# An 80 metre Receiver for ARDF Radio Sport

In December 1997, an 80 metre receiver for ARDF Radio Sport was published by Ian Stirling, VK3MZ. This unit, based on the now superseded MC3362 receiver chip, was very popular in Australia and also used overseas. An updated version of this receiver is presented here.

## What is ARDF?

ARDF is a pedestrian style of fox or transmitter hunting which requires the competitor to find, depending on age class, up to 5 hidden transmitters in a bush or parkland area. It is bound by a set of international rules of the IARU and it is not uncommon to see up to 30 countries represented at a world championships. Australia will be hosting the next region 3 championships starting on 28 November 2003 and we will be looking for competitors to fill each age class.

A standard orienteering map is used with only the start and finish locations marked. The competitor is required to determine the position of each transmitter, navigate to each one and then back to the finish in the shortest possible time. Each transmitter transmits in turn on the same frequency with morse code identification (MOE, MOI, MOS, MOH and MO5) for 1 minute out of five and then switches off for four minutes until its turn comes around again. Courses depending on age class are typically between 4 and 10km and there is normally a homing beacon at the finish on a different frequency.

Another form of radio sport popular in some European countries is called fox-oring. Ten or more circles of typically 100 metre radius are drawn on an orienteering map. Located somewhere in each circle is a rapidly pulsed very low power transmitter usually marked with an orienteering control. The transmitter should only be able to be heard within the circle. The idea is to visit as many controls as possible and get back to the finish within a specified time limit. In orienteering terms this is known as a "score" course.

# A Redesigned Receiver

Since the discontinuation of the MC3362 used in the original VK3MZ design, a more discrete design based on the more available Philips SA612 is presented here. Whilst this part has some shortcomings compared to the original Motorola part, performance has actually increased in some areas, particularly sensitivity.

There were several key requirements to this new design:

1) To duplicate the functionality of the original VK3MZ design.
2) Reduce overall size and weight.
3) The home constructor should be able to build the project using basic tools

The first objective is of primary importance. The original design has proved itself through several years of field use. It provided a good compromise between cost and complexity. It has enough performance to make it suitable for serious competition use while keeping the cost and operational complexity low enough to make it suitable for the beginner.

The second objective has been achieved through elimination a number of larger parts from the original design and the use of 1/8 watt or vertically mounted ¼ watt resistors. (A good kit containing lots of these 1/8 watt size parts is available from Jaycar: Cat RR-2000) This was done partly because the original size case had become difficult to source, and also because there is a preference for ARDF equipment to be as small and light as possible.

The third objective dictated that the design should use through hole components where possible. However, as is becoming increasingly common, many newer components are being offered only in surface mount. There is a small number of surface mount component used in this project that are not available as a leaded variant. A good pair of tweezers, a soldering iron with a relatively small tip, a steady hand and an adjustment of mindset (some of us have successfully been using this technology as hobbyists for more than a decade now) are all that is required to work with these components. For those who still claim to possess surface mount phobia the author can provide boards with these parts already loaded.

There have also been some other improvements over the original design. One of these is that wiring has been simplified since both the power and mode switch, tuning control and earphone socket mount directly on the circuit board. This minimises external wiring immensely. The sense antenna switch has also been removed, but may be included if the operator prefers it. It has generally been found, particularly when hunting in tone or “whoopee” mode, that once the sense antenna has been correctly adjusted, there should rarely be a need to switch it out. It also makes for one less control to get wrong!

## Circuit Operation:

A ferrite rod or “loopstick” antenna is used as the main receiving element. Two capacitors are used to resonate this antenna at approximately 3.55MHz. A few coupling turns are used to couple some of the energy from the loopstick into the receiver input. The sense antenna is used to pick up the electric field signal and mix it with the magnetic field signal picked up by the ferrite rod coil. In one direction this causes the signal level to increase slightly as the signals effectively add in phase. In the opposite direction the two signals arrive out of phase and effectively cancel. For this to work the sense antenna needs to be resonant. L4 adds enough inductance to achieve this. The level from the sense antenna, which effectively determines the depth of the null is controlled by RV3. A link from RV3 to L2 allows insertion of a sense antenna switch should the operator require one.

