VHF Airband Receiver

a double-conversion superhet for 108-137 MHz NAV and COM reception

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This receiver, specially designed for the VHF airband, couples decent performance to simple construction, all at an affordable price. It does not contain exotic parts and may be adjusted without special instruments, so we reckon the design makes an ideal entry-level receiver for aviation enthusiasts with two feet firmly on the ground.

Eavesdropping on police, ambulance and fire brigade communications, to mention but a few examples, is a hobby with a persistent attraction to many. This has been the case ever since these services started using unprotected mobile communications. The exact reasons for the 'addiction' are hard to pinpoint. Curiosity, of course, but there's more to it. A possible enticing factor is that scanner listening is somewhere in the twilight zone between 'illegal' and 'allowed', which no doubt adds to the excitement enjoyed by many scanner enthusiasts.

One of the most popular frequency ranges to listen to is known as the VHF airband. There, virtually all communications are heard between air traffic controllers, pilots and engineers. The band allows the above mentioned excitement to be coupled to the interest in 'all things aeronautic', and the result is sure to appeal to many.

The VHF airband is generally defined as the frequency range between 108 MHz and 137 MHz, which indicates that it is intended to form a seamless link with the VHF FM broadcast band, 87.5 MHz to

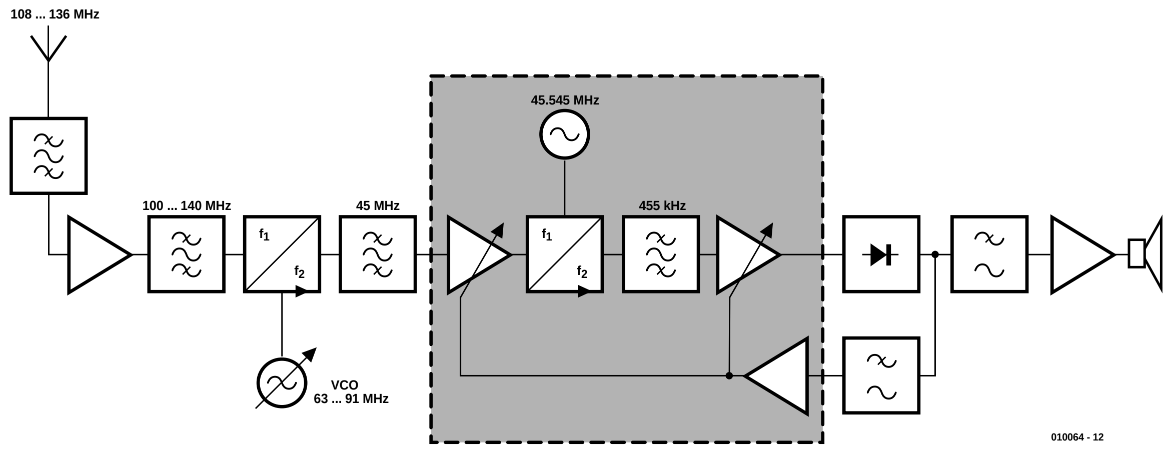


Figure 1. The receiver is a double-conversion superheterodyne design with intermediate frequencies at 45 MHz and 455 kHz.

108 MHz. This could lead us to assume (or hope) that by clever modification, an existing FM broadcast receiver can be 'tweaked' into operation at the low end of the VHF airband. Alas, this is not as easy at it seems at first blush. Firstly, the bandwidth used in the FM broadcast band is much larger than that in the VHF airband, and the same goes for the channel spacing (100 kHz as opposed to 25 kHz). The upshot is that the selectivity of the FM radio will be grossly inadequate. Secondly, all VHF airband communication is firmly regulated to employ amplitude modulation (AM), which would require the existing FM demodulator to be removed and replaced by an AM equivalent. To cut a long story short: let's forget about the FM radio and go for a dedicated VHF airband receiver.

Considerations

To make clear what sort of receiver we'll be discussing next, a short list of important features may be in order. Nearly all issues mentioned below are discussed in greater detail further on in the article as we delve into the electronics.

- Perhaps the most essential feature, the present receiver is a **double-conversion superheterodyne** design, comprising two mixers, two local oscillators (LO) and two intermediate frequency (IF) amplifiers. The superhet principle is sure to result in good receiver performance in respect of image rejection and selectivity.
- The first LO is a VCO (voltage controlled oscillator) with varicap tuning, **fine** and **coarse**.
- Because the project employs **off-the-shelf inductors**, successful construction is not limited to RF specialists like radio amateurs. Only one inductor has to be wound at home — a simple air-cored coil.
- Adjustment does **not require any specialized equipment** and can be done **by listening only**.
- Because the complete receiver including audio amplifier and power supply regulator is accommodated on a **single PCB**, wiring is down to a minimum.
- The **receiver bandwidth** is easy to select by fitting a ceramic filter with a bandwidth of 6 kHz or 15 kHz.
- The receiver has provision for extension by a counter for frequency readout and an external PLL for tuning. Note that we have no firm plans to realize these extensions.

