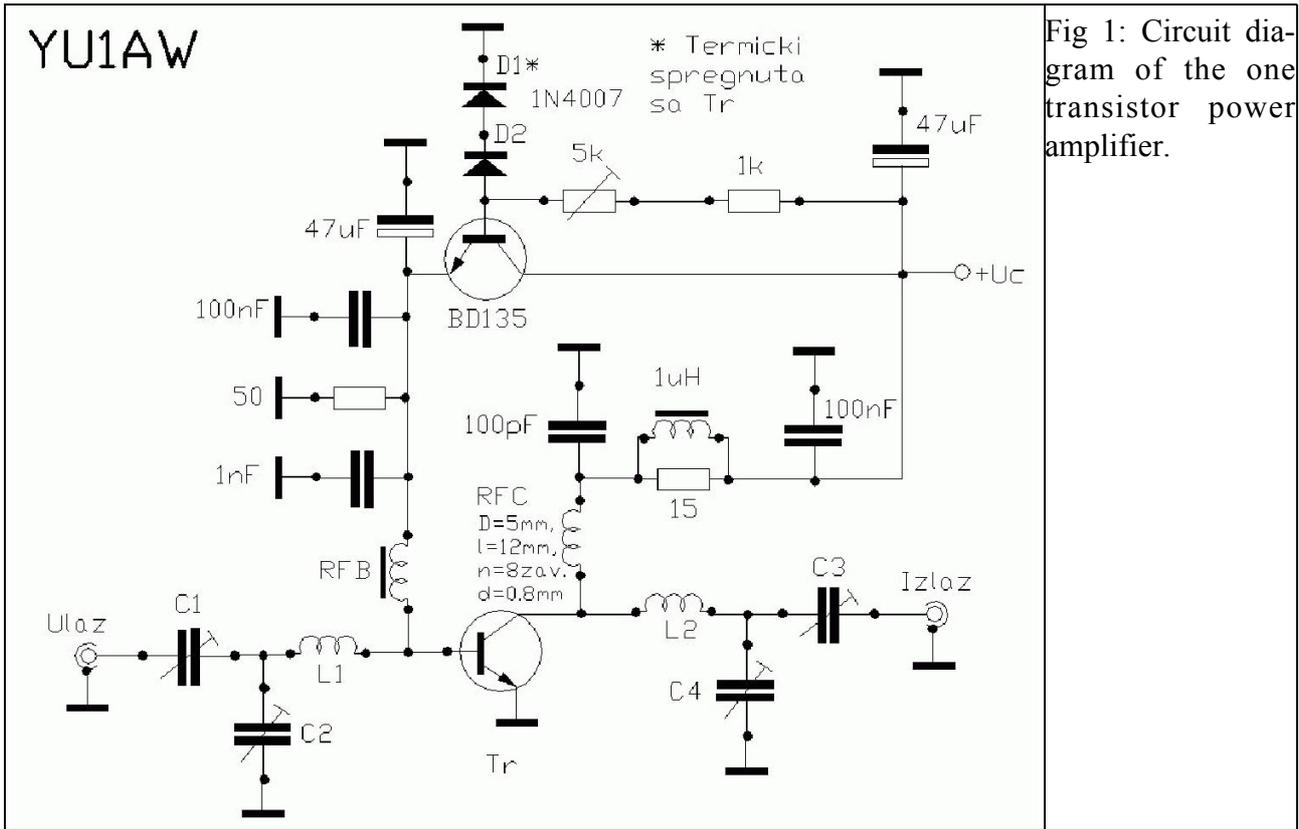


Fig 1: Circuit diagram of the one transistor power amplifier.

pull amplifier design. This is an advantage in comparison with amplifiers operating with two parallel transistors.

For amplifiers operating in linear classes (A and AB) the correct choice of the base bias circuit is also very important and it provides good linearity of the input signal. The stability of collector voltage also has an influence, it should be stabilised for amplifiers up to 20V, and for voltages above these it is sufficient if it has good regulation. For the linear operation of an amplifier, the level of excitation power is also crucial. It should

not be too high, because it “pushes” the transistor into non-linear operation.

Thermal stability is provided by the correct choice of a heatsink and more importantly, by correctly mounting the transistor. In order to compensate the thermal movement of the operating point it is necessary to provide thermal feedback that will, by monitoring the temperature of the transistor, this will change the base bias to maintain the DC operating point stability.

