CRO HeyPhone Communications System
Technical Reference Manual
– Temporary version –

Note – this manual has turned out to need more material than was anticipated when the original deadlines were set. It is currently under revision to improve clarity of presentation. However, it was felt better to issue it in its present imperfect form than to delay publication. With luck, few HeyPhones will break down and few people will need this manual before the improved version is available. Readers are therefore asked to be patient with the imperfections: figures which Word has chosen to number all as zero, cross-references to figures which are therefore missing, incomplete sections and other problems. If anyone has difficulty understanding the manual, they are invited to email the author at C.Trayner@leeds.ac.uk for help.

Summary

This manual describes the HeyPhone from the technical side. It describes how it works, its physical and electronic construction and how to dismantle and re-assemble it. It contains information for technicians who may need to repair it, although no repair instructions (e.g. fault-finding guide) are included. It also contains information essential for anyone who may wish to design and build add-on equipment such as headphones, microphones to replace broken ones, different microphone arrangements or talk-through boxes. This information includes formal specifications of connectors, voltages levels, etc.. Finally, this information is there for anyone in future years who may wish to build another such transceiver or design and build a new CRO-compatible design.

To identify the design, since others may come out in the future, it is referred to as the HeyPhone Mark 1.

The expected readership of this manual comprises CRO technicians and anyone designing or building equipment as described above. Users should not need to read it.

There are no proper repair instructions such as fault-finding guides because the resources do not exist to write them. To write such a guide requires experience of typical failures, and no such body of experience exists yet.

As regards the layout of this manual, it is divided into sections in the same way that the equipment is. The main sections match the physical objects: transceiver, microphone, and so on. Only the transceiver section is subdivided into many subsections. A brief look at the Contents below should make this clear.

Some of the technical terms may be new to some people. There is therefore a Glossary at the end; terms marked with a ☞ are listed there. For those interested in the technical side, there is also a Bibliography with further reading.

A final, important appendix is the Functional Specification. This was drawn up after much discussion while the system was being designed. Any new equipment must conform to it to ensure that it will work with existing equipment. People building replacement microphones and antennas will not in practice need this section, however, as adequate instructions are given in the earlier *Microphone* and *Antenna* sections.

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1 Introduction

1.1 General description

1.1.1 Electronic

The transceiver is a single-channel, ☞ Half Duplex, ☞ Single Side-band (☞ Upper Side-band) transceiver carrying speech at ☞ Low Frequency (LF). It is a ☞ Second-Generation design. It operates at a frequency of 87 kHz, like the Molefone. It can interwork with the Molefone. It could be re-tuned in the workshop to a different frequency should there ever be a need, though this would not be a trivial job. Batteries are external. It operates either with loop antennas or ☞ Earth Antennas. With loop antennas it has a performance much the same as the Molefone (for which it is the replacement). With Earth Antennas the range is greater. The basic unit has an internal speaker and a speaker/microphone (referred to as a mic for short) which plugs in. Many add-on units may become available later; the design has been specified with these in mind. The sets are suitable for cave or surface use. They are slightly larger than the Molefone.

A system diagram for the entire equipment is shown below. More system diagrams will be given later, expanding parts of the system into further detail. To help orient the reader, this top level is described as a Level 1 system diagram; the first expansion (next level down) as Level 2, and so on down into finer detail. The circuit diagrams provide the finest detail of all.

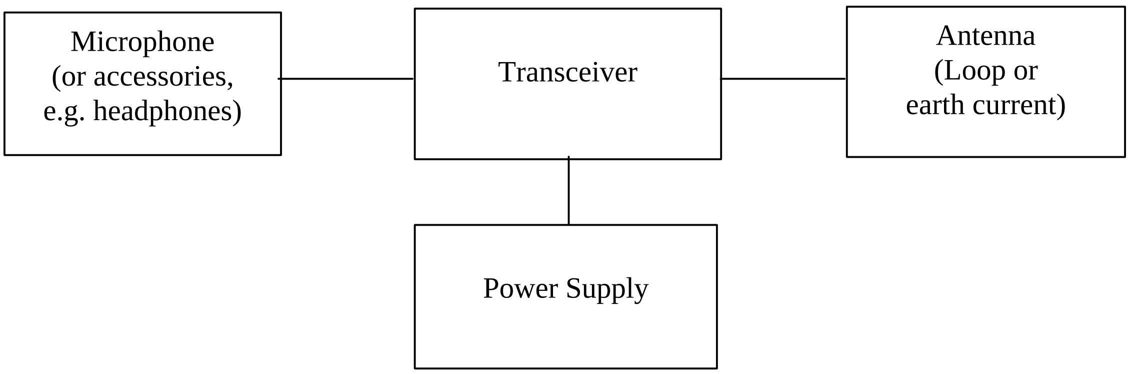


Figure 0 – Level 1 system diagram of the entire equipment.

1.1.2 Operational & Mechanical

Controls

There are two controls. One is On/Off/Volume. This is a rotary switch since rugged potentiometers are very expensive. The lowest volume level is loud enough to be heard under normal circumstances, so incoming calls should not be overlooked. The other control is a four-position rotary switch which combines the functions of three on/off switches (though not giving all combinations). The four positions are marked PHNS, SPEAKER, CONFID and BCN. It will normally be used in the SPEAKER position, where the receiver output is connected to both the speaker and the mic socket. If it is set to PHNS, the speaker is disconnected, requiring headphones to be plugged into the mic socket. (It is also possible to put the mic to the ear to hear incoming messages.) This is the only position which turns off the speaker. The CONFID position causes the transceiver to emit a ☞ Confidence Beep every 30 seconds, so all other stations know the communications link is working. There is no way of sending Confidence Beeps with the speaker turned off. The BCN position turns on the ☞ Beacon, making the transceiver transmit beeps continuously; this can be useful while setting up a communications link and adjusting antennas.

Sockets

There are five sockets on the outside of the equipment: Power Inlet, Microphone, Loop Antenna and a pair for the Earth Antenna. There is also an important connector inside, between the ☞ RF Engine, which is the heart of the transceiver, and the surrounding circuits. An External Speaker may be plugged into the microphone socket; most mics will serve this purpose, though not with as much volume as the Internal Speaker.

The Mic socket carries signals other than those needed for a microphone. These include speaker and power supply. It is also designed to carry others which future equipment might provide. These signals have been chosen to allow future add-on units

The connector pin-outs (lists of which pin does what) can be found in the *Connectors* section of the *Functional Specification* (at the end of this document).

Casing

The case is waterproof, as are all the controls and connectors. In the case of connectors, this means that they will not let water through into the case, not that they will work underwater. For reliability reasons, the case is divided into two parts. The larger, bottom part (the Bottom Box) contains the ☞ RF Engine, the expensive heart of the transceiver. On top of this is the Top Box, which contains all controls, indicators, sockets and the speaker. The assumption is that water will eventually get into the Top Box but rarely into the Bottom Box. Nor will mechanical damage to controls and connectors affect the RF Engine. The components in the Top Box are relatively cheap and easily repaired or replaced. The only connection between the two parts is a well waterproofed connector. No formal waterproofing tests have been done, but our guess is that the Bottom Box is waterproof to IP68 and the Top Box to IP67. (☞ IP ratings are a measure of waterproofing.)

1.2 Background theory

Here is not the place to write a textbook on radio theory, but a few comments are worthwhile. They are only intended for those who are interested.

Many people wonder how communication is possible through rock, since most experience and conventional logic suggest that rock stops radio signals, as it does light. Consider a radio signal striking the ground, however: it does not stop instantly, but dies off rapidly as it penetrates the rock. It only penetrates a wavelength or so, but if the wavelength is long enough then that can be a useful distance. The HeyPhone's frequency of 87 kHz implies a wavelength of about 3½ kilometres in air, though the slower speed of light in rock reduces this to a wavelength of the order of 100 metres underground. 'A wavelength or so' thus gives the few hundreds of metres penetration we achieve.

☞ Modulation is the technique by which speech is impressed on or 'put on top of' the radio signal. The HeyPhone uses ☞ SSB modulation. One of the characteristics of SSB is that a signal is only transmitted when someone is talking into the microphone. During speech pauses, even though the push-to-talk switch is held in, no radio energy is transmitted. This contrasts with Frequency Modulation (FM), which is used in the Mountain Rescue radios the CROs use on the surface. With FM, a radio signal is transmitted all the time the push-to-talk switch is in. The benefit of SSB is that it makes more efficient use of the available battery power. A disadvantage is that it is harder for a receiver to tell whether it is receiving a transmission. This has two effects relevant to the CROs. One is that the current HeyPhones cannot provide a Squelch (also known as Mute) control, so the receiver emits an annoying hiss when there is no radio traffic. The other is that it will make the design of ☞ Talk-Through Boxes harder. There are ways round this, involving sub-audible tones, but these would be for a future development. (They were envisaged in the present design; the microphone connector allows for their addition.)

Once a signal is modulated it no longer occupies a single point frequency, but spreads across the band somewhat. The amount of spread is called the ☞ Bandwidth. For SSB, the bandwidth is equal to the highest-pitched sounds transmitted. For the HeyPhone these are about 2.6 kHz. Of the two types of SSB, this equipment uses Upper Sideband. This means that the bandwidth spreads upwards from the nominal frequency, and the HeyPhone thus uses the segment 87 kHz to 89.6 kHz.

For those who want to know more, the Bibliography at the end of this manual has some useful references to books and articles.

2 Transceiver (i.e. the main equipment)

The outline of the transceiver is shown in the diagram below.

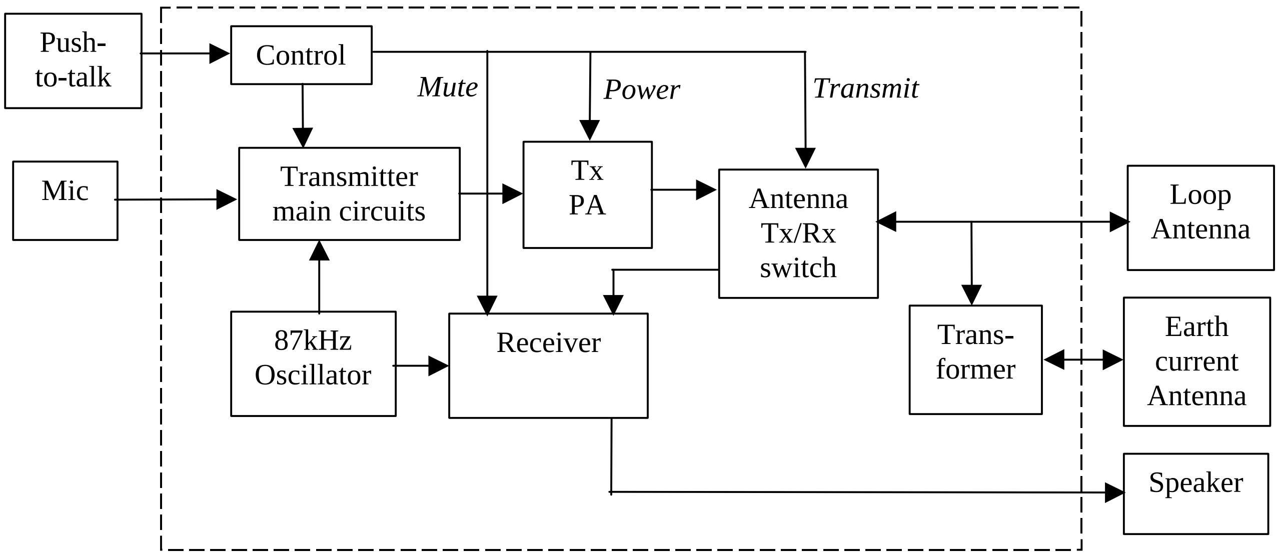


Figure 0 – Level 2 System Diagram of the transceiver. The Transceiver comprises the modules within the dashed line. See notes in the text below.

Notes:

1. The *Mute* line to the receiver and the *Power* line into the Tx PA actually come from the transmit/receive relays, not directly from the Control module.
2. The line to the speaker also feeds the speaker in the microphone.
3. The 87 kHz oscillator, antenna switch and transformer are built on the transmitter board.

Many readers will find the working of the equipment clear from the circuit diagrams (included as separate PDF files), perhaps aided by the system diagrams above and below. For those less familiar with SSB equipment, however, the following notes may be of help.

The connector pin-outs (lists of which pin does what) can be found in the *Connectors* section of the *Functional Specification*.

2.1 Transmitter

This comprises three modules of the diagram above: the Tx main circuit, the PA and the Oscillator (which is shared with the receiver). These are expanded into more detail in the diagram below.