Block diagram

The overall structure of the receiver is illustrated in **Figure 1**.

The RF signal picked up by the whip antenna (length approx. 60 cm) is first filtered to suppress out of band components. Then follows a 20 dB amplifier and a filter with a passband of about 100-140 MHz. The main function of this filter is to keep signals at the image frequencies away from the RF amplifier input.

In the first mixer, the amplified and filtered antenna signal is mixed with the output signal of a VCO (voltage controlled oscillator). The VCO has a frequency range of 63 MHz to 91 MHz, and is used to tune the receiver. The difference signal that occurs as a result of mixing the RF and VCO signals has a fixed frequency of 45 MHz. This is called the first IF. Using a 45-MHz filter, the first IF signal is freed from any spurious components.

The first IF signal is then amplified before being applied to the second mixer, where it is heterodyned with a 44.545 MHz signal from a fixed oscillator. The resulting difference signal at 455 kHz is filtered again and then amplified. Next comes the AM demodulator. The bandwidth of the 455-kHz filter determines the overall receiver selectivity.

Behind the demodulator, a signal is shown to pass through a buffer before being applied to the gain stages before and after the second mixer. This is the automatic gain control (AGC) system, which serves to reduce the overall receiver gain when extremely strong signals are received. The AGC levels out large signal strength variations and so prevents you having to re-adjust the volume every time you tune to another signal.

As indicated by the dashed outline in the block diagram, the second mixer, the 44.545-MHz oscillator, the two adjustable-gain amplifiers and the AGC are contained in a single integrated circuit. No doubt this will help to make the construction of the receiver much easier than with discrete components.

Behind the AM demodulator, we find a simple low-pass filter followed by a small audio power amplifier and of course the usual loudspeaker.

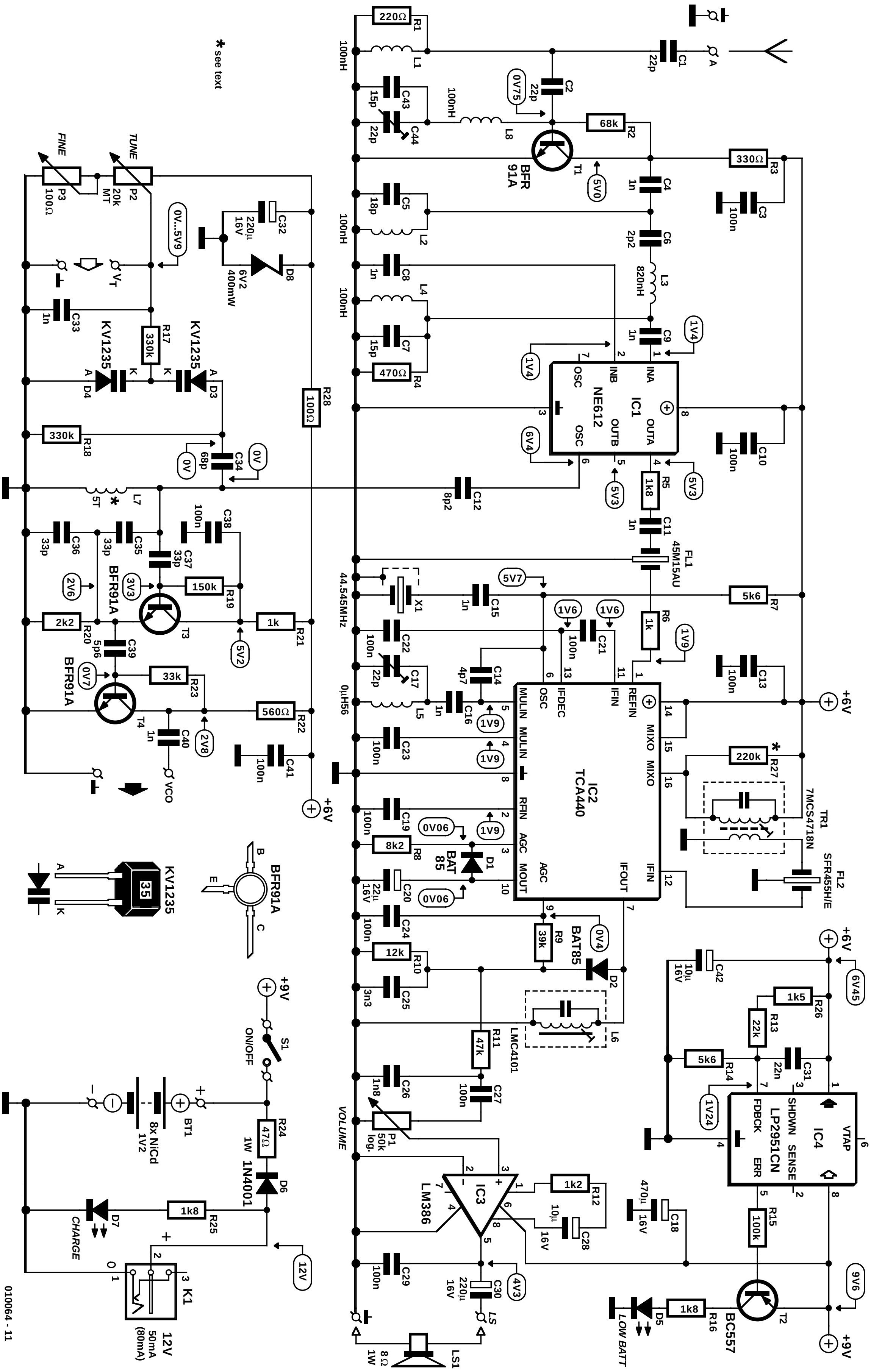


Figure 2. Thanks to the use of an integrated mixer/oscillator/IF amplifier chip type TCA440, the circuit diagram is relatively uncluttered.