All these conditions that have to be fulfilled if an

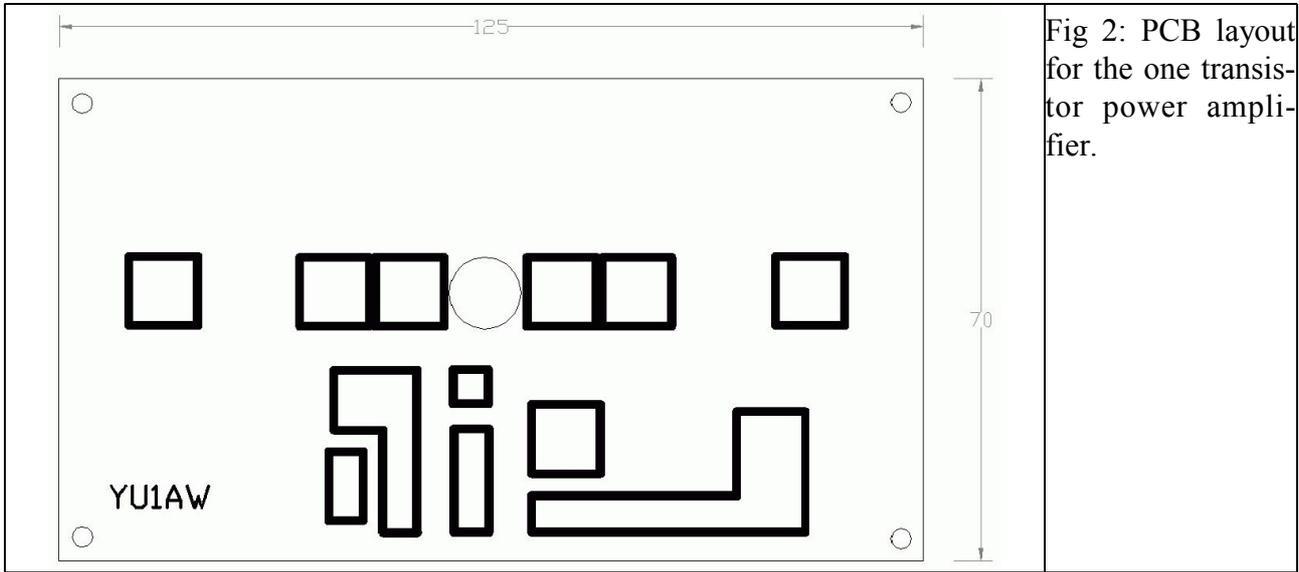


Fig 2: PCB layout for the one transistor power amplifier.

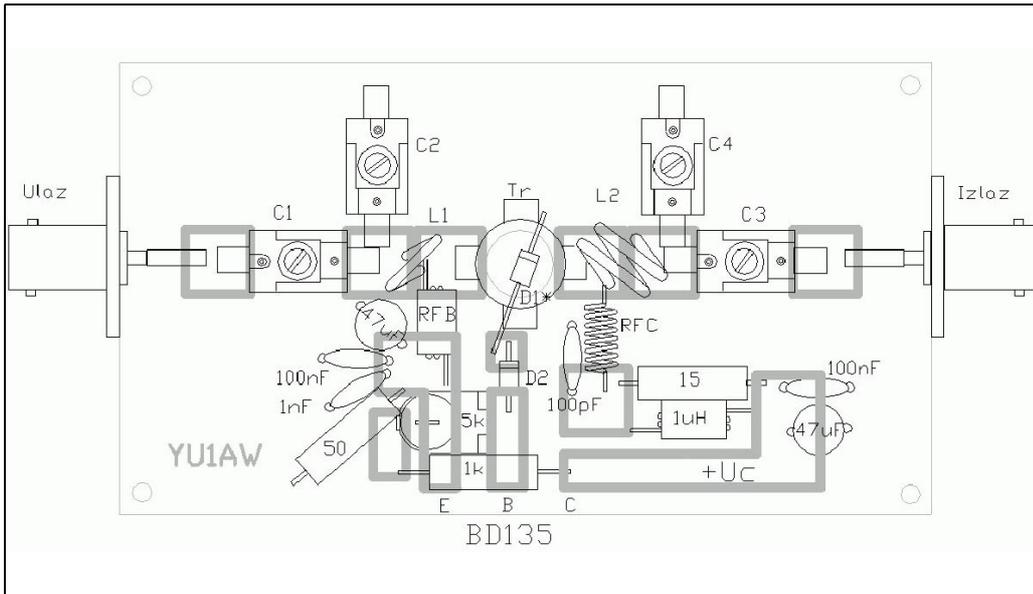


Fig 3: Component layout fro the one transistor power amplifier.

amplifier can be described as a high quality amplifier, they are only discussed briefly here. They are elaborated in literature [1] and [2].