L2 provides impedance transformation between the low impedance presented by the antenna network to the high impedance required by the MOSFET input. C17 resonates the coil secondary at 3.55MHz. Q1 is a dual gate MOSFET that is a little unusual in its design. It is in fact two dual gate MOSFETS in one. The arrangement is supposed to give a lot better cross modulation handling under gain control. For more information on this device, download the Philips datasheet. R5, R6 and R10 form biasing for Q2. R27 damps any possible oscillation in the microwave region. L1 forms the RF amp output tank resonated at 3.55MHz by C5. The output of L1 couples directly into the first mixer U3 as a differential signal on pins 1 and 2.

Tuning is accomplished by varying the voltage on RV2. Since this is an up-conversion receiver, the local oscillator frequency needs to decrease for increasing received frequency. This translates to the tuning voltage decreasing for increasing receiver frequency. R17 limits the voltage swing available and ensures the varactor does not get too close to zero volts. C41, C38 and R25 provide some filtering of the tuning voltage while R22 provides a high impedance path to couple this voltage into varactor diode D5. C34 provides DC blocking and L3 forms the main resonant element. The core MUST be made of Iron powder. Ferrite, apart from being temperature sensitive, is also susceptible to the earths magnetic field and caused shifts of several hundred hertz as the receiver was rotated. If you don’t believe this – try it! C30 places a limit on the varactor tuning range while C26 couples the VFO into the oscillator input. C30, C34 and C26 should all be silver mica or polystyrene types as they are very sensitive to self heating and temperature drift. DO NOT use NPO ceramics for these parts. Polystyrene has a slight negative temperature coefficient which helps to cancel out the positive temperature coefficient of the varactor and inductor. C29 and C24 provide oscillator feedback ensuring that the input resistance looks negative. C27 proves adjustment for band edge tolerances.

The output of the mixer feeds a crystal ladder filter. This filter uses inexpensive microprocessor grade crystals to provide a lower sideband filter approximately 2KHz wide. R8 provides input termination and R7 provides output termination. C15 serves as a DC block for the termination.

The ladder filter is fed into an IF amplifier Q2. This is a similar circuit to that of the front end amp. L5 and C13 resonate the drain at 10MHz while R28 ensures stability.

There is more than 80dB of gain control range available split between the RF amplifier and the IF amplifier.

The output of the IF amp is provided to second mixer U5 pin 2. A beat frequency oscillator is provided by Y4 and feedback capacitors C36 and C40. C37 provides tuning of the crystal frequency. The output of the second mixer is amplified by CMOS Op-Amp U6. C22 ensures stability and filters out any 10MHz. R16 sets the amplifiers gain. The output audio is DC blocked by C20.

Gain controlled Detector audio are supplied to diode detector D3 and D4. RV4 provides a bias voltage to the diodes to provide some forward bias current so that weaker signals can be detected. A filter network comprising R19, C31, R23 and C39 filter out the remaining audio component to provide a DC voltage which is linearly dependant on signal strength. This signal is provided to pin 9 of U4 which is configured as an audio frequency VCO. C35 and R21 control the oscillator centre frequency. R1 provides a filtered supply to U4. R15 can be substituted if a regulated supply is preferred.

The output of the Audio VCO is attenuated by R18 and provided to a preset volume control RV1. Audio is amplified to a level suitable for driving headphones or a small speaker by U2. R10 and C20 decouple the amplifier from the supply. R2 and C2 provide an idler load for stability of the audio amplifier. C7 provides output DC blocking.

SW1 doubles as a power switch and Tone/Audio mode control. In the Audio position the supply is provided to U4 pin 5 and Q3 via R9. This inhibits the output of the tone VCO and supplies detected audio directly to RV1. Hence Q3 is used as a MOSFET audio switch. C44 provides DC blocking for the audio path. In the Tone position R14 ensures that pin 5 of U4 and Q3's gate are at zero volts.

D1 and D2 provide reverse polarity protection for the battery. U1 provides a regulated 5 volt supply to most of the receiver circuits. Typically the receiver drains around 35mA depending on volume setting.

## Construction

Before beginning any construction or handling any active components ensure you are well earthed.

The first components to be mounted are surface mount parts Q1, Q2, L5 and U6. These devices are mounted on the underside of the PCB. Q1 and Q2 have four pins, one of which is slightly wider than the rest. Tin the wider pad on the PCB with a small tipped soldering iron and a small amount of solder. Hold the component in place with a good pair of tweezers and quickly tack the pin in place with the soldering iron. Solder the other three pins and then resolder the wider pin. L5 is not polarity sensitive and U6 orientation should be obvious. Solder these parts using a similar technique.