Practical realisation

The circuit diagram of the VHF Airband Receiver is given in **Figure 2**. Let's have a look how the functions discussed above get their practical realisation.

The antenna signal arrives on L1, with a notch consisting of L8-C43-C44 added for suppression of unwanted signals. The RF input amplifier, T1, is a type BFR91 bipolar transistor. This device ensures a fair amount of gain at an acceptable noise figure. The 100-140 MHz bandpass is a 3-pole Butterworth filter consisting of L2-L3-L4-C5-C6-C7. This network, helped by the 'coarse' filter at the input, provides about 50 dB worth of image rejection.

The first mixer employs the well-known NE612 IC, which receives the VCO output signal at its pin 6 via coupling capacitor C12.

The VCO is built around transistor T3, another BFR91 in a modified Colpitts configuration which is a classic circuit in RF technology and known for its good stability. The oscillator's resonant circuit is tuned by two variable-capacitance ('varicap') diodes, D3 and D4, whose capacitance is an (non-linear) inverse function of the tuning voltage applied across them via their common cathode. The tuning voltage may be adjusted between 0.5 V and about 6 V using potentiometers P2 (coarse) and P3 (fine). Network R28-D8 acts as an extra stabilizer on the tuning voltage, and helps to counteract VCO frequency drift causing detuning of the receiver.

Via connection V_T, the varicap control voltage is made externally accessible in case it is decided (at a later stage) to use a PLL synthesizer to tune the receiver.

Along the same lines, the VCO output signal is made available via buffer T4 to allow a frequency readout to be connected. If you do not plan to use such an extension, you may safely omit T4, C39, R22 and R23 when building up the circuit on the PCB.

The filter at the output of the first mixer is a 45-MHz ceramic type with a nominal bandwidth of 15 kHz. The filter is followed by the section in the dashed outline shown in the block diagram. All of these functions (preamplifier, mixer, oscillator, IF amplifier and AGC) are contained in the TCA440 integrated circuit, which (almost) forms a single-chip radio receiver. Of course, some external components are needed for the job. Of the more or less standard components around the TCA440 (mostly resistors and components), the most important are without doubt the 44.454-MHz crystal, X1, LC combination L5-C17 for the internal oscillator and the 455-kHz bandpass filter consisting of transformer Tr1 and ceramic filter FL2. Inductor L6 acts as an output tuned circuit.

Further towards the output of the circuit we find a simple diode detector, D2, for AM demodulation, a low-pass filter R10-R11-C25-C26 and, finally, an integrated audio amplifier type LM386, IC3.

Power supply

The receiver was designed to operate from an unstabilized 9 V supply voltage. The supply voltage directly powers audio amplifier IC3, as well as voltage regulator IC4, which supplies a stabilized 6-V rail (actually, 6.45 V) for the rest of the receiver circuitry. Because the 'error' output of IC4 (pin 5) goes low when the input voltage drops between the minimum level for proper stabilisation, it is used to control a 'LowBatt' indicator LED via transistor T2. The minimum voltage drop across IC4 being a mere 0.1 V, the battery can be 'juiced' before LED D5 will light to indicate that it's definitely flat.

The receiver draws about 60 mA with a loudspeaker connected, and about 35 mA if you use 32-Ω headphones with both earpieces connected in parallel. Consequently, a 9-V PP3 battery will last for about 5 or 10 hours, respectively. If you need more battery capacity, you may consider using eight 1.2-V NiCd penlight-size batteries (AA), as indicated in the circuit diagram. These batteries may be charged by connecting a 12-V mains adaptor to K1. LED D7 then acts as a charging indicator, while resistor R24 determines the level of the charging current. The indicated value of 47 Ω results in a (generally safe) charging current of about 50 mA. This allows the mains adaptor to remain on and connected up without problems, irrespective of the exact type of battery used.

If the receiver is used with non-rechargeable batteries only, components R24, D6, R25, D7 and K1 may be omitted to reduce cost.

Tuning and selectivity

As already mentioned, ceramic filter FL2 determines the selectivity of the receiver. Two options are available: a filter with a bandwidth of 6 kHz (SFR455H or the CFW455H), or 15 kHz (SFR455E or CFW455E). Although you may want to go for the highest selectivity straight away, we would advise using the 15-kHz version, at least to begin with. Radio equipment that conforms to the 8.33-kHz channel spacing standard (introduced in 1999 for ATC communications) is still a bit thin on the ground, 25 kHz still being the most widely used channel distance. Also, tuning the receiver is much more difficult when using a 6-kHz filter. Despite the use of a multiturn pot for P2, you would easily miss stations. Of course there's the fine tuning control P3 but this is of little use once you've tuned past the signal already.