## One transistor power amplifiers

The circuit of the one transistor power amplifier is shown in Fig 1. A PCB layout is shown in Fig 2 and the component layout in Fig 3. The PCB may have to be varied slightly depending in the actual RF transistor chosen. Table1 shows the component values for various transistors and Table 2 shows the expected performance. A circuit consisting of C1, C2 and L1 performs input matching. The Q of this circuit is about 10-15,

which is the optimal value in this case. Base bias is fed via an RF choke, which is a VK 200 ferrite bead with six holes. The output circuit that matches the output of the transistor to 50Ω is performed by L2, C4 and C3. All capacitors in the matching circuits are ARCO, ceramic-mica trimmers of corresponding capacity. The values of the matching circuit elements are shown in Table 1. The number printed on the trimmer gives the range of certain trimmers (Fig 4). Certain types of trimmers and the corresponding range of capacity are given in Table 3. The voltage values, currents, power and efficiency for each separate type of transistor are illustrated in Table 2. The collector supply is fed via an RF choke which instead of a ferrite is open wound. The diameter of this choke is 5mm, it is 12mm long, and has 8 turns of 0.8mm wire. After the

Table 1: Components required for various transistors.

| Transistor | Freq. MHz | C1 pF | C2 pF | C3 pF | C4 pF | L1      |      |      |         |      | L2      |      |      |         |      |
|------------|-----------|-------|-------|-------|-------|---------|------|------|---------|------|---------|------|------|---------|------|
|            |           |       |       |       |       | Ind. nH | D mm | L mm | n turns | d mm | Ind. nH | D mm | L mm | n turns | d mm |
| BLW76      | 50        | 36    | 200   | 21    | 46    | 44      | 6.5  | 6    | 3       | 1.2  | 157     | 12   | 10   | 4       | 1.5  |
| BLX15      | 50        | 56    | 363   | 20    | 37    | 23      | 6    | 4    | 2       | 1.2  | 195     | 15   | 12   | 4       | 1.5  |
| MRF317     | 50        | 40    | 210   | 24    | 57    | 47      | 10   | 10   | 2.6     | 2    | 140     | 15   | 15   | 3.7     | 2    |
| 2xBLW84    | 145       | 12    | 33    | 5     | 3.3   | 15      | 6    | 3    | 1.5     | 1.2  | 113     | 10   | 10   | 4       | 1.5  |
| 2xMRF245   | 145       | 21    | 50    | 21    | 33    | 7.5     | 7    | 3    | 1       | 1.5  | 14      | 10   | 4    | 1       | 2    |
| 2xMRF247   | 145       | 21    | 50    | 21    | 33    | 7.5     | 7    | 3    | 1       | 1.5  | 14      | 10   | 4    | 1       | 2    |

| Transistor | Frequency<br>MHz | $V_C$<br>Volts | $I_{C0}$<br>mA | $I_{Cmax}$<br>A | Pdrive<br>W | Pout<br>W | Efficiency<br>% |
|------------|------------------|----------------|----------------|-----------------|-------------|-----------|-----------------|
| BLX15      | 50               | 50             | 50             | 6.5             | 15          | 150       | 65              |
| BLW76      | 50               | 28             | 50             | 8               | 6           | 90        | 60              |
| MRF317     | 50/145           | 28             | 10             | 6.5             | 12          | 100       | 60              |
| MRF238     | 145              | 13.8           | 20             | 4               | 3           | 30        | 55              |
| 2xMRF245   | 145              | 13.5           | 2x30           | 2x18            | 35          | 200       | 50              |
| 2xBLW84    | 145              | 28             | 2x30           | 2x2             | 6           | 60        | 55              |
| 2xMRF247   | 145              | 13.5           | 2x30           | 2x18            | 35          | 200       | 50              |

choke, a fairly small value capacitor decouples VHF frequencies to the ground. The 100nF capacitor decouples low frequencies via a 15Ω resistor to ground. The choke in parallel with the resistor is a VK 200 ferrite or a similar one that can carry the high currents that flow through the transistor.