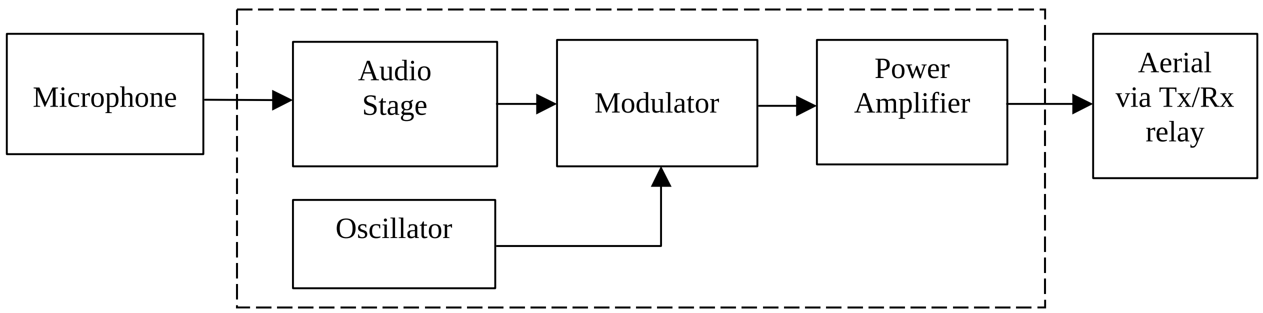


Figure 0 – Level 3 system diagram of the transmitter.

It will help to read the following circuit description whilst looking both at the Level 3 system diagram above and at the circuit diagram (a separate PDF file).

2.1.1 Audio stage

The op-amp of U9a is a microphone pre-amplifier. Note that, as well as the mic input, it has a second audio input from the Control board: this carries the various tones (confidence, SOT, EOT) which are also transmitted.

R65-68, C28-30 and U9b are a multiple-feedback Butterworth low-pass filter to limit treble and thus transmitted bandwidth. The cutoff frequency is currently 2.6 kHz, but check the *Specification*.

2.1.2 Modulator

The next few sections comprise the SSB modulator. Of the various methods of SSB modulation, the Phasing technique is used here.. This involves two slightly different copies of the RF frequency (currently 87 kHz, but see the *Specification*). These have the same amplitude and frequency but are 90^o out of phase with each other. Since they are square waves, their waveforms are as in the Figure in section 2.1.4 below. Such pairs are known as the **I** (in-phase) and **Q** (quadrature) signals. The oscillator (see below) generates these. Here we refer to them as RF-I and RF-Q to distinguish them from the I and Q components of the audio signal.

It will help to refer both to the circuit diagram and to the level 4 system diagram below.

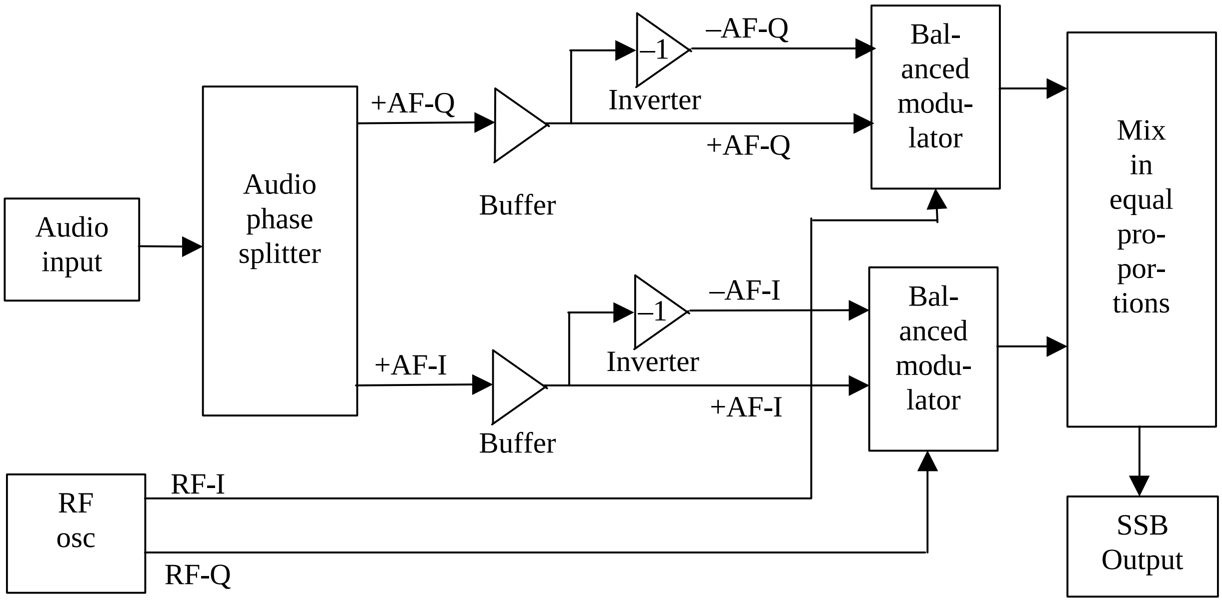


Figure 0 – Level 4 system diagram of the modulator.

The audio signal is also split into I and Q components. An inverted copy of each of these is then made. This produces four components: +AF-I, –AF-I, +AF-Q and –AF-Q. The SSB modulation can now take place. A balanced modulator switches between +AF-I and –AF-I, switching at the RF frequency. An identical modulator switches between +AF-Q and –AF-Q at the same rate. These two RF switching signals are themselves in quadrature, however, being RF-I and RF-Q. The outputs of these two balanced modulators are mixed in equal proportions. At this mixing point, the wanted sidebands reinforce each other but the unwanted sidebands cancel, ideally completely. The result is a single-sideband signal. For an introduction to the Phasing method of SSB generation, see (Gibson, 1992[8p12]).

If AF-I is modulated with RF-I and AF-Q with RF-Q, LSB (lower sideband) will be generated. If AF-I is modulated with RF-Q and AF-Q with RF-I, USB (upper sideband) will be generated. This equipment does the latter.

(A change to LSB would be simple if ever needed. The RF-I and RF-Q signals to the modulator must be swapped over. Alternatively, the AF-I and AF-Q signals could in principle be swapped: the two methods are equivalent. This circuit board, however, only makes provision for swapping the RF signals.)

The above paragraphs have explained in outline how Phasing modulation works. Turning to the circuit components which implement this, U9c produces an inverted copy of the AF signal 3.5 times larger. This and the original AF signal are fed to the passive RC network of R76–R85 and C31–C34, which produce the signals AF-I and AF-Q. This RC network only works well if it is effectively unloaded, so +AF-Q is fed via U10b and +AF-I via U10d acting as unity-gain buffers; the input resistances of these op-amps are effectively infinite. U10a inverts +AF-Q to generate –AF-Q and U10c inverts +AF-I to generate –AF-I. U11 is a pair of balanced modulators; R92 and R93 mix their outputs in (ideally) equal proportions and feed them to the amplifier of Q4. (This stage will have an input resistance of the same order as R92 and R93.)

In practice, due to the spread of component tolerances, the proportions mentioned above will not be exactly equal. Potentiometer VR1 sets the voltage levels in both modulators to achieve fine balance; the Adjustment instructions are still to be written.

2.1.3 Transmitter Power Amplifier (PA)

The first stage of this is Q4, tuned by L3/C35 to reduce harmonics to an acceptable level. (Since the RF oscillator produces a square wave, these will initially be large, about 1/6 of the power.)

VR2 sets the drive level, i.e. the RF output power of the transmitter. (Adjustment instructions are yet to be written.)

U14 is the final power output stage. This is not an RF device but an audio amplifier designed for applications such as car radios. The frequencies used in cave communication systems are less than five times the highest audio frequencies and many audio amplifiers work well. The values of components around it have been modified slightly for the higher frequency. In this usage, it can drive 5W maximum into a 3Ω load. More typically, however, it delivers 3.8W.

Power to the entire PA is switched on only when the transceiver is transmitting.

2.1.4 Oscillator

This produces a square wave at the carrier frequency. This is currently 87 kHz (but check the *Specification*) and the calculations here are based on this. Two versions of the output signal are produced, I and Q, as described under *Modulator* above.

The oscillator is crystal controlled. Crystals for such low frequencies are expensive, so a higher frequency is used and divided down. The crystal oscillates at 5.568MHz which is divided by 64 to give 87 kHz. In fact, the division is done in two stages: divide by 16 followed by divide by 4.

U12 is a standard square wave oscillator circuit; no provision for fine-tuning the frequency is needed. Even a crystal tolerance of 1 part in 10^4, which would be poor, would produce an error of less than 10Hz in the carrier frequency. U12 provides a selection of division ratios, of which Q4 (divide by $2^4 = 16$) is used.

U12 Q4	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
U13a Q	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0
U13b Q	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0

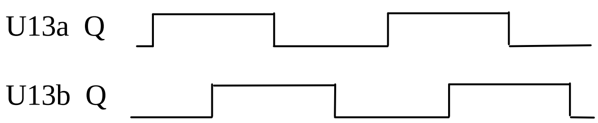


Figure 0 – Logic levels and waveforms generated.
U13a Q generates RF-I and U13b Q generates RF-Q.

U13 is a pair of D-type flip-flops wired together to divide by 4 and produce the RF-I and RF-Q signals. These are square waves 90^{o} apart, as shown above in Figure in this section. These signals are used by both transmitter and receiver.

2.1.5 Sundry transmitter points

Like most op-amp circuits these need a split power supply, allowing signals to go both positive and negative of the signal earth. The traditional solution, twin supplies of (e.g.) +12V and –12V, is uneconomical with equipment only powered from +12V. A common alternative, used here, is to have the signal earth mid-way between the positive and zero-volt lines. The op-amps are in fact run from a +9V line, so the signal earth is at +4.5V with respect to the 0V line. The +4.5V line is AC-coupled to the 0V line, so microphone earths (etc.) can be connected to the 0V line in the normal way. U9d provides this +4.5V line: it is a potential divider with a unity-gain buffer. This latter approximates to an ideal voltage source, stabilising the +4.5V and providing the AC coupling to the 0V line.

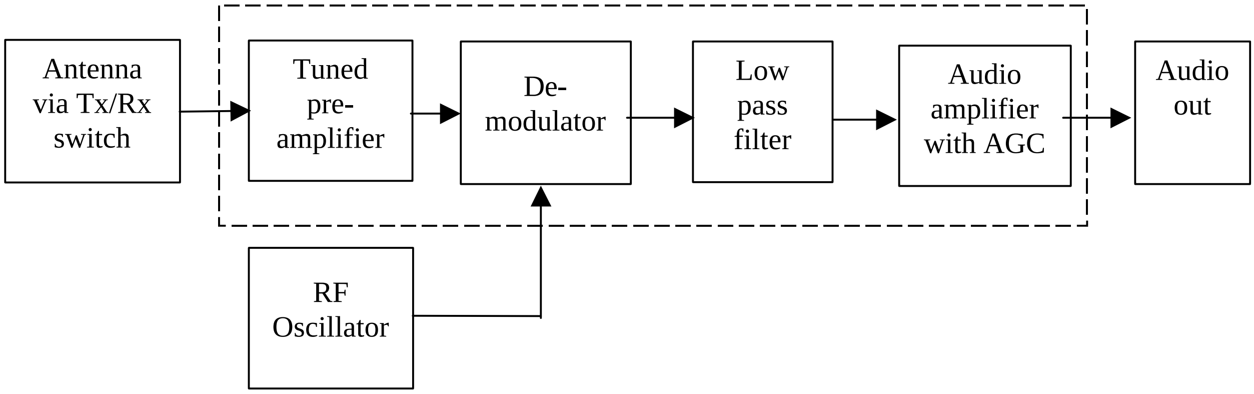


Figure 0 – Level 3 system diagram of the receiver. The modules within the dashed line are on the receiver board. The RF oscillator is part of the transmitter.

The four resistors R69 (for U9b), R73 (for U9c), R90 (for U10c) and R91 (for U10a) were needed with a prototype, but not with the low bias current op-amps used here. They do no harm.

2.2 Receiver

The level 3 system diagram of the receiver is shown below; the circuit diagram is in a separate PDF file.

2.2.1 Pre-amplifier

The first stage is a dual-FET cascode amplifier with a gain of about 40dB. The second stage, with a gain of 2, is a buffer which both avoids loading L2/C6 (reducing their Q) and prevents the two switches (U2a and U2b) from feeding each other. A low-noise op-amp is used.

2.2.2 De-modulator

This may be most easily understood by referring to the level 4 system diagram below as well as the circuit diagram.