However, if an external PLL synthesizer is used to tune the receiver, it is better to go for the narrower filter if only because it reduces the noise level.

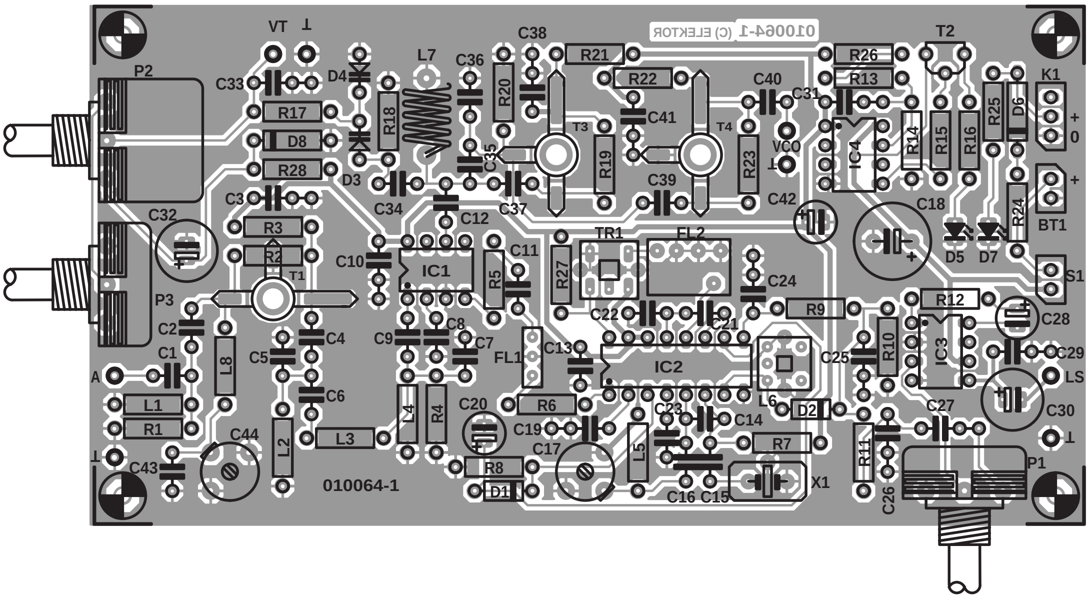
A final note regarding the tuning — some drift may be noted immediately after the receiver is switched on. The effect should disappear after a 5-minute warm up period.

Construction

Figure 3 shows the copper track layout and component mounting plan of the printed circuit board we've designed for the receiver. The board actually accommodates the circuit shown in Figure 2, that is, including audio amplifier IC3, regulator IC4 and the NiCd charger circuit consisting of R24, R25, D6, D7 and K1.

Despite a fair number of components on the board, construction is mostly plain sailing. As usual, make sure you fit the polarized components the right way around — we mean integrated circuits (look for the notch), electrolytic capacitors, transistors and diodes. Varicap diodes D3 and D4 require particular attention because they do not have a clear marking. If you hold the diode such that the type code is legible with the pins downwards, then the left leg is the anode, and the right leg, the cathode. On the board, D3 and D4 are not fitted in the same direction, so watch out!

Construction is best started by fitting the low-profile components simply because that is most convenient. So, start with the resistors, then the smaller capacitors, the electrolytics, and so on. Sockets may be