A BD135 transistor connected as an emitter follower with extremely low output resistance carries out base bias, this ensures a stable operating point. Thermal monitoring and compensation of the operation point is done by diode, D1, positioned so that it has physical and thermal contact with the transistor (not with the heatsink!). This ensures stable operation over a large temperature range. The other diode, D2, monitors the ambient temperature. Both diodes are of the 1N4007 type or similar. Transistor BD135 is mounted on the same heatsink as the RF transistor. Adjusting the operating point is performed by 5KΩ trimmer

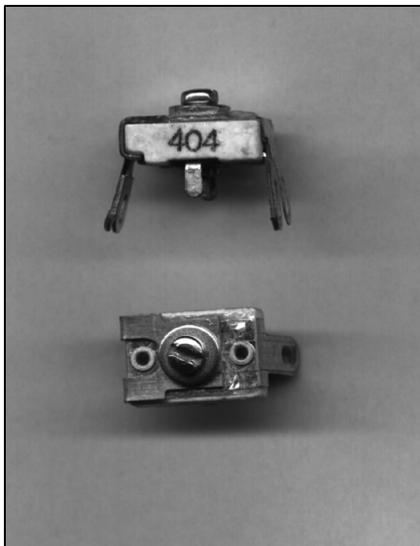


Fig 4: Picture of an ARCO trimer capacitor.

potentiometers. Beside electrolytic (or tantalum) capacitors all the others are disc ceramic or of some similar VHF quality.

## Two transistor amplifiers

As can be seen in the circuit diagram show in Fig 5 there are two identical amplifiers connected by phasing transformers, they operate in a symmetrical anti-phase or push-pull connection. A PCB layout is shown in Fig 6 and the component layout in Fig 7. The PCB may have to be varied slightly depending in the actual RF transistor chosen. Table 1 shows the component values for various transistors and Table 2 shows the expected performance. Circuits for supplying the base and collector of the transistors are the same as the one transistor amplifiers. Even the input and output matching circuits are similar. The only novelties are two pieces of 50Ω coaxial cable 95mm long that transform the asymmetric input and output of the amplifier onto the symmetric connection of two transistors. Teflon cable several millimetres thick, RG-142, type or similar should be used. The coaxial cable can be wound in a coil, or even better on some small

| Type of ARCO trimmer | Range        |
|----------------------|--------------|
| 404                  | 7pF – 60pF   |
| 423                  | 7pF – 156pF  |
| 426                  | 37pF – 250pF |
| 462                  | 5pF – 80pF   |