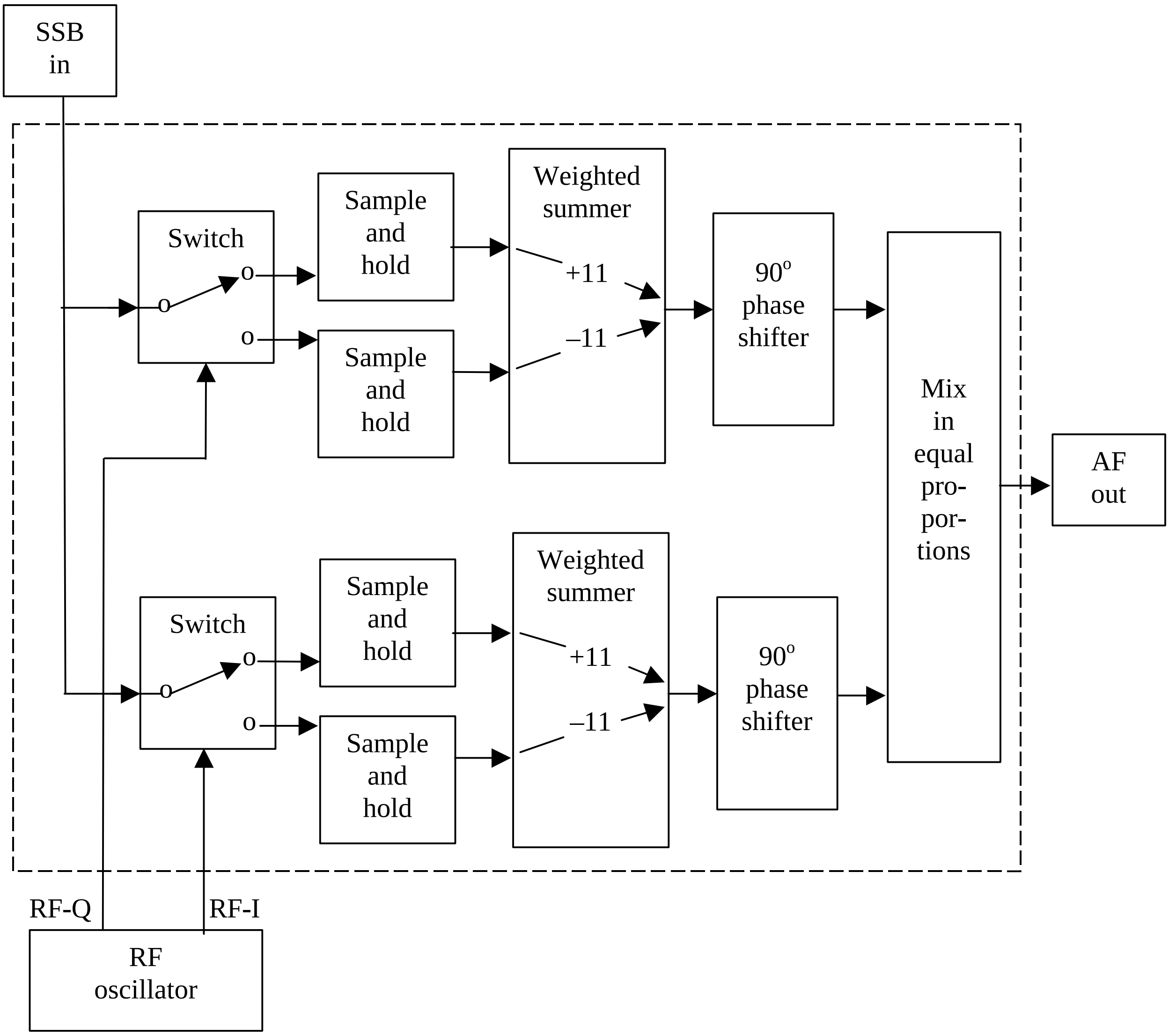


Figure 0 – Level 4 system diagram of the de-modulator. The modules within the dashed line comprise the de-modulator

Two copies of the RF SSB signal are taken. Each is switched at carrier frequency between two sample-and-hold circuits. One difference between the two halves of the demodulator is that one switch is switched by the I (in-phase) version of the local RF oscillator and the other by the Q (quadrature). (These RF-I and RF-Q signals are generated by the Oscillator, described in the *Transmitter* section above.) The IC used for the switches is, in fact, the same type as that used for the balanced modulator in the transmitter.

All four sample-and-hold circuits are identical, being merely the switch plus a capacitor (C8-11) to store the charge and a resistor (R8-11) to help define the charge time constants. The sampling is controlled by these switches: when they are connected to the resistors the circuits sample, when disconnected they hold. The charge time constants are R8.C8 (=R9.C9, etc.), namely 1.5 µs. The switch is feeding each sample-and-hold for half a cycle of (currently) 87 kHz, i.e. 5.7 µs. In this time the capacitors will charge to 98% or better of the sampled voltage. The outputs of the sample-and-holds are fed to op-amps with input resistances that are extremely high, and certainly enormous compared with R8-

11, so they present negligible load. There will thus be negligible discharge of the capacitors while the sample-and-holds are holding.

The weighted summers (U3a and U3b for the top half, U4a and U4b for the bottom) each take the difference between the two held voltages and apply a gain of 11. The upper signal of each half is fed through U3a (or U4a), which has a voltage gain of +11 from its non-inverting input to its output. The lower signal of each half is fed through U3b (or U4b), which has a gain of +1.1. It is then fed through U3a (or U4a), which has a gain of –10 from its inverting input to its output, giving a total gain of –11. The output of U3a (and U4a) is the sum of these two outputs.

The two phase shifters are of the same design as in the transmitter (see above). Amplifiers U3c and U4c each apply a gain of –3.5 to supply the top end of the passive RC filters R28-33/C12-13 and R34-37/C14-15. Note that the resistor values differ between the two filters. U3d and U4d provide unity-gain buffers to avoid loading the filters.

U5a mixes the signals from the two halves in equal proportions, with unity gain.

2.2.3 Low-pass filter

R42-45, C17-19 and U5b provide a third-order multiple-feedback Butterworth filter. R47-48, C47-48 and U5c provide a second-order Chebychev Sallen and Key filter. These both have unity gain in the passband.

2.2.4 Audio amplifier with AGC

R49 and the drain-source resistance of Q3 provide a voltage-controlled attenuator at the input to this amplifier. U5d provides a gain of 11. The output of this (as well as being fed to the rest of the amplifier) is rectified by D1 and smoothed by C23/R54, which have a discharge time constant of 1 second. (The charge time constant is unclear, depending on the output resistance of U5d and the dynamic (i.e. AC) resistance of D1, but it will be far less than the discharge time constant.)

The larger the signal from U5d, the more positive the voltage across C23, and the less negative the gate-source voltage v_{GS}. This change tends to turn the FET on. As the audio signal rises, therefore, the FET becomes more conductive and (along with R49) attenuates the input signal more. This negative feedback loop provides the Automatic Gain Control.

There are a few details. VR3 sets the source voltage against which the gate voltage is working, and thus controls the target audio level which the AGC attempts to produce from U5d. C59 earths the FET source for AC purposes. C20 prevents the output of U5c from providing sufficient negative voltage to forward-bias the gate-drain junction (see (Hey, 1998[31p21]), p.22, col.2). R50 improves the linearity of the circuit. C21 keeps the gate bias off the drain. For more details of this use of an FET, see (Horowitz & Hill, 1989, pp.138-140).

The volume control comprises R55-60 and SW1b. A switch is used rather than a potentiometer purely because rugged (metal shaft) potentiometers are extremely expensive. R55 is provided to limit the maximum volume, which would otherwise be excessive, occasionally causing feedback and oscillation. It will be noted that the Functional Specification requires that the volume is not down to zero even at the lowest setting. The wire from the lowest (most anti-clockwise) position of the switch to earth appears to contravene this. It does not, however, since this is the setting at which the power is turned off. This arrangement is used since the most anti-clockwise position provides a convenient solder tag for R60.

U6 provides the audio PA (power amplifier).

2.2.5 Sundry receiver points

The audio PA (U6) runs from +12V, but the rest of the receiver runs from a +9V supply. This is derived from the +12V supply by a straightforward 7809 regulator (U7, with C26 for reservoir) mounted on the receiver board. This +9V line is also fed to the transmitter board.

As with the transmitter, the op-amps need a +4.5V supply as a signal earth (see *Sundry Transmitter Points* above). This is produced by R101/R102/U8 with C16 for additional smoothing.

The four resistors R23 (for U3c), R41 (for U5a), R46 (for U5b) and R27 (for U4c) were needed with a prototype, but not with the low bias current op-amps used here. They do no harm.

2.3 Control

This performs several control functions: handling the PTT (push-to-talk) line and providing the various automatically generated tones. The circuit (supplied as a separate PDF file) may be more easily understood with reference to the level 3 system diagram below. These circuits are mounted on the Control Board.

It should be noted that two variants of the design have been issued, described under *Variants* below.

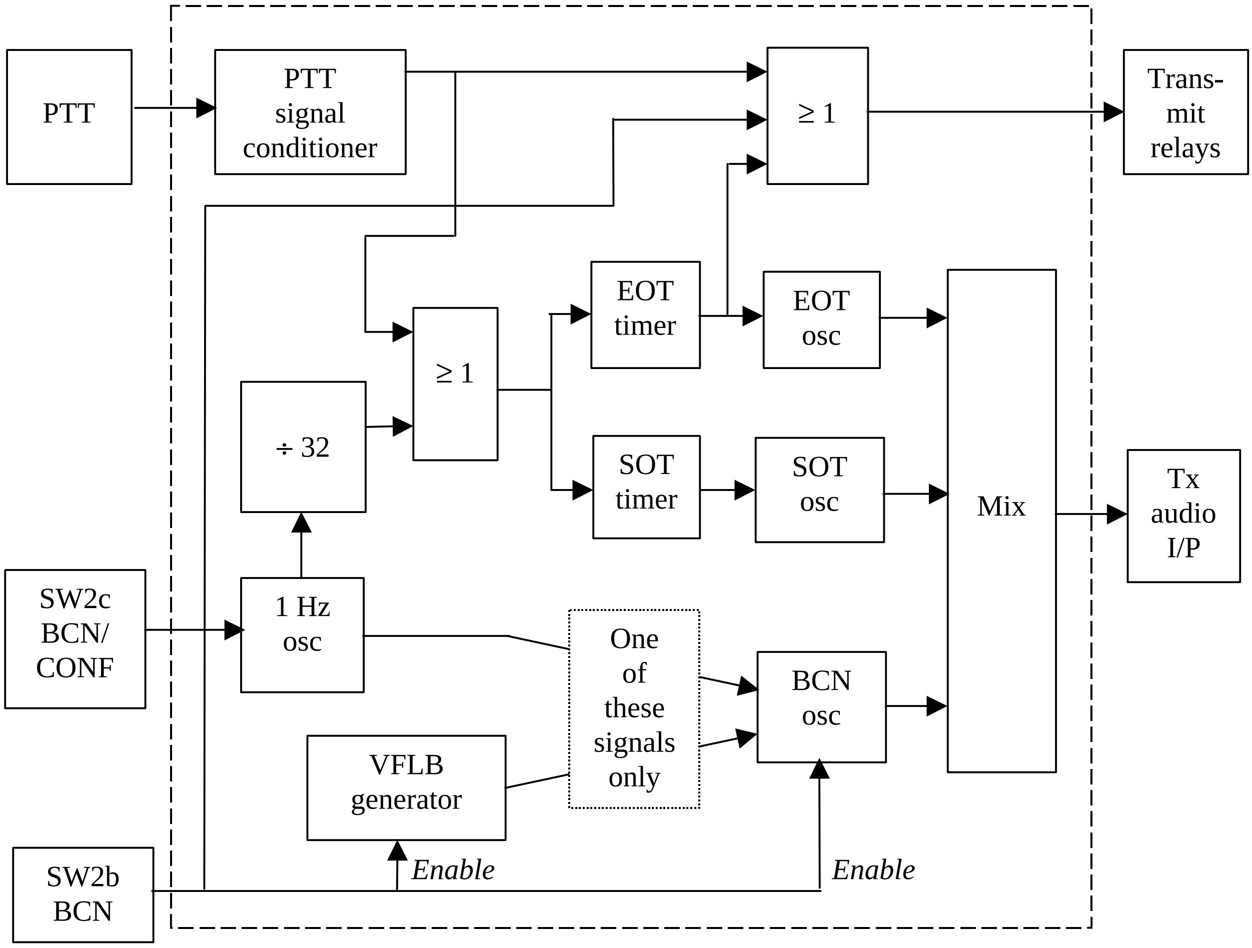


Figure 0 – Level 3 system diagram of the Control circuit. See also the notes in the text.