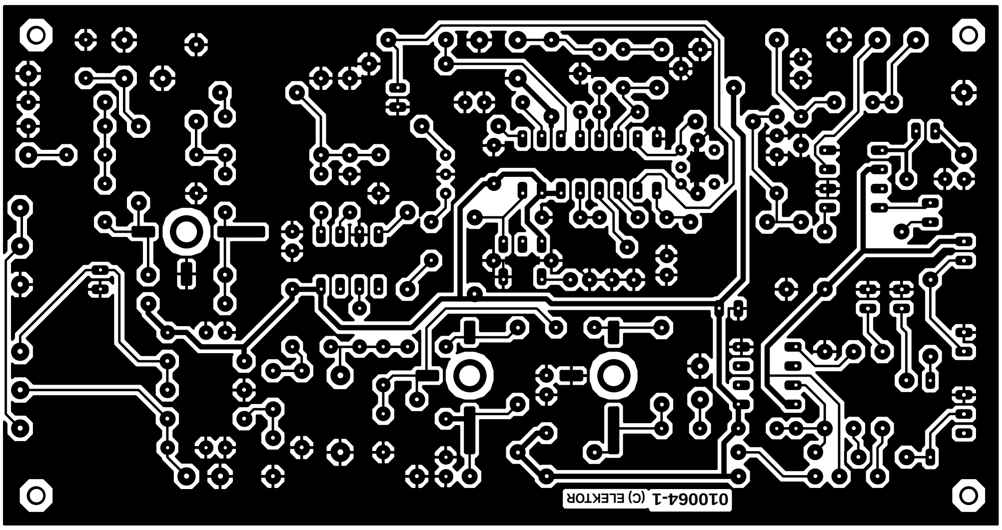
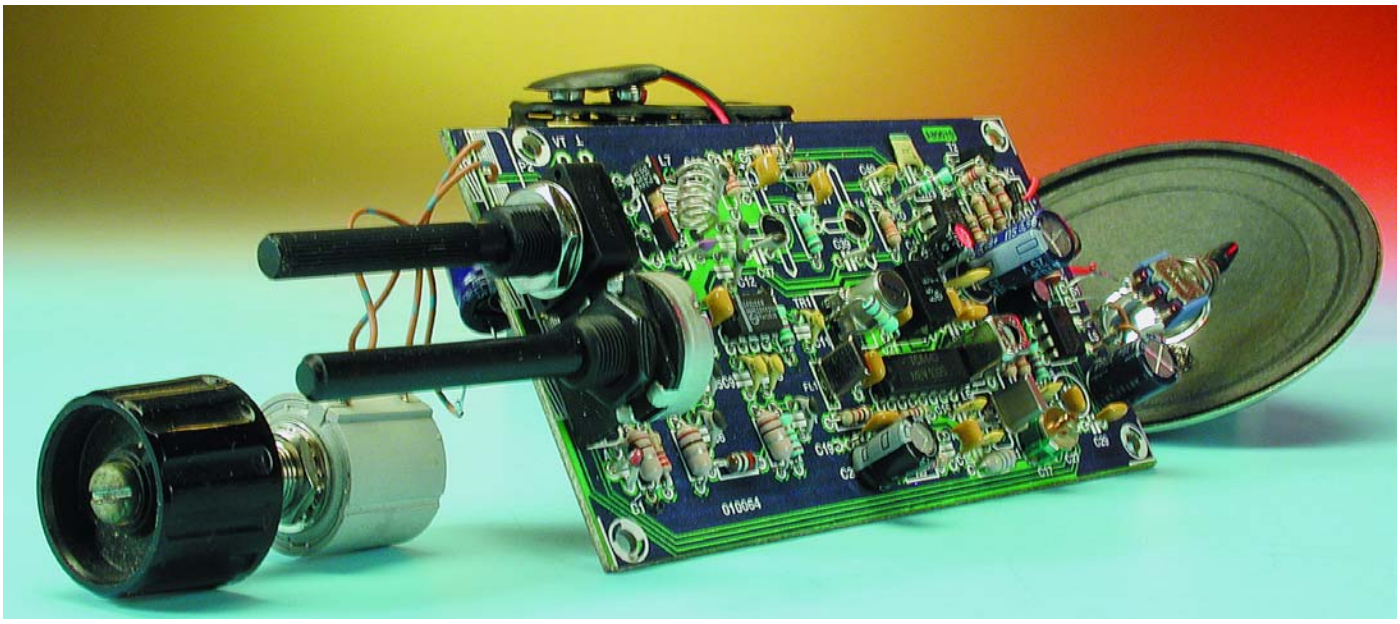


Figure 3. Copper track layout and component mounting plan of the PCB designed for the receiver (board available ready-made).



used for IC3 and IC4, while IC1 and IC2 may be soldered directly on to the board.

RF transistors T1, T3 and T4 (only if a buffered VCO output is required) are soldered at the bottom side of the board, with their legs directly onto the relevant copper tracks. They will only fit in one way and holes are provided in the PCBs for their round cases to be seated in.

Next, the inductors. L1-L5 and L8 are ready-made miniature chokes that look like precision resistors, complete with coloured bands indicating the value. IF transformer Tr1 and tuned circuit L6 are also off-the shelf components. Both are housed in metal cases that will only fit one in one way. The only inductor to be wound at home is L7. Easy, really, because it consists of 5 turns of silver-plated wire with a diameter of 1 mm. The inside diameter is 5 mm obtained from a drill bit or a pencil. After winding the inductor, space the windings evenly by pulling them apart until an overall length of about 12 mm is obtained.

A few more details about populating the board. Resistor R24 should be a 1-watt type, mounted slightly above the board because it may get a little warm. Resistor R27 is not used because our testing of the receiver indicated that it was not required. Indicator LEDs D5 and D7 have to be mounted so that they can be seen from the outside. In most cases, that will require connecting them to the board via light duty flexible wires. The metal case of quartz crystal X1 has to be (quickly) soldered to ground using a very short piece of leftover component wire.

You will find that potentiometers P1, P2 and P3 will fit the board directly. However, whether or not that is actually done depends mostly on the enclosure you have in mind for the receiver. P2 and P3 may be connected to the board using flexible wire. P1 on the other hand will require a short piece of screened audio cable.

Having fitted all the components on the board, it is a good idea to use a multimeter to check the indicated measurement point for the correct voltages. If they are (roughly) correct, you may safely assume that there are no constructional errors in the circuit.