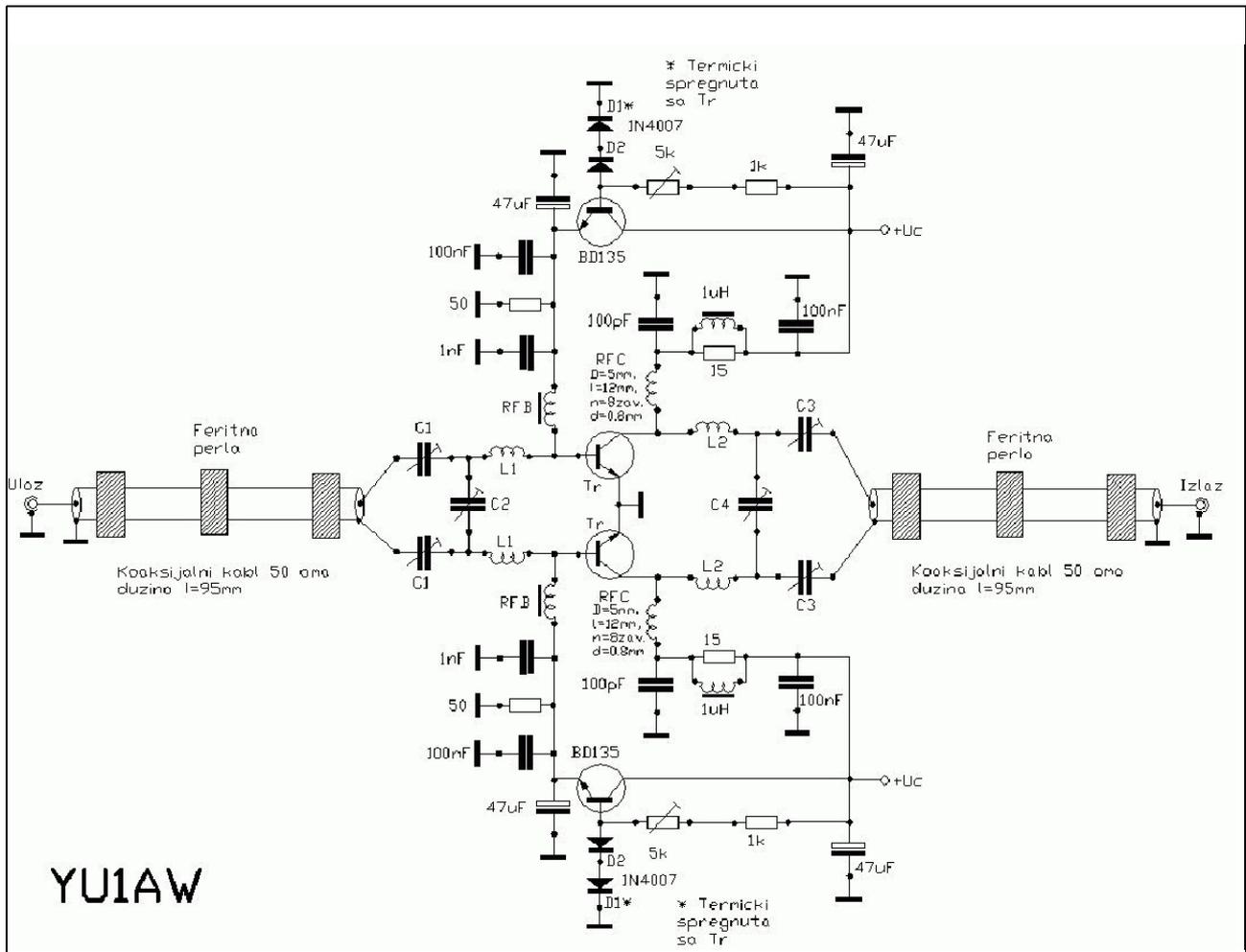


Fig 5: Circuit diagram of the two transistor power amplifier.