Notes:

1. The Control circuits constitute the contents of the outer, dashed box.
2. The inner, dotted box indicates two options. The lower signal is connected for the Morse beacon, the upper for the non-Morse beacon. (See *Variants* below.)
3. Switch section SW2c provides an Enable signal if the switch is set to either the Beacon or the Confidence position. SW2b provides an Enable signal if it is set to the Beacon position.
4. The rectangles containing the legend "≥ 1" are OR gates. (These are the New Logic Symbols.)
5. The rectangles marked "osc" are oscillators; the inputs from the left are Enable inputs. The BCN oscillator thus has two enable inputs, both of which must be operated for it to oscillate.
6. The frequencies of the three audio oscillators EOT, SOT and BCN are given in the text.

The components which implement these modules will now be described. It should be noted that many gates can be described in several ways. For instance, an AND gate can also be described as an OR gate with inverters at all inputs and outputs, or as an OR gate in inverted logic (0V=TRUE, 12V=FALSE). The usage here is to describe what is intended by the designer, i.e. what is being achieved, which makes the above system diagram more logical. The implementation (e.g. of an inverted-logic OR gate by an AND gate) is described below.

The PTT (push-to-talk) Signal Conditioner comprises R103, U15a and U15b. These arrange for the switching between transmit and receive to occur at a defined voltage. See the Functional Specification for details. (Similar systems such as CAIRO (see section 4.6) which have not defined this have suffered problems later.)

The (approximately) 1Hz oscillator used for both confidence tones and the non-Morse beacon comprises R108-109, C50, U17a and U17b. It is controlled by SW2c which leaves the oscillator operational in its BCN (beacon) and CONF (confidence) positions but disables it in all others. The disable line shorts the junction of R108 and R109 to earth. It could have equally earthed the junction between R108 and C50; the choice was purely to simplify wiring layout.

The divide-by-32 counter comprises U18 and U15d. It generates a negative-going pulse approximately every 30 seconds (when the 1Hz oscillator is enabled). The length of this pulse is determined by the SOT Timer, which resets counter U18 at the same time that it resets itself, i.e. at the end of its SOT pulse.

The OR gate feeding the EOT and SOT Timers comprises R105 and D2-3. Since inverted logic is used here, these three components can also be viewed as an AND gate in normal logic. At the electronic level, either the PTT being pushed or the 30-second timer operating pulls the output voltage low, and this voltage is fed to both EOT and SOT Timers.

The SOT (start of transmission) Timer comprises R104, C52 and U16b. It is triggered by a falling edge coming from the aforementioned OR gate, i.e. at the start of transmission. It generates a pulse whose duration is the product of R104 and C52; currently this is 0.22 seconds. This pulse is fed to the SOT oscillator and allows it to operate. It is also fed back to the I input of the timer: the falling edge resets the timer. **NOTE** that when the divide-by-32 counter operates the SOT Timer, no SOT tone is transmitted because the transmit line is not operated. It is only operated by the EOT, as described below.

The EOT (end of transmission) Timer comprises R106, C51 and U16a. This is triggered by a rising edge from the aforementioned OR gate, i.e. when the PTT is released or the divide-by-32 counter is reset. It generates a pulse whose duration is the product of R106 and C51, currently 0.33 seconds. This pulse is fed to the EOT oscillator and allows it to oscillate. It is also fed to the OR gate feeding the Transmitter Relay Driver, to keep transmitting briefly after the PTT is released or the divide-by-32 has finished its pulse.

The EOT oscillator comprises R121, C58 and U17c. In most sets, the frequency is about 1950Hz. The SOT oscillator comprises R120, C57 and U17d. In most sets, the frequency is about 1620Hz. In a few sets these frequencies are transposed; see *Variants* below.

The VFLB Generator comprises R113-115, C53, D4-6 and U19-20. Note that U19-20 are not powered directly from the 12V supply, but from the supply switched by SW2b. This amounts to an Enable signal. When enabled, it produces a continuous cyclical sequence of dots and dashes making the letters VFLB (Voice-Free Location Beacon) in Morse code. The output (from the junction of R114 and D6) is fed to the Beacon oscillator (below). Incidentally, the Morse for VFLB is ...– ..–. .–.. –... and was chosen partly because it could be produced by a simple logic circuit. Since this form of beacon has not found favour with the CROs, no detailed analysis of the logic will be presented. R119 and C54 decouple the local supply to prevent mis-behaviour of the logic circuits. **Note** that for sets with non-Morse beacons (the majority, see *Variants* below), these components are not fitted.

The Beacon Oscillator comprises R116-117, C55 and U21. It oscillates at 808Hz. Note that U21 is not powered directly from the 12V supply, but from the supply switched by SW2b. This amounts to an Enable signal, and is the one shown entering the oscillator from below on the system diagram above. Note that, when the beacon is turned off, the large resistor R112 prevents any significant voltage from the other oscillators getting through U21a to its power supply line. The other enable input (from the left on the system diagram above) is the input of U21d not connected to R117. For the Morse beacon variants, this comes from the VFLB generator (above). For the non-Morse variants, it comes from the 1Hz oscillator via D8; the pattern is half second on, half second off. (See the *Variants* section below.) D8 is a diode and not a resistor to prevent voltage from the 1Hz oscillator getting through U21d to its power supply line when the beacon is off. In practice, no pull-up resistor from the anode of D8 was found necessary.

The Mixer comprises R110 (from the EOT oscillator), R111 (from SOT) and R112 (from BCN). The behaviour also depends on the first stage of the transmitter, into which the mixed signal is fed. This stage (R62, R64 and U9a being relevant) comprises, with R110-112, a weighted summer (a.k.a. virtual-earth mixer). The gains from the outputs of the oscillators to the output of U9a are –R64/R110, –R64/R111 and –R64/R112. These ratios are all about 1/26, i.e. an attenuation of 28dB. This brings the oscillator outputs of about 12V pk-pk down to about 0.5V pk-pk, equivalent to an input of about 50mV pk-pk at the microphone input.

The 3-input OR gate is a little fiddly, comprising a 2-input NAND gate (U15c), a 2-input OR gate (R107, R118 and D7) and a transistor relay driver! The functioning can be considered as follows. (1) If the PTT is pressed, the output of the PTT Signal Conditioner is low, forcing the output of U15c high, and (through R107) turning Q4 on. (2) While EOT is being sounded, the Q-bar output of U16a in the EOT timer is low. This feeds into U15c and the same reasoning as before applies. (3) If the Beacon is on, the 12V supply from R119/C54 provides current through R118 and D7 to turn Q4 on. D7 is needed to prevent the equipment oscillating between transmit and receive under certain circumstances. Transistor Q4 is used to provide enough current to drive relays. These are connected between the collector of Q4 and are on the Transmitter Board. Two 2-pole relays were cheaper than one 4-pole.

2.3.1 Variants

Early production models of the HeyPhone produced requests for minor modifications. These were implemented, but some early sets carry the earlier design. There are two variants.

1. The original beacon sent the letters VFLB in Morse; the later design simply sends regular beeps. The sets with the Morse beacon are identified with a sticker bearing the letter “M” on the control panel.
    - For the Morse variant U19-20, R113-115, C53 and D4-6 are fitted but D8 is omitted.
    - For the non-Morse variant, the situation is reversed: D8 is fitted but the other above-named components are omitted.
2. For most sets, the EOT tone is the lower of the two; the SOT and confidence beep are the higher. For these, R120 and R121 have the values marked on the circuit diagram. A few sets have these resistors swapped, however, reversing the tones. This variant is not marked on the case. It is unclear whether equipment records note which these sets are.

2.4 Other transceiver modules

2.4.1 Antenna change-over relay

There are few points to note here. As well as the normal antenna changeover, the receiver input is earthed on transmit to reduce the transmitter signal reaching the front-end. Rather than one 4-pole relay there are two 2-pole ones, purely for reasons of cost. They are mounted on the transmitter board.

2.4.2 Antenna transformer

This is wound by hand on a core and former of type EE42/15/F44, available from RS (a.k.a. Electromail) as part number 231-8785.

The secondary is wound first. This comprises 100 turns of 24 SWG (or 23 AWG) enamelled copper wire, wound as three layers interleaved with one layer of Prespahn or varnished paper. Over the secondary are three layers of Prespahn or varnished paper.

The primary is wound next. This is 10 turns of 19 SWG (or 18 AWG) enamelled copper wire, which will occupy about half a layer. On top of this, the finishing insulation is another three layers of Prespahn or varnished paper.

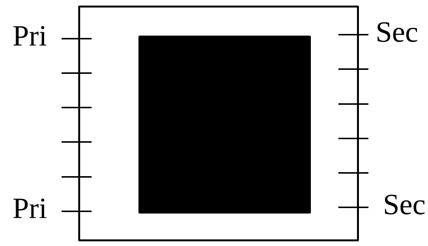


Figure 0 – Pin-out of the transformer T1.

The transformer former has two rows of 6 pins, to the four corner pins of which the ends of the wires must be soldered. The wires should be connected to the pins as shown in the Figure in this section. It does not matter which primary wire goes to which primary pin. Nor does it matter which secondary wire goes to which secondary pin. Nor does it matter which row of pins get the primary and which the secondary.

When soldering the wires to the pins, do not forget to remove the insulating varnish from the last half centimetre of each wire, e.g. with emery paper.

The transformer is mounted on the transmitter board. The row of pins with the two secondary wires should be nearest the end of the circuit board. Although only four pins are used, all 12 should be soldered to the circuit board for mechanical strength.

3 Antennas (aerials)

It is anticipated that this transceiver will almost always be used with Earth Antennas, for which construction details are given below. Loop antennas still have their place, however: they are adequate in shallow caves and quicker to deploy. Since they are not issued with the equipment, their description here constitutes help for those who may want to build them.

3.1 Earth antennas

It is anticipated that these antennas will get damaged and lost frequently and will often need repair or replacement. Fortunately they are extremely easy to make. There are several ways of making them and these have operational implications: they affect ease of use and the chances of leaving equipment behind. The design chosen should therefore be a matter of policy for each CRO. This section presents (1) suggested designs, (2) considerations affecting choice, (3) hints and kinks and (4) background information to inform the choice.

3.1.1 Designs

These are simplicity itself, though there are some subtleties. All that is required is to run two wires out from the transceiver, in opposite directions, and connect the far ends of the wires to the earth. Two methods have been found convenient for the earth connections. On the surface, metal pegs can be pushed into the soil. Underground, two-metre lengths of electric fence tape can be dropped in a streamway or trampled into mud. In practice, it has been found easiest for each transceiver to have two lengths of wire and separate earthing kits to attach to each end. Wooden cable tidies to wind the wires on are useful.

Wires. Each transceiver needs two of these; they are identical. A length of about 10 metres each is recommended. Stranded wire of 10 or more strands should be used, this will be rated at around 3 to 5 Amps. It should have plastic insulation; see below for recommendations about colour. One end needs to be fitted with a 4mm plug to connect the transceiver. The other end can have another 4mm plug or a crocodile clip.

Metal pegs. These should not be meat skewers or normal, narrow-diameter tents pegs, which give poor connections (see *Background* below). A suitable type is shown in the diagram below; Bulldog make tent pegs of this type, around 15cm long. Each earth connection should have about half a dozen of these, connected together with wires about half a metre long. A radial arrangement is better than a daisy-chain (see diagram below), as a broken wire can only lose one peg.

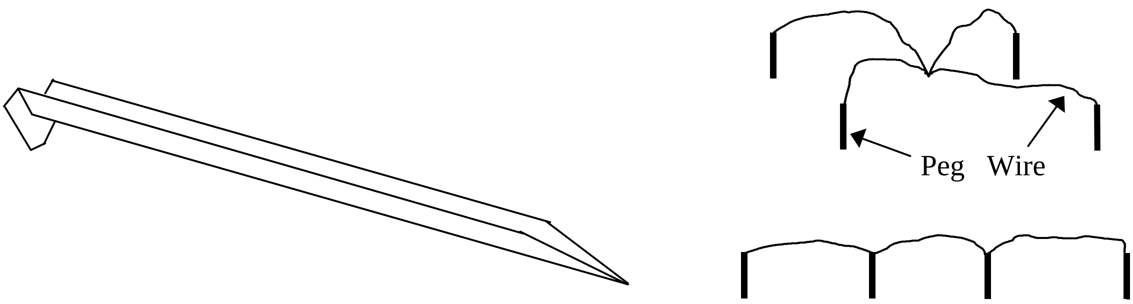


Figure 0. Left: Bulldog-type tent peg. Top right: spider connection. Bottom right: daisy-chain connection

Electric fence tape. This is a plastic woven tape about 2cm across with conductive wires woven into it. This is easier to handle than the older, circular-section electric fence wire. One end of the tape must be fashioned to make connection with the end of the wire. One possibility is to crimp a piece of metal round it for a crocodile clip to clamp onto. Another is to attach a 4mm socket for a plug to plug into.