As a further aid in getting the project to work without too much time spent on fault-finding, **Figure 4** shows the wiring diagram of the complete receiver, with the PCB at the centre of things.

Mechanical work

Having modest dimensions, the printed circuit board should fit in a reasonably compact case, together with the receiver's loudspeaker and the batteries. Although we have no grave objections against a plastic (ABS) enclosure, a metal one is highly recommended because it minimizes the risk of VCO detuning by the so-called 'hand effect'. Our prototype of the VHF Airband Receiver was built into an aluminium diecast enclosure type BIM5005 which has outside dimensions of 15?8?5 cm. Although the board will fit neatly into this case, we should add that space is at a premium if the NiCd batteries and the loudspeaker have to be squeezed in as well. For example, near multiturn pot P2 we had to remove some aluminium from the inside of the lid.

Figure 5 allows an inside view of the prototype receiver. The antenna we used for our experiments was a common or garden telescopic rod.

COMPONENTS LIST

Resistors:
R1 = 220Ω
R2 = 68kΩ
R3 = 330Ω
R4 = 470Ω
R5,R16,R25 = 1kΩ8
R6,R21 = 1kΩ
R7,R14 = 5kΩ6
R8 = 8kΩ2
R9 = 39kΩ
R10 = 12kΩ
R11 = 47kΩ
R12 = 1kΩ2
R13 = 22kΩ
R15 = 100kΩ
R17,R18 = 330kΩ
R19 = 150kΩ
R20 = 2kΩ2
R22 = 560Ω
R23 = 33kΩ
R24 = 47Ω (1W)
R26 = 1kΩ5
R27 = not fitted
R28 = 100Ω
P1 = 50kΩ logarithmic potentiometer
P2 = 20kΩ multiturn
P3 = 100Ω linear potentiometer.

Capacitors:
C1,C2 = 22pF
C3,C10,C13,C19,C21-C24,C27,C29,C38,C41 = 100nF
C4,C8,C9,C11,C15,C16,C33,C40 = 1nF
C5 = 18pF
C6 = 2pF2
C7,C43 = 15pF
C12 = 8pF2
C14 = 4pF7
C17,C44 = 22pF adjustable (trimmer)
C18 = 470µF 16V radial
C20 = 22µF 16V radial
C25 = 3nF3
C26 = 1nF8
C28,C42 = 10µF 16V radial
C30, C32 = 220µF 16V radial
C31 = 22nF
C34 = 68pF
C35,C36,C37 = 33pF
C39 = 5pF6

Semiconductors:
D1,D2 = BAT85
D3,D4 = KV1235
D5 = LED, red, high efficiency
D6 = 1N4001
D7 = LED, green, high efficiency
D8 = zener diode 6.2V, 0.4W
IC1 = SA612AN or NE612
IC2 = TCA440
IC3 = LM386
IC4 = LP2951CN
T1,T3,T4 = BFR91A
T2 = BC557

Miscellaneous:
BT1 = 9V battery (PP3) or 8 NiCd batteries (1.2V)
FL1 = 45M15AU
FL2 = SFR455H or -E (CFW455H or -E)
K1 = mains adaptor socket, PCB mount
L1,L2,L4,L8 = 100nH
L3 = 820nH
L5 = 560nH
L6 = LMC4101 (Toko)
L7 = 5 turns ∆1mm silver-plated wire on ∆5mm former (no core)
S1 = switch, 1 make contact
TR1 = 7MCS4718N (Toko)
X1 = 44.545MHz quartz crystal (case connected to ground)
LS1 = loudspeaker 8Ω 1W
PCB, order code **010064-1** (see Readers Services pages)
Enclosure: e.g., BIM, dim. 150×80×50mm, order code 06.11.5005 (normal) of 06.11.5105 (enamel finish)

Many RF parts for this projects, including inductors, varicaps ceramic filters and trimmers are available from Barend Hendriksen HF Elektronica BV, PO Box 66, NL-6970-AB, Brummen, The Netherlands. Tel. (+31) 575 561866, Fax (+31) 575 565012. Website www.xs4all.nl/~barendh/, email barendh@xs4all.nl.