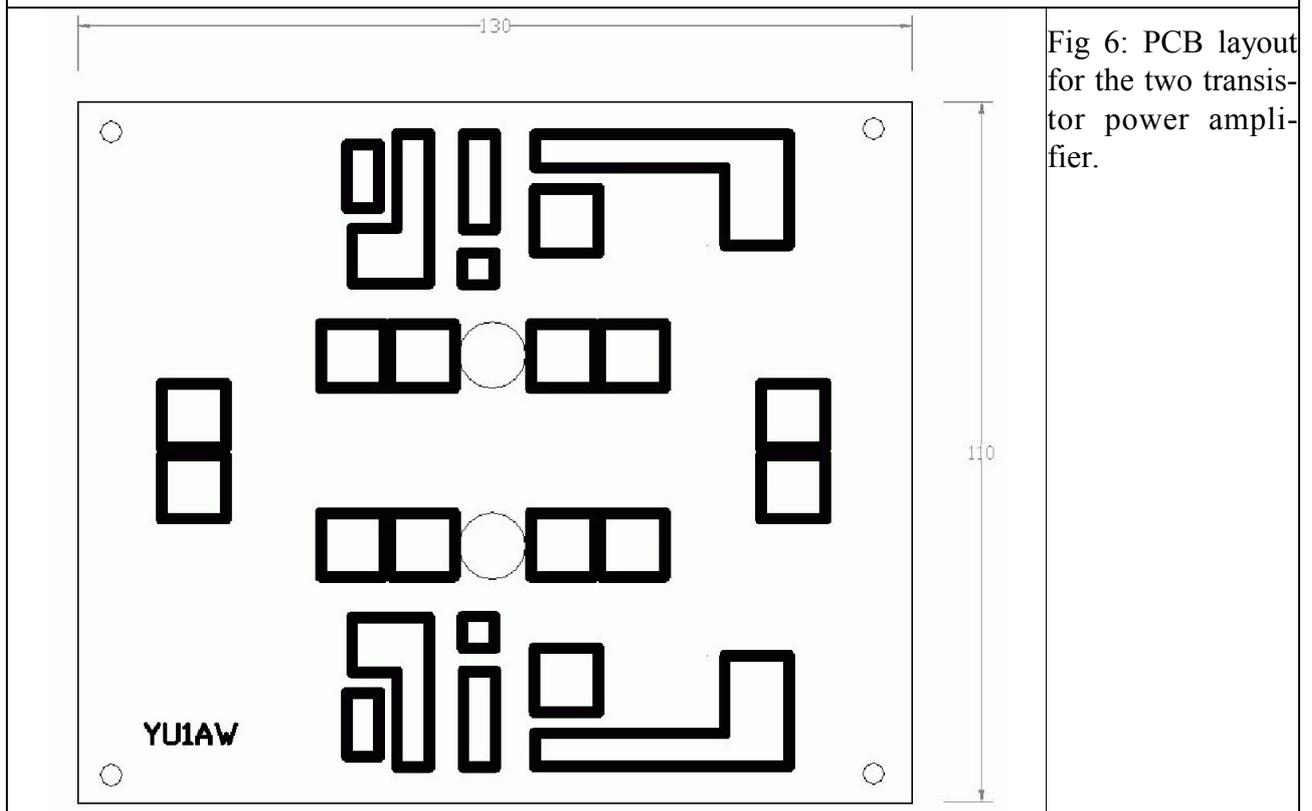


Fig 6: PCB layout for the two transistor power amplifier.

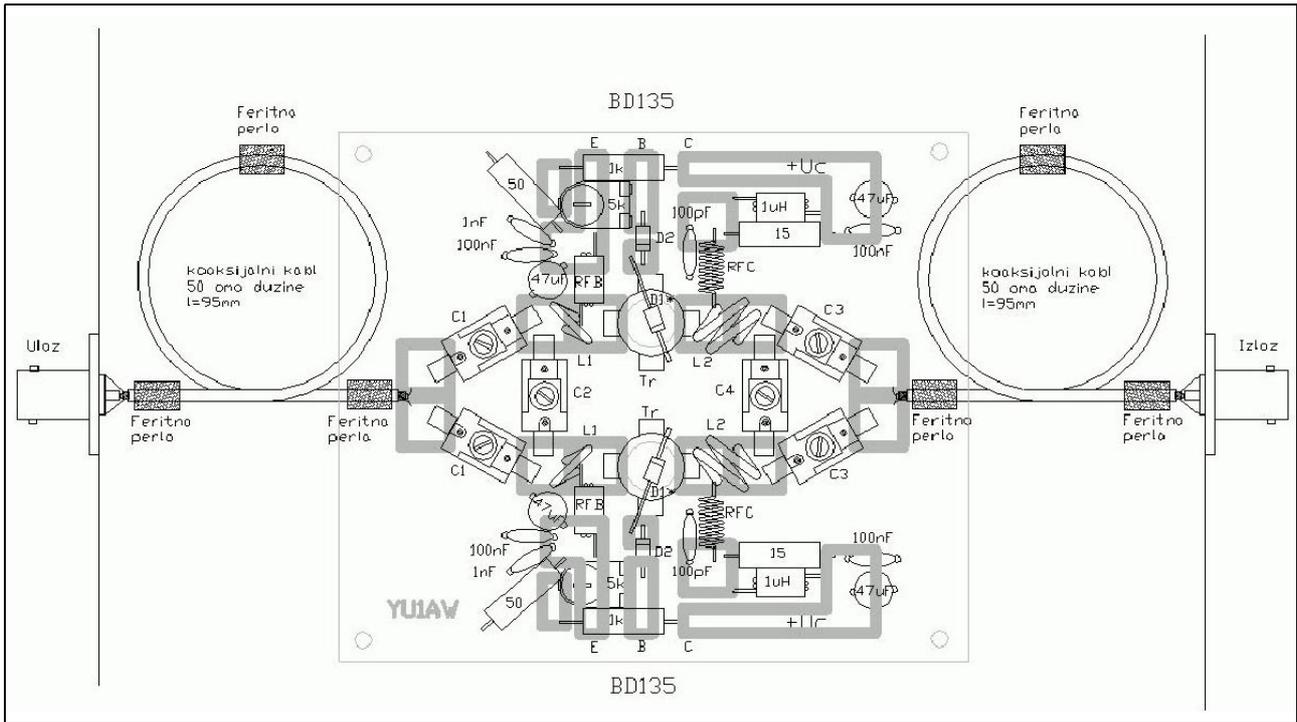


Fig 7: Component layout for the two transistor power amplifier.