Wooden cable tidies. These can be made out of thin board as shown in the diagram below. The design with a single nick in each end takes the wire alone; that with two nicks also takes the fence tape. Two such formers should be made, one for each wire. Length is important: the shorter they are the faster one has to wind when collecting the wire in, and this can slow down the operation significantly. The greatest length that will fit in the carrying case (e.g. Pelicase) is probably best.

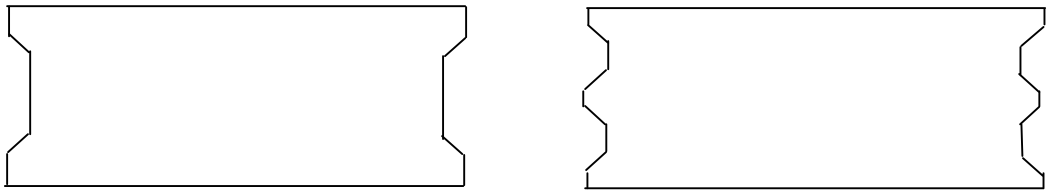


Figure 0. Wooden cable tidies to wind antenna wires on. Left: for wire only. Right: for wire plus fence tape.

3.1.2 Selection considerations

These are presented as a set of questions that each CRO should answer, with considerations listed.

- Should every transceiver have both pegs and fence tape? In favour: all transceiver kits are identical; it is impossible to take the wrong kit underground. Against: extra bulk to carry (the extra weight is probably negligible).
- Should the wires have a 4mm plug at each end or a crocodile clip at the outer end? In favour of 4mm: the wire cannot be unreeled the wrong way round, delaying setting up the transceiver. In favour of croc clips: they can attach to anything, even if connectors have fallen off; they make terminating the fence tape easier. See also the comment (below) on tying the wire to the cable tidy.
- Should the wiring of the peg spiders be permanent (soldered) or put together in the field (short leads with a croc clip at each end)? In favour of croc clips: ease of construction and repair (these leads can be bought ready-made); interconnection geometry is unrestricted. Against croc clips: some pegs and leads can get forgotten or borrowed. (CREG experience is that this happens regularly!)
- Number of pegs per spider. The more there are, the better the earth and the better the communication. There will be a number beyond which there is no real improvement. We do not yet have enough experience to give definite recommendations, but four seems the minimum. Wires and pegs **will** get pulled off, so it is wise to have more than are needed so repairs need not be immediate. Six would therefore seem a reasonable number.
- Colour of wire. Surprisingly, this is important. If wire is hard to see, people often catch it as they walk and pull earth connections out. Yellows and greens are good in a cave. On the surface, green is always hard to see; so is yellow when the vegetation is yellowish. I have known brown almost impossible to find on fells, even knowing the route of the wire. Red is good. Unless you are certain which wire will be used upstairs and which wire downstairs, maybe all wires should be of the same colour.
- Length of wire. Longer wire takes longer to install and pack up, but gives better communication, though probably only up to a point. Unfortunately our practical experience and understanding of theory are not yet good enough to give clear recommendations. The current recommendation of 10 metres is merely current practice, not necessarily optimal.

3.1.3 Hints and kinks

- Soldering wire to a tent peg may require a gas gun or gas stove.
- After a while these spiders will start to fall apart. Inspect and re-solder them regularly.
- Croc clips rust, and stainless steel types seem unavailable. They may need replacing a few times per year.
- Get experience of the hardest communication path in your area. Find how many pegs are needed for the surface set and make your spiders with a couple more.

- Tie a loop of cord through the hole in the top of each peg: people will be less likely to pull the pegs out by the wires.
- If this cord is bright (ideally daglo orange?), the pegs will be quicker to find.
- Make a hole in the cable tidy and tie the wire to it a few centimetres from the croc-clip end. This will prevent the following sequence of events:
  1. The wire is reeled out correctly.
  2. The person who placed the distant earth spike returns with the cable tidy.
  3. When the wire is reeled in, the transceiver end (with the plug) is wound onto the cable tidy first. This leaves the croc clip on the outside.
  4. When the wire is next reeled out, the croc clip is left by the transceiver and the plug taken to the far end. This may only be noticed when this person tries to connect the plug to the earth spike.
  5. The entire wire must now be reeled in and re-deployed the right way round, delaying deployment.

3.1.4 Background

This is provided for those who may want to understand why the above advice is given. The antenna current from the transceiver flows out along one wire, into the earth at its outer end, back through the earth to the outer end of the other wire and back along the wire to the transceiver. It might be expected that the current in the earth would take the shortest route between the two earth connections. In fact, it spreads out and takes a wide range of curved paths between the two earth connections; see the Figure below.

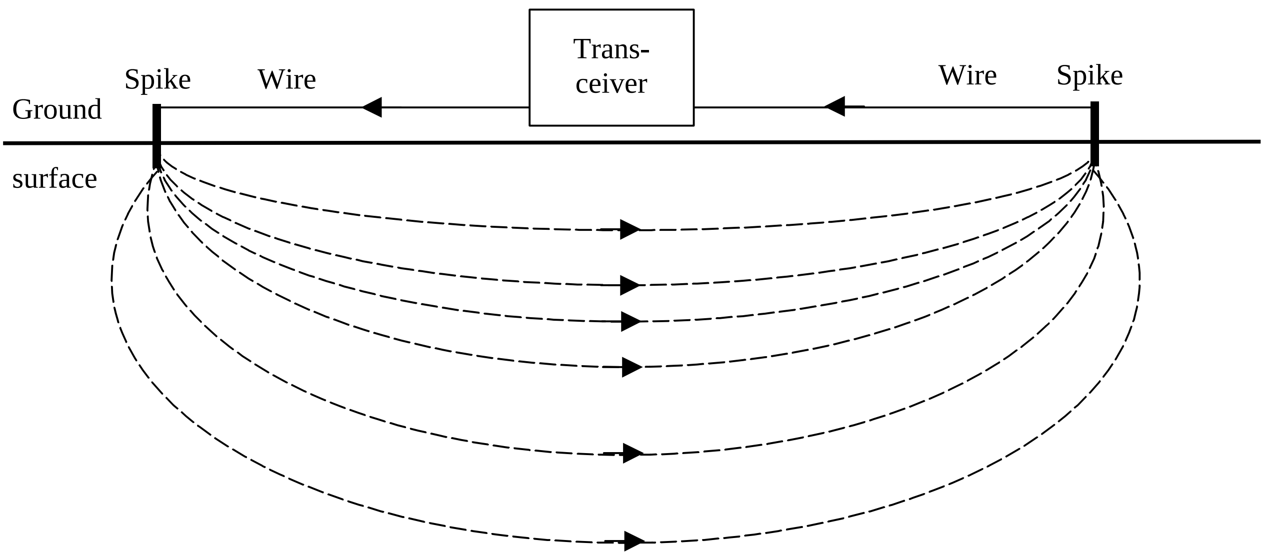


Figure 0 – Current paths in an Earth Loop Antenna. The arrows show the direction of current flow. The dashed lines indicate the spread of the current underground. The paths shown are only an approximation. In reality, the current spreads out deep down into the earth and as high as the surface. This is a 2-dimensional section, and the current also flows above and below the plane of the page.

The antenna operates as a one-turn coil of very large area. The actual effective area is not easy to calculate because portions of the current take different routes, as described above. Nevertheless, the further apart the earth connections are, the larger the effective area.

The longer the wires the better the signal, though there may be a limit; this is not well understood yet. About ten metres per wire is currently thought to be a reasonable figure.

The earth connections warrant care. On the surface, these are metal pegs (typically tent pegs) pushed into the soil. All the current through the earth converges on these earth connections, which can cause problems: these two points can become bottlenecks which limit current and thus communication range.

The important factor is the surface area of the connections which is in contact with the soil: this must be reasonably large. For this reason narrow diameter spikes such as meat skewers are poor: their surface area is small compared with that of (e.g.) copper water pipe. Most tent pegs are like meat skewers and poor. This is why the L-section Bulldog types are recommended: they have a large surface area in contact with the ground but a small cross-section, making them easy to push into the soil.

The resistance in the soil is probably far greater than that in the metal, so there is probably no advantage in copper spikes, even though they are better conductors than steel.

A single tent peg at each end may work for easy communication routes but not for hard ones. There are two approaches to increasing surface area: a longer rod or several short ones. A long rod is normally useless as the soil tends to be shallow. A reasonable arrangement is half a dozen of the L-section tent pegs joined together with wires. It is important that the pegs are separated by a bit more than their length, or their currents interfere with each other. This suggests connecting wires of about half a metre, allowing some room for manoeuvre to avoid stones and hard ground.

3.2 Loop antennas

It is intended to publish a loop antenna design in the CREG Journal; until this appears, these notes are intended as a guide for anyone who may wish to make such a loop. There are four main design considerations: diameter, number of turns, tuning capacitor and physical construction. These will be taken in turn.

3.2.1 Diameter

All other things being equal, the larger the area of the loop, the better the signal transmitted and received. A circle makes best use of the wire length. A large loop is cumbersome in a small passage, however, and it may prove easier to deploy earth antennas. A larger loop also involves more wire and thus more volume to be carried. (Weight is unlikely to be an issue with reasonable antenna sizes.) Most existing loops are about one metre diameter, but this probably owes more to tradition than to actual design thought. Nevertheless, this size has proved a reasonable compromise.

3.2.2 Number of turns

All other things being equal, the larger the number of turns, the better the signal transmitted and received. Once again, however, more turns imply a bulkier antenna to carry. There is no clear optimum and no advice can be given, though most existing designs seem to be from half a dozen to a couple of dozen turns.

3.2.3 Wire thickness

To be written.

3.2.4 Tuning capacitor

The loop antenna needs to be tuned to the operating frequency. (This is not true of the earth antenna.) Note that the equipment uses frequencies from 87 kHz to 89.6 kHz (see *Background theory* above). This is achieved with a suitable capacitor in series or parallel with the coil. The size of capacitor depends on the inductance of the loop. These quantities are related by the equation

$$f = 1 / (2 \pi \sqrt{(L C)})$$

where f is the frequency in Hz, L is the coil inductance in Henries and C is the capacitance in Farads. Remember that f will be about 88.3 kHz, the middle of the band. In practice, there is stray capacitance between turns of wire in the coil, and this contributes to C, so the actual capacitor value needed may not be that given by the equation above. Some experimentation will be needed. Consideration should also be given to the Q (quality) factor of the antenna, which determines its bandwidth. High Q implies narrow bandwidth. With such antennas it is easy to get a Q high enough to reduce the bandwidth below 2.6 kHz, preventing the transceiver from operating over its entire band. The antenna is a resonant circuit and builds up high voltages on the capacitor, far higher than the 12V which powers the equipment. Some designs have developed hundreds of volts and have destroyed normal capacitors, so high quality types may be needed. The capacitors should also be boxed to protect fingers from them. See (Hey, 1998Z) for further information.

3.2.5 Physical construction

The two most common construction techniques for the coil are several turns of stranded wire (e.g. mains cable) and ribbon cable. If all the strands of ribbon cable are used in series to maximise number of turns, their thin wires will limit the current (due to the skin effect, not simply resistance), making an inferior antenna.

Thought should be given to ruggedisation of the design. Ideally, the wires of the loop should be bound together, e.g. in an outer flexible cover. At the least, they should be bound every 10 cm or so. With ribbon cable this bonding is ready-made. All connections should have heavy-duty mechanical strain reliefs: sooner or later someone will snag the loop with their foot, and solder joints are not strong.

The loop can simply be spread out on the ground. It is useful to have a more-or-less rigid structure to support it in a rough loop, however. This enables it to be tilted and turned to different angles to seek the best signal. This can have a radical effect when the surface station is not directly above the cave station.

The antenna should be connected by a metre or two of co-axial cable to a UHF (PL259) plug; see the *Functional Specification* section below. The impedance of this co-ax cable does not matter.

The box for the tuning capacitors may be part-way along the co-ax lead or where it joins the loop. This is a matter of mechanical design convenience.

3.2.6 General comments

The designer would be advised to read (Hey, 1996) and (Hey, 1998Z), listed in the Bibliography below.

It may be possible to use old Molefone loop antennas with some modification, e.g. an adaptor lead. It is intended to investigate this possibility but time has not yet allowed this.

4 Microphone

This is a conventional fist microphone with a PTT (push-to-talk) switch in one side. It has in fact been modified as a speaker/mic as the received audio can be heard through it, though quietly. From past experience they often get destroyed in caving use, so will often need to be replaced. This will involve changing the plug and possibly re-wiring the mic, as described below.