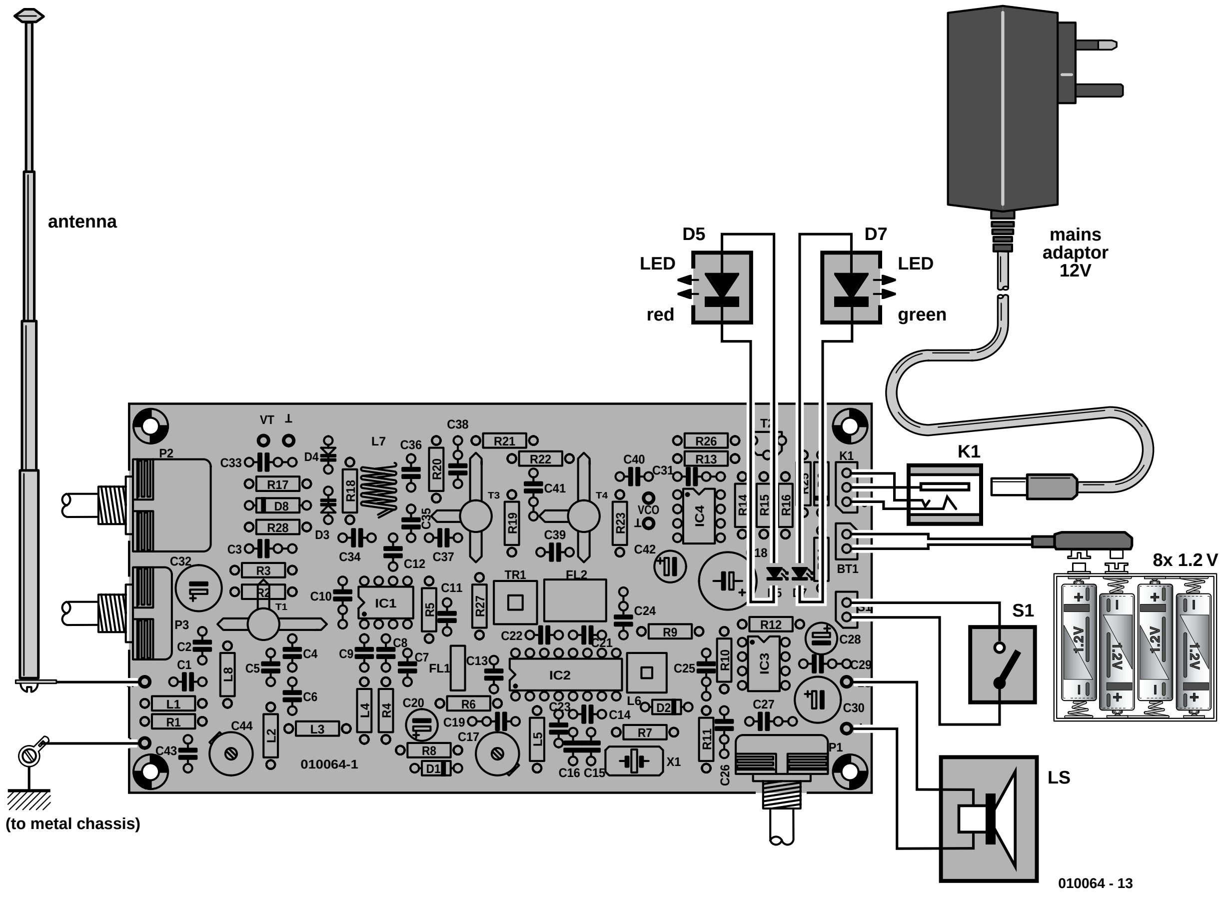


Figure 4. Overview of external controls and other elements connected to the board.