Next mount all the through hole passive components. All fixed resistors have a 6mm lead spacing. If ¼ watt resistors are used, these can be mounted on end or parallel to the board with the leads bent slightly inwards. It is highly recommended to use the 1/8W package style if possible. Most capacitors have 5mm lead spacing. Take note of the polarity on the electrolytic capacitors. Solder the crystals and inductors L1 and L2 in next. L3 and L4 are to be placed later. Don't forget the wire link between the TP5 and TP6 pads.

Solder the diodes, transistors and integrated circuits. For U4, a CD4046 is specified. A 74HC4046 can be used, but with some types the setting of RV4 can be considerably touchy and the values of R21 and C35 may need adjustment. The upside of this device is that it can be effectively run from a regulated supply. Use R15 is used instead of R1. Never fit both R1 and R15 at the same time. This can be done with the standard CD4046 but the audio pitch range will suffer.

Power switch SW1, headphone socket X1 and tuning control RV2 should be mounted next. Make sure they are sitting parallel to the board before soldering them into place. If you are using 2-pin headers for SP1 and B1, solder them in now.

For L3, wind 32 turns of 0.25mm enamelled copper wire onto an Amidon T-37-6 core. The turns need to be evenly distributed around the core. Start and finish positions and winding direction are not important. Tin the ends and solder the coil into place. Fasten the core in place with a 3mm nylon screw and nut.

For L4, wind 110 turns of 0.25mm enamelled copper wire in a multi layer format on a 5mm former. Keep the turns to the bottom 10mm of the former. Tin the leads and solder them onto the two posts on the coil former. Screw an F16 ferrite core half way into the former and solder the core into place.

Drill out the box as per the detail shown in figure 3.

Wire up the gain control, battery and speaker connections to the PCB using flexible hookup wire.

Note that for ARDF Radio Sport use it is a requirement that the receiver does not emit sound. Headphones are therefore compulsory. It is also common practice to mount a compass to the receiver. The constructor may therefore wish to omit the speaker altogether if the receiver is intended only for ARDF competition use. Also, the Ferrite Rod distorts the earths magnetic field, so if a compass is used it should not be mounted close to the Ferrite Rod.

Cover the mid section of the ferrite rod with a 60mm long section of 15mm heatshrink tubing and shrink to fit. Wind 20 turns of 0.5mm enamelled copper wire over the mid section of the ferrite rod with tails 40mm long. Wind two coupling turns of 0.5mm enamelled copper wire over the mid section of the ferrite rod with tails 80mm long. Strip and tin the ends. Mount the rod inside PVC electrical conduit as shown in figure 4. Note that the recommended ferrite rod is obtained from Truscott Electronics World. Cheaper equivalents are available from Jaycar and DSE have been found to contribute more than 7dB of additional loss due to Q reduction which limits receiver sensitivity.

Mount the PCB into the box using 6mm long M3 spacers. Mount the sense antenna socket and controls and wire up as shown in figure 5.

A sense antenna is needed. This can be made of brass rod or even coat hanger wire. A 450mm length of wire is needed and this should be soldered into a 4mm plug. Cover the top end of the antenna with a dozen or so layers of electrical tape to reduce possibility of eye damage with the end of the antenna.

## Alignment

Alignment requires a low level signal source and an attenuator or an RF signal generator. If you don't have a signal generator a special board that can be used as a 3.58MHz alignment source is included in the board set. It is recommended that you build it first. This board also doubles as a fox-or mini-transmitter!

Set RV1 to mid position. Provide power to the receiver, switch the power switch to "Audio" and set the gain to maximum. Depending on how close the initial tuning is, a small amount of "hiss" should be heard in the speaker.

Adjust C37 (BFO adjustment) for a peak in the noise level in the speaker. At this stage there is no need to be precise with this adjustment.

Connect the signal generator to the receiver input (use the loop terminals) and set the input level to about –80dBm at 3.58MHz. Adjust the tuning until a tone is heard in the speaker. If the tone is too loud, reduce the signal level into the receiver or turn down the receiver gain slightly. Adjust L2 for maximum level. Reduce the gain and adjust L1 for maximum level. Set the signal generator to –120dBm and ensure the signal can still be heard when the gain control is set to maximum.

Set the signal level to –80dBm and reduce the gain to a comfortable level. Tune past the signal with the tuning control and check that the tone has an even spread and is not too "peaky". If it is, adjust C37 to try to even the response out. Be careful not to set it so that the overall audio level drops or so that the receiver responds to part of the wrong sideband. The receiver should only respond to one side of zero beat and the received tone should increase as the tuning control is increased.