Note that a common fault with such mics is a “stuck PTT switch”, with the PTT stuck on transmit. Dirt such as mud in the mechanism is one possible cause. Symptoms include the transceiver permanently on transmit, with the receiver thus making no sound.

4.1 Choice of type

A wide range of types is available at a wide range of prices. They can often be picked up cheap at sales; since they get destroyed frequently in caving use, it may be worth picking them up when available cheap. Expensive types are not necessarily better, and often appear to be identical products at a higher price. An exception to this is the Motorola.

The traditional type earned the name fist mic as it fills the fist when held. More modern types are far smaller. These are probably ergonomically inferior and harder to operate with cold or gloved hands. They also tend to be electret not dynamic mics (see below). On the other hand, they are available waterproof.

The equipment was designed primarily for use with a dynamic mic insert, which can also be used as a speaker. Many mics nowadays have an electret mic insert and (possibly) a separate dynamic speaker. These are harder to use as the electret needs a power supply, unlike a dynamic insert.

For further details, see the *Dynamic mic* and *Electret mic* sections below.

4.2 Plug and wiring

4.2.1 Plug

The plug is a DIN connector. Note that it is the traditional size, not the newer miniature DIN. See the *Connectors* section of the *Functional Specification* below for sources and type numbers. The socket is 8-pin, but only a 5-pin plug is needed for a straightforward dynamic speaker/mic, although an electret mic would need a 7-pin plug. Plugs with more pins than needed can be used, of course.

Many styles DIN plug are available. It is strongly recommended that only metal-cased types are used for strength. A range of mechanical locking mechanisms is available, such as ring locking, screw locking and XLR-style latches. Only the ring-locking type specified here will mate properly with the transceivers. Note also the warning in the *Connectors* section about a similar but inferior type.

4.2.2 Connections

The full specification is given in the *Connectors* section, but the five pins needed for a dynamic mic are copied here. A diagram of the plug pin-out is also shown, as the numbering scheme owes more to history than to logic!

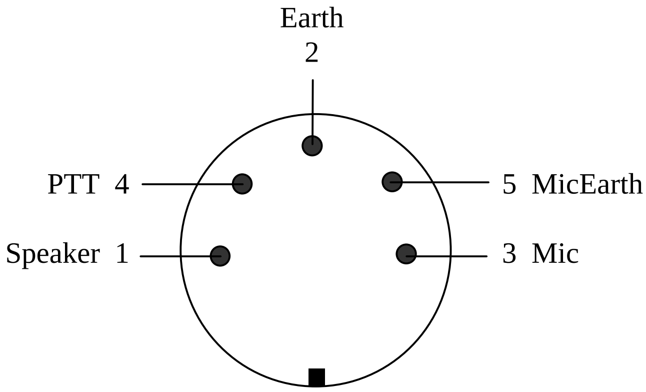


Figure 0 – The five connections needed for a dynamic microphone. This is seen from the back of the plug, as soldered. The numbers are the pin numbers moulded on the plug.

Note that the **MicEarth** pin MUST be connected to the normal **Earth** pin in the plug. The *Connnectors* section explains the need for these separate earth wires.

4.2.3 Ruggedisation

The microphone suffers the slings and arrows of outrageous caving, and it is worth making some effort to increase its lifetime. Remember that if a cheap £5 mic dies on a rescue, the true cost is not £5: it is a rescue party without communications. The following are suggestions to improve matters. Most of them are to avoid straining solder joints.

- Delegate the job of soldering to someone with plenty of experience. Don't solder in a hurry.
- Spend some time cutting the outer cable covering back properly. The length of inner wires protruding should allow a couple of millimetres of slack on each inner wire, so they are not under strain. Too much slack will result in the inner wires being crammed into the plug case tightly enough to wrench them.
- After soldering each wire to its pin of the DIN plug, put some Heat Shrink over the wire and pin. (Obviously, it must be threaded on the wire first.) This provides a mechanical strain relief. If the wire starts to come adrift and strands get loose, the heat shrink also keeps them from adjacent pins. This last point is especially important for the screen of the mic wire with many fine strands.
- After soldering all the pins, make sure the cable grip is properly used. It should grip the overall outer covering of the cable, not the exposed inner wires. Its prongs should be squeezed shut enough to hold the cable firmly, but not enough to damage the wires inside.
- To allow the slack in the inner wires to be taken up without strain, try rotating the outer cable slightly (perhaps a half turn) relative to the pins, so the inner wires follow helices. This has to be planned before the cable grip is squeezed shut.

4.3 Dynamic mics

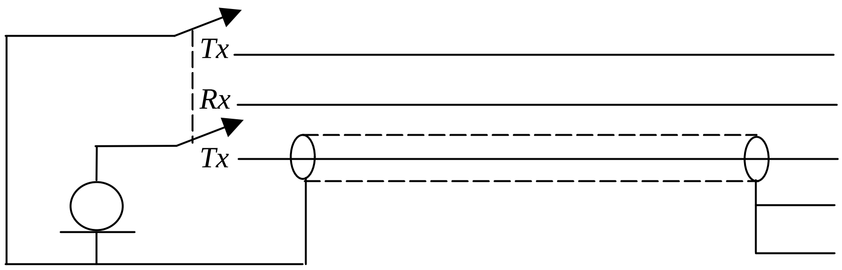
4.3.1 Suitable types

The mic must have at least

- One screened wire in the cable
- Two other wires in the cable (need not be screened)
- A switch with one change-over contact and a second which is normally open or change-over.

4.3.2 (Re-)wiring

The mic should be wired according to the Figure in this section. The mic body must be opened up to check what the connections as supplied are. Note that the mic audio must be screened, and that in the plug this screen must be connected to both **Earth** and **MicEarth**.



Pin	*Signal*
4	PTT
1	Speaker
3	Mic
2	Earth
5	MicEarth

Figure 0 – Wiring of a dynamic speaker/mic.

While the mic body is open the quality of existing solder joints should be checked, especially with a second-hand mic. It might be worth re-wiring all and using heat shrink for reliability.

4.4 Electret mics

No such mics have yet been used with the HeyPhone, though they should be compatible.

4.4.1 Suitable types

To be written.

4.4.2 (Re-)wiring

To be written.

4.5 Molefone compatibility

The plug is identical to that used by the Molefone mic but the wiring is different. Old Molefone mics could easily be re-wired as HeyPhone mics; the changes should be purely within the plug. This is described in CREG Journal 48.

Given such mechanical compatibility but electrical incompatibility, it is important to analyse the effects of plugging the wrong mic into the wrong set.

4.5.1 Plugging a Molefone mic into a HeyPhone

The transceiver will receive but it will be impossible to make it transmit. Only if the PTT is pressed will any received audio be heard from the mic.

No damage will result to either transceiver or mic.

4.5.2 Plugging a HeyPhone mic into a Molefone

This analysis must be regarded as provisional until more reverse-engineering of the Molefone has taken place.

The transceiver will be transmitting all the time the mic is plugged in, regardless of the PTT. Only if the PTT is kept released will the transceiver transmit any sound.

As far as is known, no damage will result to either radio or mic.

Because the Molefone antenna socket is the same as the mic socket, the effects of plugging a HeyPhone mic into a Molefone antenna socket need to be considered. There will probably be no effects if the mic socket is empty or has an antenna plugged into it. If a HeyPhone mic is plugged into the antenna socket, a Molefone mic is plugged into the mic socket and both PTTs are pressed simultaneously, there might be damage to the transmitter. Would the insurers believe you?

4.6 Raynet CAIRO compatibility

Raynet (Radio Amateurs' Emergency Network) use a microphone standard called CAIRO. It is possible that a CRO and Raynet might operate next to each other on a large incident; indeed, this happened at Lockerbie (UWFRA, 1998, p.116). Since CAIRO uses the same plugs and sockets as the HeyPhone, it would be possible for mics to get swapped, either accidentally or to help the other party. It is therefore important to analyse compatibility. The analysis here covers all 8 pins, not just the 5 needed for mics.

The two systems are almost entirely compatible. (The HeyPhone standard was designed to avoid any dangerous incompatibility.) Any normal dynamic mic from either system should work fully on a transceiver of the other system. Most other equipment which plugs into the mic socket should be equally compatible. The few potential incompatibilities are listed below.

- HeyPhone add-on equipment which operates the PTT line with a transistor may not operate all CAIRO equipment properly. (Some CAIRO equipment needs a PTT voltage less than 0.5 V to transmit; the HeyPhone standard was specified to avoid this problem.)
- The **PowerOut** line (pin 7) is defined as "+8V, at least 700mA" for the HeyPhone but "about 12V" for CAIRO.
- Pin 6 is **Expansion** in the HeyPhone but Secondary Audio for CAIRO. (No current HeyPhones use this signal anyway.)
- The **SigRx** line (pin 8) has different voltage definitions in the two systems. (No current HeyPhones generate this signal anyway.)

It seems highly unlikely that any damage to transceiver or add-on unit would result from any such incompatibility.

5 Power supplies

The transceiver has no internal batteries; all power is supplied through a connector on the front panel. Different CROs have different preferences for batteries and different choices as to the number and size of spare batteries to be carried. They will therefore wish to build different styles of power supply, and the following are serving suggestions. Supplies will probably fall into three groups, however: rechargeable batteries, non-rechargeable batteries and leads to run the set from a car battery.

The type and connections of the connector are defined in the Power Inlet section of the *Functional Specification*. A short lead can have one of these connectors soldered on one end and be connected to the battery at the other. It is advisable for the positive and negative wires to be fastened side by side, as separate wires form a loop which can hook over things. Suitable wires are figure-of-eight (where the two wires are welded together) and mains cable (where they are enclosed in an outer, protective sheath). It is sensible to use a colour coding that others will expect, such as

Positive:	red	or	brown
Negative:	black	or	blue

The wire should be rated for a current of at least 0.5 Amp, though heavier duty cable will probably be chosen for ruggedness.

It is highly desirable for the battery terminals to be fully covered, not exposed, for two reasons. (1) Exposed terminals can be shorted out if something conductive such as a tent peg or electric fence tape is dropped on them or packed next to them in the box. (2) Many types of rechargeable battery have spade terminals. If exposed, the spade connectors can be dislodged and may be re-connected the wrong way round. The transceiver is internally protected against such reverse polarity, but will not work; if the mis-connection is not noticed, the communication link will fail. At the very least, insulating tape should be bound over exposed terminals, insulating them and holding any connectors on. Better still, the battery should be built into a box. The problem here is that boxes may not be available in the right sizes, and the next size up may waste much space.

The following comments are specific to certain types of battery.

- **Non-rechargeable batteries** (primary cells). All the useful batteries of this sort are cylindrical and produce 1.5V nominal. They will have to be accommodated in battery holders taking a total of 8 batteries. Suitable battery holders can be obtained from standard suppliers such as Farnell, Maplin and RS (a.k.a. Electromail). Care should be taken when soldering to these holders, as the plastic often melts easily. Some are designed to take push-on PP3 connectors, but it is probably better to solder to these to avoid unreliability (1) through connectors falling off and (2) as these connectors often fail.

The common useful sizes of such batteries are listed below. The nominal capacities are given for the Manganese-Alkaline forms made by Duracell. These figures only give an approximate idea of performance, for four reasons. (1) Battery technology improves; these are 1995 figures. (2) Battery lifetime depends strongly on the pattern of use (how long at how many Amps; how long resting). (3) The voltage decays gradually, so any such figure assumes an end-point voltage; here this is 0.9V, whereas the HeyPhone requires 1.125V. (4) These figures are for a temperature of 20^{o}C. For 4^{o}C, capacity will probably be between 40% and 80% of the 20^{o}C figures.

Cell type	D	C	AA
Capacity (Amp-hours)	18	7.75	2.7

(Source – Duracell technical leaflets.)

A problem with most primary cells, including Manganese Alkaline, is that the voltage falls gradually as they are discharged. With rechargeable cells it tends to hold up better until the last moment, when it falls fast. This means that primary cells fall below the required voltage relatively early in their lifetimes. Duracell figures suggest that the HeyPhone can only use about 2/3 of the rated Amp-hour capacity.