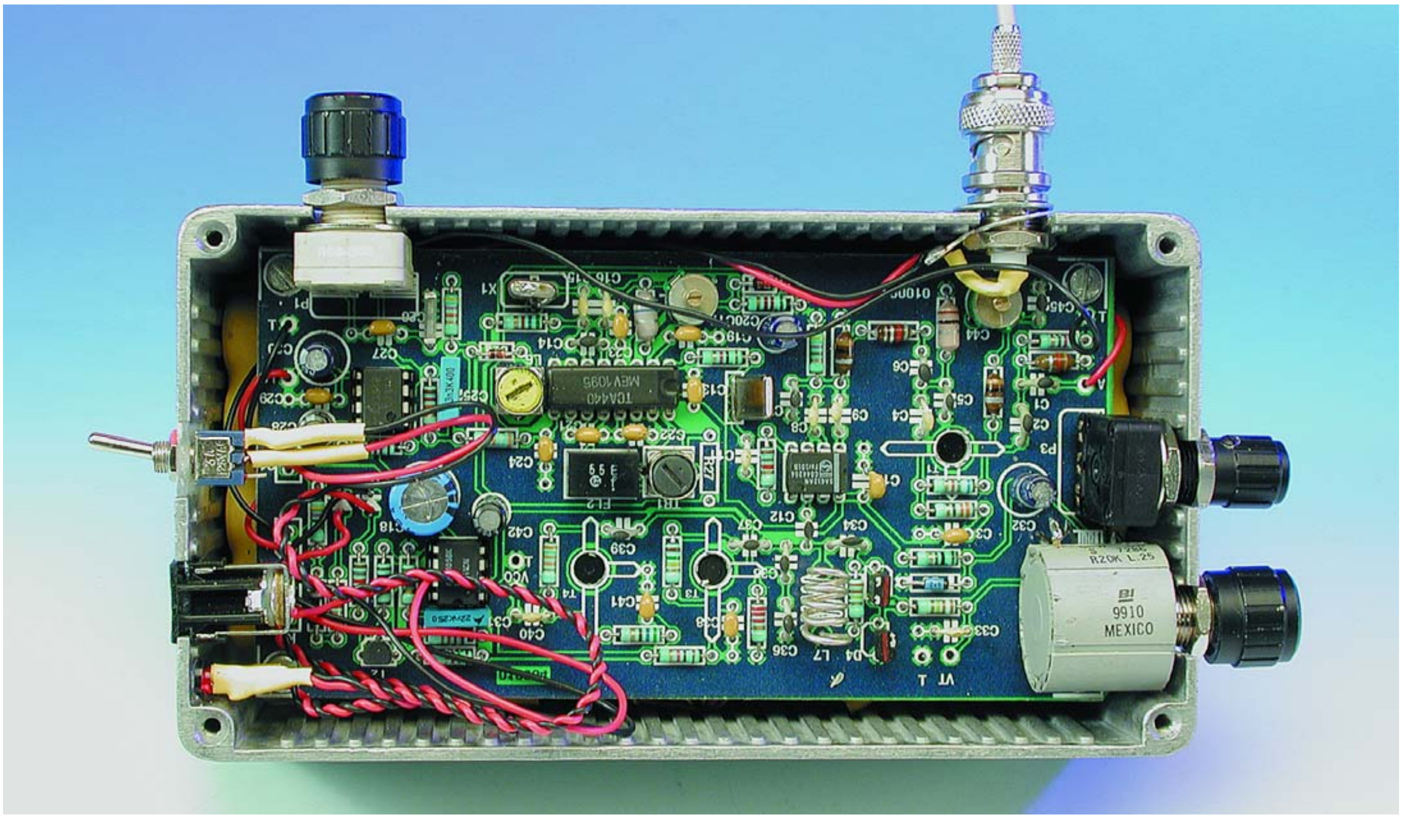


Figure 5. The PCB and ancillaries are a tight fit!

Alternatively, you may want to use a piece of rigid wire with a length of 60 cm or so, mounted in a banana plug.

Adjustment

There are four adjustment points in the receiver. The cores of Tr1 and L6, as well as trimmer C17, are simply adjusted for maximum noise output. Trimmer C44 is set to mid-travel and may be re-adjusted later to cancel breakthrough of strong signals from nearby FM broadcast stations. That's it, really!

If you have closely followed the winding directions for inductor L7, the VCO should be up and running with the correct tuning range, which may be verified if you have a frequency meter available — connect it to the VCO output and turn P2 to see if the VCO can be tuned between 63 and 91 MHz. If necessary, tweak the tuning range by compressing the turns of L7, or pulling them further apart. Make small adjustments at a time!

Reception

Most air-traffic communication may be picked up in the so-called COM (communications) section of the band, between 117 and 137 MHz, The lower part, 108-117 MHz, is reserved for beacons, in-flight landing systems (ILS), navigation beacons and other utility systems, hence it is often referred to as NAV. The best way to find out about the frequencies used on or near the airport you live close to, is to consult a Scanner Guide, which are available in several countries.

Using the HP8640B signal available in the *Elektor Electronics* design laboratory, the sensitivity of the receiver was measured at about 0.5 µV for 12 dB (S+N/N). This should be sufficient to pick up communication between air traffic controllers and pilots at a distance of more than 25 kilometres from any major airport. At first, you may be surprised to note that the aircraft signal is often stronger than that of the control tower, but bear in mind that the aircraft is up in the sky so its reception path will have a minimum of obstacles!

Finally, by tuning the receiver to weak navigation beacon signals, it can be used as an excellent propagation monitor to predict sporadic-E openings in the VHF band.

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Image rejection

Inherent to its design, any superheterodyne receiver (single or double conversion) is in principle open to two bands, the desired band and the 'image frequency' band. These bands are spaced apart two times the first intermediate frequency. Image frequencies are caused by unwanted output products of the mixer(s) used.

In a superheterodyne receiver, the received signal (RF) is mixed with a local oscillator (LO) signal, in such a way that the mixer output produces an intermediate frequency (IF) which is constant over the entire frequency range. In the receiver shown in **Figure A**, the RF signals are in the desired band between 108 MHz and 136 MHz, and the LO signal can be tuned between 153 MHz and 181 MHz. This is called **high-side injection**. The difference frequency is simply LO–RF = 45 MHz being the centre frequency of the IF passband.

However, from simple mathematics it follows that an identical 45 MHz signal is produced by RF signals between 198 MHz and 226 MHz, as indicated in dashed type. The filter fitted ahead of the mixer has a passband that corresponds to the desired frequency range, i.e., 100-140 MHz, and so serves to suppress signals picked up in the 'image band'.

In this case, at an intermediate frequency of 45 MHz, the image band is less than an octave away from the desired band. Consequently, the passband filter needs to have pretty steep skirts. Alternatively, its tuning needs to 'track' the VCO. Both solutions are relatively difficult to implement, which is not what we are after.

In this example the best way to achieve good image rejection is to resort to **low-side injection**. After all, using a VCO tuning range of 63-91 MHz again results in a fixed IF of 45 MHz (RF–LO). As shown in **Figure B**, the image band is then between 18 MHz and 46 MHz, which is — on average — 2 octaves away from the input filter passband. As a result, these image frequencies can be adequately suppressed using a relatively simple passband filter.