ferrite toroid or onto a larger bead. Ferrite with two small holes can be used for this purpose. Using two such ferrites, two windings could be wound. If you do not have these, you could thread two small ferrite beads with one hole each onto the cable so that there is one bead on each end, but it is even better if you thread several beads and place them along the cable length. This will improve the symmetry of the transformer, especially at low frequencies, which can be significant for a stable amplifier. It is very important that the entire amplifier has to be totally symmetrical with regards to the mechanical layout of components and electrical parameters (values of

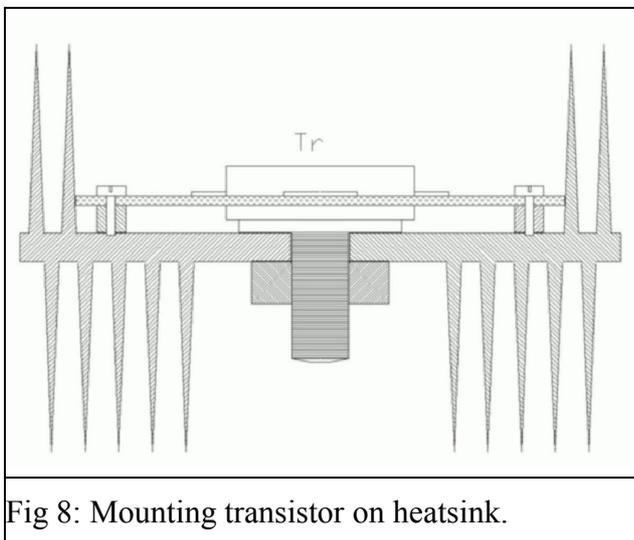


Fig 8: Mounting transistor on heatsink.

elements, currents and voltages, etc.), so that more power, amplification, efficiency and suppression of even harmonics can be achieved. While adjusting, it is very important to maintain the capacitances of C1 and C3 in both amplifiers that same.

## Mechanical construction

The whole amplifier has to be built on a relatively small piece of a single layer FR4 printed circuit board (Fig 6). Emitter leads are soldered as short as possible onto the ground of the board. The transistor should be mounted onto a large heatsink using thermal paste as illustrated in Fig 8. The surface of the board should be small to enable the fins of the cooler to be as close to the transistor as possible. To provide better cooling it is important to make sure that the hole drilled for mounting the transistor onto the heatsink is big enough to allow a screw to pass through it. The transistors should be mounted with their entire surface on to the heatsink. The surface of the heatsink where the transistors are mounted has to be smooth. Input and output connectors can be fixed onto the board but also on to the

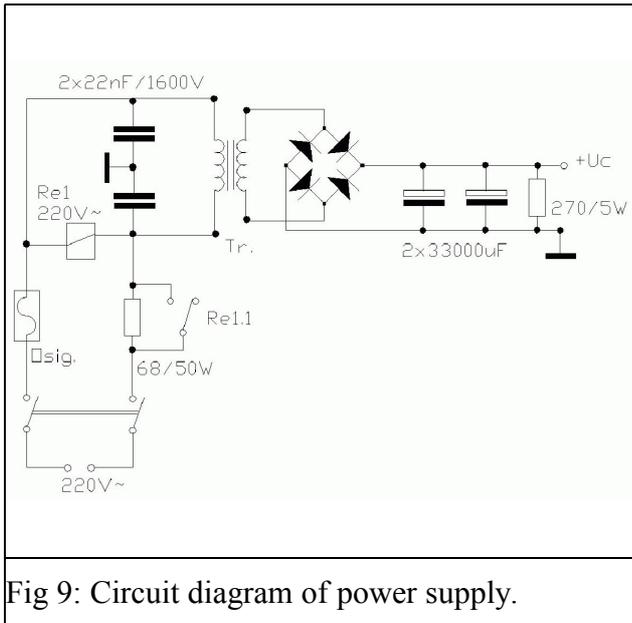


Fig 9: Circuit diagram of power supply.

heatsink or eventually the box and connected with coaxial cable to the board with its grounds soldered on both ends. The coils, L1 and L2, in the matching circuits should be mounted so that their axes are at a right angle, to decrease interactive coupling.