- **Cylindrical rechargeable batteries** (secondary cells). These are designed to fit into equipment in lieu of primary cells and are sold in the same sizes (e.g. D, C and AA cells). There are two slightly different styles. Those without solder tags are identical to primary cells and can be fitted into the same battery holders. Those with solder tags do not need such holders but can be wired together permanently. The former can suffer from bad contacts, especially if they get wet and suffer corrosion, and are probably less reliable. These types are available with NiCd, NiMH and Li-ion chemistry (see below).
- **Rectangular rechargeable batteries** (secondary cells). Most of these are of Lead-Acid chemistry (see below). Most have spade terminals; the use of coloured spade connectors (red +, black –) is highly recommended. Batteries of 12 V are available in capacities ranging from 1.2 Amp-hour up to sizes which could not realistically be carried. Yuasa and Sonnenschein are makes with good reputations. They are available from standard sources such as Farnell, Maplin, RS (a.k.a. Electromail) and shops selling burglar alarm equipment.

There are further considerations which apply to rechargeable cells.

- **Chemistry** by which the battery functions. There are many, of which four are currently relevant:

Name:	Lead-Acid	Nickel Cadmium	Nickel Metal Hydride	Lithium Ion
Abbreviation:		NiCd	NiMH	Li-ion
How recent:	Oldest	→	→	Newest
Weight:	Heaviest	→	→	Lightest
Price:	Cheapest:	→	→	Dearest
Other comments:		Some memory effect	Slight memory effect	

(By 'weight' is meant weight per unit Amp-hour capacity.) By and large, the better batteries are further to the right. Lead-Acid are still a reasonable solution where large capacity is needed and weight can be afforded; they can also be float-charged without ill effect. NiCd should now be regarded as obsolete. NiMH are a good solution where weight is important, until Li-ion come down in price. Li-ion are still very expensive (written in 2001) but are probably the future (Bedford, 1996Y) (Gibson, 1995). They may never be available off the shelf, however, as without proper chargers they can burn or explode.

If different batteries are used above and below, a reasonable choice might be Lead-Acid for the surface and NiMH underground. (Remember that the surface may maintain a listening watch during the entire operation, which the cave party will not.) From personal experience, adding a 6 Amp-hour lead-acid battery to a rucksack is noticeable but does not slow one down much.

- **Battery chargers**. Lead-acid batteries are easy to charge. A normal car battery charger will do for overnight charging, though not for float-charging where the battery is charged continuously. For better chargers see (Hey, 1998Y). The other three types need special chargers. These can be bought from the standard sources such as Farnell, Maplin and RS (a.k.a. Electromail). For techniques and circuits, see (Bedford, 1996Z) (Gibson, 1992) (Horowitz & Hill, 1989, pp.926-928) (Whitaker, 1996, chap 70).

The easy and obvious way to charge lead-acid types is to fasten the crocodile clips of a normal battery charger onto the spade terminals. If they are connected the wrong way round, the battery will be destroyed. Moreover, people doing this will tend to remove the spade connectors, leaving the possibility of re-connecting them the wrong way round after charging. A better approach would be to have a charger with a connector that took the power inlet connector, so the unopened battery pack could be plugged in. Such a connector would have ‘live’ pins, so it should be short-circuit proof.

For more information on the various battery types and their characteristics, see (Bedford, 1998) (Horowitz & Hill, 1989, p.920 *et seq*) (Whitaker, 1996, chap 70)

6 Add-on equipment

To be written.

Appendix A. Glossary

Bandwidth – Although you think of tuning a radio to one particular frequency, the signal from the transmitter actually spreads across a range of frequencies around the one you tune to. The width covered is the Bandwidth. For instance, the HeyPhone has a bandwidth of about 2.6 kHz, starting at its stated frequency of 87 kHz, so it occupies the range 87 kHz to 89.6 kHz. The form of ☞ Modulation used determines the bandwidth. Transmitting licences often specify a maximum bandwidth.

Beacon – A continuous transmission from a transmitter, normally of an audible tone or a repeating beep. This can be useful to enable the other end to adjust equipment position and antenna orientation for the best reception.

Bottom Box – The main part of the HeyPhone case containing the ☞ RF Engine. The ☞ Top Box is fastened on top of it.

Confidence Beep – A facility where every transceiver, when it is on Receive, automatically goes over to Transmit every so often and sends a brief beep. The HeyPhone pattern is a one-third second beep every thirty seconds. This gives the operators the confidence that they can still hear the other station.

Cross-Band Repeater – See Talk-Through Box.

Earth Antennas – An alternative to the traditional loop antenna. Two insulated wires are run out in opposite directions from the transceiver. Their ends are connected to the ground, typically by half a dozen tent pegs driven into the soil. The antenna current from the transmitter flows out along one wire, into the ground, through the ground to the far end of the other wire and back to the transceiver. This provides a loop antenna with one very large turn (though the electrical behaviour is actually very complex). Wire lengths above ground tend to be ten metres or so. Below ground they depend on how difficult the passage is. In both cases, the longer the better. Earth Antennas can be used both for transmitting and receiving. Communication with Loops at one end and Earth Antennas at the other is perfectly possible. Earth Antennas give better performance (more range and/or less noise) that Loops. The technique has been known of for a long time, but seems to have been applied to caving only since about 1995.

Full Duplex – A communication method where both ends can talk to each other at the same time. An example is the telephone. Different from ☞ Half Duplex.

Half Duplex – A communication method where both ends can talk to each other, but not at the same time. They must take turns, possibly saying "Over" as they do so. Examples are the walkie-talkie and the HeyPhone. Different from ☞ Full Duplex.

Note that there are two conflicting usages of such terms. What we here term Full Duplex is sometimes called Duplex; what we term Half Duplex if sometimes called Simplex (which has two meanings). The terms used in this document are unambiguous.

Intrusion Protection (IP) – A specification of how dustproof and waterproof a case is. IP67 is proof against dust and brief immersion in water, IP68 against continuous immersion. Higher numbers are better. For more details, see Appendix D and CREG Journal, Issue 11, pp. 7-10, Mar 1993.

IP – See Intrusion Protection.

Low Frequencies (LF) – The range of frequencies from 30 kHz (with a wavelength of 1000 metres) to 300 kHz (with a wavelength of 100 metres). The HeyPhone and the Molefone operate at 87 kHz, which is in the LF band.

Modulation – A way of putting some useful information 'on top of' a radio signal. The information is something such as speech, text or images. Two of the most common forms of modulation are Frequency Modulation (FM) and ☞ Single Side-Band.

RF Engine – The transceiver module which is the heart of the transceiver. It is the most expensive part and is protected in the ☞ Bottom Box of the case.

Rx – An abbreviation for Receive, Receiving or Receiver.

Second Generation – The generation of cave communication systems of which the HeyPhone and Grenoble’s Système Nicola are examples. The First Generation were equipment such as the Molefone and Ogofone. The Second Generation use the same basic technology (SSB speech) but are re-engineered with the materials and techniques available in the late 1990s. The Third Generation is still at the pipe-dream stage but may involve such techniques as digital transmission, adaptive forward error correction and possibly store-and-forward.

Single Side-Band (SSB) – A form of ☞ Modulation where the strength of the transmitted signal is varied to represent the signal coming from the microphone. In particular, the ☞ Bandwidth of the signal is no more than that of the audio signal from the microphone. For speech quality, this is normally 3.5 kHz or less. (NB– the VHF walkie-talkies used by most CROs do not use SSB, but another form of modulation called FM.)

Talk-Through Box – Properly known as a Cross-Band Repeater. A piece of equipment which can ‘copy’ signals from one band (e.g. LF) to another (e.g. VHF). It normally works in both directions, though only one at once. It comprises a transceiver for each band with the speaker output of each connected to the microphone input of the other. Extra circuitry makes each transceiver transmit only when a signal is received on the other, i.e. when there is some traffic in that direction. It never makes both transmit at once. It can therefore be in one of three states: (1) repeating LF signals on VHF, (2) repeating VHF signals on LF or (3) doing neither but waiting for a signal. Some CROs have expressed interest in LF/VHF talk-through boxes. They are not available yet, for reasons of development time and licensing considerations.

Top Box – The small top part of the case, fastened on top of the ☞ Bottom Box, and containing the cheaper and more vulnerable components: controls, sockets and a few others.

Tx – An abbreviation for Transmit, Transmitting or Transmitter.

Appendix B. Bibliography

Much yet to be added.

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Appendix C. Functional Specification

This section formally defines certain characteristics of the equipment. These are characteristics which describe how the equipment appears to the outside world, such as the voltage on a certain socket. The specification says nothing about how the internal circuitry or mechanical design fulfils the requirements. There are two reasons for writing such formal specifications:

- To require that the equipment produced is up to certain standards, for example degree of waterproofing.
- To ensure that builders of replacement or new equipment know what they can expect, for instance where the microphone is connected and what voltage it must produce.

Equipment which does not meet the specification my not work or, worse, may work on the workbench but not in the field.

This specification was produced after much discussion, and all the CROs in the British Isles were consulted before it was finalised.

There will be two main users of this section. Most commonly, people making a replacement microphone, battery connector or antenna will need to know what connector to buy and which pin to use for what. These people will just need the subsections titled *Connector – Outline* and *Signals* of the relevant sections. Less commonly, anyone designing and building new add-on equipment, or even a new transceiver, will need all the gory detail.

Conventional specifications just state the requirements, assuming everyone will accept that "orders is orders" and obey them. Here, *Reasoning* often explains what might otherwise appear an arbitrary and bureaucratic decision. In some cases, circuits are also suggested to meet the requirements.

6.1 Mechanical requirements

6.1.1 Waterproofing

As far as possible, the transceiver should be waterproof to ☞ IP68 to a depth of 1 metre. In practice this may be impossible to achieve, which is why it is merely stated as desirable. Below this standard, any improvement in waterproofing is worthwhile as it slows the ingress of water.

6.1.2 Ruggedness

Switches may not be toggle switches. Experience has shown these to be very vulnerable to damage; they are also easy to knock accidentally. Push-on/push-off push-buttons are unacceptable for the same reasons. Temporary contact push buttons are acceptable (e.g. to operate a beacon). Rotary switches are acceptable, but must have metal shafts of about ¼" (≈6mm) diameter; plastic and narrow shafts are weak.

Potentiometers (e.g. for the volume control) must be of rotary types; linear types (slide faders) are weak and would allow water ingress. They must have metal shafts of about ¼" (≈6mm) diameter. *Note – these proved too expensive for the HeyPhone Mark 1, so a rotary switch was used.*

Controls with no moving parts (e.g. capacitive sensing of a finger) would be preferred to all the above.

6.2 Panel controls and indicators

Controls:

6.2.1 On/Off/Volume

6.2.1.1 Specification

The On/Off and Volume controls shall be combined into a single rotary control. *Reasoning: ergonomic – normal in domestic equipment, more obvious to those without training.*

The On/Off switch shall operate at the anticlockwise end of the travel. Types which pull or push to turn them on are not acceptable. *Reasoning: too easy to knock accidentally.*

This Volume control shall control both the volume of the internal speaker and the signal level on the Speaker pin of the Microphone socket.

At the lowest-volume position, the volume shall still be adequate to hear the other end calling. (For a potentiometer, his requires a resistor between the bottom end and earth.)

A potentiometer is preferred, but a rotary switch may be used. If a potentiometer is used, it must be logarithmic (sometimes termed A-law or A taper).

6.2.2 Privacy (internal speaker mute)

6.2.2.1 Specification

This shall be a rotary switch which can silence the internal speaker, but not the Speaker pin on the Microphone connector.

If the internal speaker is not fitted, the switch must not be fitted either.

This switch may be part of a multi-function switch. *Note – in the HeyPhone Mark 1, this is part of the Mode switch SW2.*

6.2.2.2 Reasoning

This switch is essential to provide privacy when members of the press or general public are near the surface transceiver.

The switch is rotary since toggle switches have been found very vulnerable to damage.

If no speaker is fitted, a control for it would be confusing to operators with little or no training on the equipment.

6.2.3 Beacon

6.2.3.1 Specification

This shall turn the beacon on and off.

Provided the transceiver On/Off switch is turned on, only this switch need be pressed: it shall not be necessary to press the push-to-talk switch as well.

This switch may be part of a multi-function switch. *Note – in the HeyPhone Mark 1, this is part of the Mode switch SW2.*

This switch should preferably be a push button. When pressed, the Beacon shall operate; it shall stop when the button is released. *Note – in the HeyPhone Mark 1, space precluded this.*

It would be advantageous for this switch also to disconnect the microphone so that background sounds such as noisy water are not transmitted.

See also the specification of the Beacon signal itself in the Sundry Facilities section of this document.

6.2.3.2 Reasoning

It is essential that this switch cannot be accidentally left on. Such mistakes would block all communication. They would prevent the offending set from receiving (which means that they can't be told to switch it off), and they would block the channel for all users.

Indicators:

6.2.4 Power on

6.2.4.1 Specification

This shall be a yellow LED (light emitting diode) in a protective bezel. Ideally the bezel will be as near flush as possible and dark coloured.