Remove the signal source and set the mode switch to “Tone”. Adjust RV4 until a slow “ticking” is heard in the speaker (approximately 1-10Hz). Adjust RV1 (volume) to a comfortable level. Apply a signal to the input of about –80dBm. The tone should change to a high pitch. You may need to switch back to “audio” temporarily to ensure the receiver is still correctly tuned. Reduce the gain so that the pitch is at a “mid way” level. Carefully adjust L2 and L1 for the highest pitch.

Set the signal source to 3.5MHz. Wind the tuning control down to ensure the tuning will cover this frequency. Adjust C27 so that there is a few KHz of overlap below 3.5MHz. Set the signal source to 3.6MHz. Wind the tuning control up to ensure the tuning will also cover this frequency. The tuning is designed to cover around 200KHz so there should be plenty of overlap on each end. If the range is not covered, it may be necessary to add or remove a turn off L3. Remove a turn if 3.5MHz is not covered, and add a turn if 3.6MHz is not covered.

Connect the ferrite rod antenna to the receiver input. Set up a signal around 3.58MHz, into an antenna nearby. Tune the receiver to the signal frequency and adjust C42 for maximum signal level.

The next step is to verify loop tuning and align the sense antenna. This should be done during the day to avoid skywave effects.

Set up a continuous vertically polarised transmitter on about 3.58MHz in an open field. Set up the receiver at least 250m away in an area free of reflecting objects with a clear view of the transmitter location. Orient the receiver so that the ferrite rod is at right angles to the direction of the transmitter. Tune the receiver to the transmitters frequency in “audio” mode then set the mode to “tone” and adjust C42 for the highest received level. Do not readjust L1 or L2.

Attach the sense antenna. Orient the receiver so that it faces exactly 180 degrees from the transmitter. (i.e. away from the signal source.) Set RV3 for maximum resistance. Tune L4 and then RV3 for minimum signal level. There may be some interaction between the two adjustments which may require both RV3 and L4 to be readjusted. The sensitivity will also need to be increased to ensure the greatest null is achieved. Once the sense antenna has been aligned, face the receiver towards the transmitter to ensure there is a large difference between the forward and reverse directions.

Assemble the case cover and make sure that the reverse direction null is still deep. Take care to keep any wiring away from the VCO components (L3 and associated capacitors and pins 1 and 2 of U3)

# Operation

Operation of the receiver is fairly simple. In most cases, the receiver will be tuned to a known frequency between 3.5 and 3.6MHz using the audio mode with the sensitivity set to maximum. It is possible to tune to the wrong sideband with much reduced sensitivity. The audible pitch of the received signal should increase as the tuning frequency is increased. If this is not the case, keep tuning in the upward direction past the signal currently being heard. Be careful as the signal level of the proper sideband will be many times greater in level and may be much higher than you may expect. Be ready to turn down the gain!

Once the signal is tuned to a received pitch of between about 400 and 1000Hz, change the mode to “tone” and adjust the attenuation so that the direction of the signal can easily be determined. The direction of the transmitter is indicated by maximum audio pitch. For very weak signals, the Audio mode may need to be used until there is enough signal to allow the signal to be received in tone mode.

As you move closer to the transmitter, the maximum pitch will increase. Increase the attenuation to avoid the receiver saturating so that the direction can be determined. There should be enough attenuation to allow you to get within a metre of a conventional vertically polarised 2 watt transmitter. You may even wish to put calibration marks for say 50, 100 and 200 metres away from the transmitter. This can be useful to allow you to gauge whether it is possible to get to a transmitter within its one minute cycle. In international ARDF competitions there is usually a typical transmitter set up on the training day before the competition for this purpose.

With a little practice, the operation of the receiver will become second nature. It is also useful to make sure that there is no easy way to “bump” the receiver tuning control while navigating through the bush.