Once everything is connected, as illustrated in Fig 7, check once again to ensure that there are no mistakes and short circuits to the ground, and adjust the potentiometers for maximum resistance. Connect the supply to one transistor and adjust the collector current to the value from Table 2. The same procedure should be carried out with the second transistor. Even more important than the exact value of quiescent current is that they are identical in both transistors! Then connect both transistors to the supply and connect a 50Ω dummy load to the output via a wattmeter or SWR meter. If you do not have a dummy load, a good aerial with low SWR can be used. Supply minimal excitation and by measuring the output power alternately adjust trimmers until maximum output power is achieved. Repeat the adjustment several times, gradually increasing the excitation power. Finally, with full excitation, which should not exceed the permitted output power, adjust all trimmers to the highest output power. At the same time the transistor's current should be measured so as not to exceed the maximum allowed value. If input trimmers, C1 or C2, need to be at maximum or minimum capacity during adjusting, it is necessary to

change the length of the cable between the exciter and the amplifier itself. The optimal length of the cable should be determined experimentally to obtain adjustment with approximately the same values of C1 and C2. This experimentally determined cable should always be used when operating the amplifier. A change of exciter could occasionally require a new length of cable to be determined. In push-pull amplifiers it is extremely important to perform adjustment so that the corresponding trimmers on each transistor are adjusted simultaneously to ensure that they have approximately the same capacity during adjustment. By maintaining symmetry during adjustments, extremely dangerous situations are avoided which can cause the amplifier to self-oscillate.

For transistors with a higher than 20V power supply, a non-stabilized supply can be used, but it is constructed so that it has very good voltage regulation as illustrated in Fig 9. It should be well specified with good quality electrolytic capacitors. The transformer should be slightly over specified. To avoid blown fuses caused by the charging current of electrolytic capacitors, it is necessary to build in a delayed switching device. It is performed simply by a 220V relay connected as shown in the circuit. At the moment when power is switched on, the transformer is connected to a power supply via a resistor that limits high charging currents. When the capacitors are charged and transients in the transformer settle down, the current through the resistor decreases, the voltage on the primary increases and the relay that bridges the resistor with its contacts is switched on. It is also possible to use relays that switch on via some electronic timer after a couple of dozen seconds. Although this appears to be a more elegant solution, it is a far worse solution, due to two reasons: first, in the case of a very short interruption of supply voltage the timer has not been reset, voltage is switched on without delay; and second, in the case of a fault that causes high current consumption, when the relay would not be switched on, the entire system would protect itself, whereas the timer would switch on the relay and subsequently full power.

Transistors with 12-18V collector voltage must be supplied with stabilized voltage. In this case it is compulsory to build in a thyristor device for over voltage protection. This device must connect the voltage via a thyristor to the ground and thereby induce a forced blown fuse if the voltage exceeds some preset value. This prevents the RF transistor from blowing up. Any type of relay protection is not recommended in such cases as it simply cannot react quickly enough and by the time the relay is switched, the transistor is already blown up!

## Conclusion

In this article the necessary conditions are listed for the construction of transistor power amplifiers for the VHF range. On the basis of all that has been stated above, it can be concluded that the proposed amplifiers have a design to provide nearly optimal results with regards to performance, maximum simplicity of construction and adjustment. In practice good agreement with the expected results has been demonstrated, which justifies the proposed solutions.

## Credits

I thank all my colleagues who helped me in the construction of numerous amplifiers that I have designed throughout the years. Some of them have not been published since some use rare and difficult to obtain transistors. However, all the ones that I considered relatively easy to construct have been collected and published here.

## References

- [1] Transistorised power amplifier for 144MHz, Dragoslav Dobricic, YU1AW, Radioamater, 2/1988 pp 34-37, Radioamater, 3/1988 pp 66-68.
- [2] Internet address: [www.qsl.net/yu1aw/](http://www.qsl.net/yu1aw/)