# Parts List

## Resistors:

R1, R7 – 330R 1/8W Resistor (2)
R2 - 10R 1/8W Resistor (1)
R3 - 6R8 1/8W Resistor (1)
R4, R20, R26 – 100R 1/8W Resistor (3)
R5, R10, R11, R13, R14, R19, R21, R22, R23 – 100K 1/8W Resistor (9)
R6, R12 – 150K 1/8W Resistor (2)
R8 – 470R 1/8W Resistor (1)
R9, R16, R24, R25 – 10K 1/8W Resistor (4)
R15 – not normally fitted (see text)
R17 – 3K3 1/8W Resistor (1)
R18 – 330K 1/8W Resistor (1)
R27, R28 – 10R surface mount 0805 resistor. (2)
RV1, RV4 – 20K PCB Mount Horizontal Trimpot (2)
RV2 - Bourns-83A1DB24J15-10K PCB mount 10-turn rotary potentiometer
(with model 16 multidial for better tuning accuracy) (1)
RV3 - BOURNS-3296 5K linear PCB multiturn Vertical Trimpot (1)
RV5 – 10K Linear panel mount potentiometer (1)

## Capacitors:

C1, C18, C33 - 10u/16V Polarised RB Electrolytic capacitor, 5x11mm (3)
C2, C3, C6, C8, C12, C15, C16, C19, C20, C21, C23, C25, C28, C31, C32, C38, C39, C41, C44 -100n, 25V X7R Monolithic capacitor (19)
C4, C9, C10, C14 – 120p NPO ceramic capacitor (4)
C5, C17, C24, C29 – 47p NPO ceramic capacitor (4)
C7, C11 - 47u/16V Polarised RB Electrolytic capacitor, 5x11mm (2)
C13 – 22p NPO ceramic capacitor (1)
C22 - 10p NPO ceramic capacitor (1)
C26, C30, C34 – 120p Polyester or Silver Mica ** do not substitute ceramic** (3)
C27 –Variable Capacitor Murata 2-10p (white) (1)
C35 – 1n, 50V X7R Monolithic or ceramic capacitor (1)
C36 - 150p NPO ceramic capacitor (1)
C37, C42 – Variable Capacitor Murata 9.8-50p (brown) (2)
C40 – 68p NPO ceramic capacitor (1)
C43 – 33p NPO ceramic capacitor (1)

### Crystals/Inductors:

Y1, Y2, Y3, Y4 – 10MHz, HC49/4H microprocessor crystal, parallel resonant 16pf load (4)
L1, L2 - Toko RCL 93281 coils (available from author) (2)
L3 – 32 turns 0.25mm enamelled copper wire on Amidon T-37-6 (yellow) core (from Truscott Electronics, Bayswater) (1)
L4 - 110 turns 0.25mm enamelled copper wire on 2 pin 16mm vertical former (available from author) with 4mm F16 tuning slug (DSE R-5025) (1)
L5 – 10uH surface mount inductor. Coilcraft 1008LS-103XJ or equiv. (1)

### Semiconductors:

D1, D2 – BYV10-40, 1A Axial Shottky Power Diode (2)
D5 - BA102, Varactor Diode (1)
D3, D4 – BAT46 Shottky diode or OA95 Germanium diode (2)
Q1, Q2 - BF904R, Philips N-Channel Dual Gate Mosfet (2)
Q3 - BSS138 SOT-23 surface mount low voltage N-channel MOSFET (1)
U1 - 78L05CZ, 3-terminal 100mA TO92 Regulator (1)
U2 - LM386N, 8-pin DIP Audio Power Amplifier (1)
U3, U5 – Philips SA612N Mixer/Amplifier (1)
U4 – CD4046N, CMOS low power VCO/PLL (1)
U6 - TLV2231CDBVR Rail to rail, Low power surface mount Op-Amp (1)

### Mechanical/Misc:

SW1 - C&K T103MH9ABE, SPST centre off toggle switch-R/A PCB mounting (1)
X1 – Stereo 3.5mm PCB mounting socket, Jaycar PS-0133 or equiv. (1)
SP1 – 8 ohm 27mm speaker (optional) (1)
Quick release 9V battery holder (Jaycar PH-9235) (1)
4mm plug, Jaycar PP-0391 or equiv. (1)
4mm socket. Jaycar PS-0408 or equiv. (1)
F14, 200 x 10mm Ferrite Rod antenna (Truscott Electronics, Bayswater) (1)
Aluminium case, 100 x 60 x 45mm (DSE H-2305) or 1mm aluminium sheet (1)
Single sided PCB (available from Author)
Knobs (2)
16mm Inspection tee - Clipsal 246/16 (1)
16mm Conduit, 67mm long (2)
8mm M3 threaded standoffs (4)
M3x5 screws (8)
3mm nylon screw and nut (1)
15mm heatshrink tubing
9V 216 type alkaline Battery (1)

## For more information:

The Victorian ARDF group web page: http://www.ardf.org.au
Joe Moell's (USA) foxhunting web page: http://www.homingin.com
The Author's web page: http://www.foxhunt.com.au
The Author's email address: info@foxhunt.com.au