6.2.4.2 Reasoning

Yellow is specified as these types tend to be brighter for a given current. Flush types will minimise damage from sideways impacts. Dark surrounds will maximise contrast above ground.

6.3 Connectors and their signals

This section defines the signals passing between the transceiver and its electrical attachments (e.g. battery, microphone, antenna). It specifies the signals, their electrical characteristics, the connector types and the connector pins on which they appear. Designers of this equipment will need to know these details. CROs using the equipment will not normally be interested, though when they make up replacement microphones or headphone sets, for instance, they will need to know a little of this.

The term Signal Characteristics means any characteristics of the signal (and sometimes the circuitry), but not of the connectors. It includes voltages, currents, impedances, rise times and fall times.

6.3.1 Power Inlet

This conveys all power into the transceiver.

6.3.1.1 Connector - Outline

This shall be a 3-pole connector of a type sometimes known as an audio or microphone connector; there seems to be no correct term. (Four-pole versions are commonly used as microphone connectors on CB transceivers.) Unlike most connectors, it has panel-mounting males (plugs) and line-mounting females (sockets).

Panel-mounting	Male	for Transceiver	Maplins type	FM51F
Line-mounting	Female	for Battery	Maplins type	FK23A

Looking at the back of the socket with the polarising lug at the top: Pin 1 is on the right, Pin 2 at the bottom and Pin 3 on the left. For the plug back, of course, this is reversed.

See also the subsection ‘Note on waterproofing connectors’, below.

6.3.1.2 Signals

Pin 1 +12V	Pin 2 Unused	Pin 3 Earth

The unused pin may not be used. **Warning**: it may be tempting to use it to connect the Idiot Diode D8/9. [**CHK with Mike B – not sure which :-)] This would sidestep the protection: were the line connector rotated 1/3 turn clockwise and plugged in, power would be applied backwards to the transceiver.

The unused pin is reserved for future expansion.

6.3.1.3 Connector - Reasoning

The advantages of this connector are that

1. It has no bare pins on the line connector, being a line female. This is essential for a power in-feed, as such pins would easily be shorted out.
2. It is visually different from the other sockets and impossible to plug into them.
3. It is reasonably rugged.
4. There is a good cable clamp on the line connector.
5. It can be waterproofed.

The disadvantage is the fine thread on the locking ring, which will probably clog with mud. It was thought likely that this ring would rarely be screwed up, so this matters less.

In the absence of any better affordable alternative, this connector was chosen as the best compromise.

It has been found that connectors of this type, if worn or badly made, can be connected up the wrong way round despite the polarising lug. Thus a 3-pin connector is used: any such mis-connection will leave one of the two power wires disconnected. This does not actually provide any protection beyond that provided by the Idiot Diode. **Warning**: it still leaves a potential hazard. If

(a) the line connector is rotated 1/3 turn clockwise and plugged in, and

(b) the power is from a supply with an external earth to the negative line (such as a vehicle) and

(c) something connected to the transceiver has external earthed metal (such as a metal-boxed add-on plugged into the Microphone socket) and

(d) this metal touches the supply earth (e.g. by being put down on vehicle metalwork),

then the supply will be shorted out. (This hazard would exist with 2-pin connectors too.)

6.3.2 Loop Antenna

6.3.2.1 Connector

This shall be a UHF connector. Type numbers: PL259 plug, SO239 socket (note different number as well as letters). The socket shall be on the transceiver. These are easily available in many brands from all the normal suppliers (e.g. Farnell, RS, Maplin).

The socket shall not be the single-hole mounting type, but the type with a square flange having four mounting holes. (*Reason – these are more resistant to a sideways impact.*) These holes are in a square of side 18.2mm, i.e. 18.2mm fixing centres. They are 3.2mm diameter and take M3 bolts. (These seem to be the only flanged UHF sockets sold.)

See also the subsection ‘Note on waterproofing connectors’, below.

6.3.2.2 Signals

The outer connector shall be earth.

No specification is made as to impedance. *Reason – The normal reasons for doing so do not apply at LF, where all lengths are a tiny fraction of a wavelength and standing waves are not a problem. This applies both to co-ax cable and to connectors. UHF connectors have no specified impedance anyway.*

6.3.3 Earth Antenna

6.3.3.1 Connector

There shall be two identical 4mm single-pole sockets on the transceiver. The plugs are 4mm single-pole types, sometimes called Banana Plugs.

They shall be as flush as possible to minimise the likelihood of sideways impact damage. (This is why binding pillars were not chosen. If the plugs have been lost, the wire ends can be stripped with the teeth and stuffed in the sockets.)

The sockets shall be of the same colour, but no specification is made as to that colour. *Reason – different colours might make operators worry about polarity.*

See also the subsection ‘Note on waterproofing connectors’, below.

6.3.3.2 Signals

The signal shall be balanced and floating: there shall be no path to earth from either socket. It shall not matter which plug goes into which socket.

Impedance – **JohnH** – is there any spec. on this?

6.3.4 Speaker / Microphone

Despite its name, the Microphone Connector carries non-microphone signals as well. These are intended to provide for as much future expansion as is economically possible. The number of signals is limited by the pins available in reasonably priced connectors.

The standard has been set so that the normal cheap(ish) 600Ω dynamic microphones as used with Molefones will work.

6.3.4.1 Connector

This is an eight-pin twist-lock DIN connector. There is one centre pin with seven in a circle around it. Many attachments such as microphones only need the five pins provided by 5-pin DIN connectors; cheaper plugs may be used for these. (Note that these must be 180^{o} types, meaning that the five pins subtend 180^{o} as seen from the centre of their circle. There are also 240^{o} 5-pin types.) The sockets must always be the 8-pin types shown below, as they sometimes have to take 8-pin plugs. The type number given below should be adhered to, as there are other closely similar 8-pin DIN connectors with the centre pin in a slightly different place; these will not work. The mic (i.e. line) connector is Male.

They are made by Preh and sold by Farnell and CPC. Unfortunately, RS and Maplins do not stock them (these notes written in 2001). The type number are as follows.

	Preh	Farnell	CPC
Line 8-pin plug (for full attachments)	71430-080	437-232	CN00753
Line 5-pin plug (for Speaker/Mic)	71430-050	308-894	CN00750
Panel socket (for Transceiver)	71206-080	437-293	CN00765
Line socket (for extension leads)	71506-080	437-268	CN00759

See also the subsection ‘Note on waterproofing connectors’, below. Note that the gaps between the pins and the surrounding plastic are large in these connectors. Thin, runny sealant would run through them and cover the contact areas, rendering the socket inoperable. It is essential to use thick, a viscous sealant.

6.3.4.2 Signals – Outline

Name	Use	Direction Note 1	Imp’ce Note 2	Signal characterstics Note 3	Pin no
Earth	Common for all except Mic	N/A	E	N/A	2
MicEarth	Common for Mic only	I/P	E	N/A	5
Mic	Transmitter audio input	I/P	E	Quality: 1mV to 1V Safe: 0 to 12V	3
Speaker	Receiver audio output	O/P	E	Min. 0.4V pk-pk at 300Hz into 600Ω load. Output impedance 600Ω max	1
PTT	Push-to-Talk	I/P	E	Tx: 1V or less, 0.25 to 1mA drawn Rx: 8V or more	4
PowerOut	Power supply to attached equip	O/P	D	+8V to +10V 700 to 1200mA	7
SigRx	Indication that receiver is picking up an incoming transmission	O/P	D	Off: 0V to 0.6V On: 3.5V to 9V source impedance < 5kΩ current 0.1mA max.	8
Expansion	Reserved for expansion	I/O	L	N/A	6

Note 1: Direction: I/P means into the transceiver and O/P out of it. I/O means bidirectional.
Note 2: Importance: E = essential: must be implemented in all systems.

D = desireable: should be implemented where practical.
L = later: should not be implemented yet.

Note 3: Signal characteristics: These should be read in conjunction with the following Details and Reasoning subsection.

6.3.4.3 Signals – Details

These assume that the transceiver's internal supply may be anywhere in the range of 10V (flattish 12V battery minus safety margin) to about 16V (car battery charging).

In addition to the details below, there is a requirement which would be highly desirable. No damage to the transceiver should result if any pin is connected to any other pin or combination of pins via any impedance (including short-circuit); nor shall any damage result if any pin is connected to any DC supply in the range –18 to +18V. It may be impractical to achieve this, but it should be observed where possible. Similar conditions are placed on some of the individual pins: these are mandatory.

6.3.4.3.1 Earth

This is the common, zero-voltage point (also called ground). Metal cases will normally be connected to it. With a non-metallic case, the metal shell of the socket must be connected to it. With DIN connectors it is traditional to use pin 2 (the middle one at the top) for Earth.

6.3.4.3.2 MicEarth

Good practice dictates that weak signals (e.g. mic) share no current path with strong ones (e.g. speaker). This includes the earth return, and dictates a separate earth line.

6.3.4.3.3 Mic

Voltage levels from mics are hard to measure without expensive equipment. The specs given here are for the average level as judged by eye on an oscilloscope, while talking quietly (but not whispering). Any decent transmitter will have an ALC (automatic level control) which will be forgiving of a range of voltages. The likely signal sources are:

Normal dynamic mics (e.g. Molefone types)	1mV
Electret mics (becoming common)	~100mV?
Other equipment	Widely variable, normally < 1V

The specifications tabulated above stipulate that the transceiver input circuitry can withstand anything up to the 'Safe' voltage without damage, and that anything within the 'Quality' range will produce an acceptable speech-quality transmission.

Good practice dictates that weak signals (e.g. mic) are physically as far as possible from strong AC signals (e.g. speaker, general earth). They should preferably be adjacent to their own return line (here MicEarth). They can usefully be screened slightly by being surrounded with other pins that carry no AC signal (e.g. PowerOut, PTT). This affects the choice of pinout.

6.3.4.3.4 Speaker

A convenient name, but the signal may not be strong enough to drive a normal loudspeaker at any useful volume. It is intended to produce a reasonable level from a dynamic mic; for more volume, an additional amplifier may have to be used.

By 'Min' in the output voltage spec. is meant that it must produce this level when the receiver's volume control is at the quietest position.

The receiver's audio output amplifier must not be damaged by any load impedance (including open– and short–circuit) between it and earth.

6.3.4.3.5 PTT

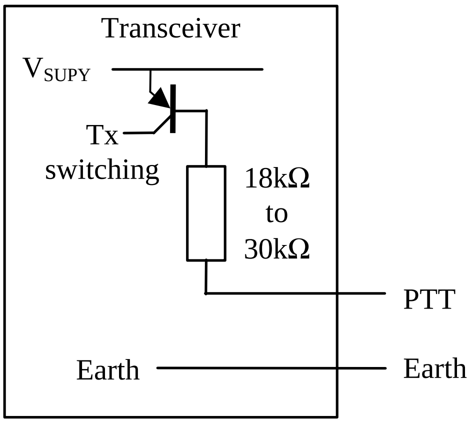
This causes the transceiver to transmit. When the transceiver is turned on but not in the transmitting state, it shall be in the receiving state.

The line is taken low (i.e. connected to Earth) to transmit. The normal arrangement will be to short the line to earth with a switch (as in a mic) or a transistor (as in a ☞ Talk-Through Box).

To transmit (Tx), the external equipment (e.g. microphone or talk-through box) must pull the voltage below the lower specified voltage and draw at least the lower specified current. The transceiver design (discussed below) must ensure that these two requirements do not clash. The external equipment will not be required to draw more than the maximum stated current. In practice, a switch or transistor turned fully on and arranged to draw the larger current will suffice.

Reason: The specification implies a relatively low impedance to minimise the effects of partial short-circuits which might be caused by slightly conductive cave water wetting the connector. The Tx voltage level is chosen so that transistors (which typically drop $Vce_{SAT} \approx 0.5V$ when turned on) can be used for switching. Some systems with sloppier specifications cannot be switched with transistors.

One possible arrangement inside the transceiver is to connect the PTT pin to the positive supply line with a resistor in the range 18kΩ to 30kΩ; either the pin voltage or the resistor current may be sensed. A possible current sensing arrangement is shown in the diagram on the right. For voltage detection, the top of the resistor can be taken directly to V_{SUPY} and the PTT pin measured with a threshold anywhere between the Tx and Rx voltages tabulated above. With power supply voltages V_{SUPY} in the range 10V to 18V, the current will be in the stated range.



The maximum current drawn from the transceiver's power supply is about 1mA, only taken when transmitting. This will be small compared with the current taken by the transmitter; it will have negligible effect on battery lifetime.

This signal is defined for ☞ Half Duplex systems, which includes all current ones. No specification is made of its meaning should ☞ Full Duplex systems be used.

6.3.4.3.6 PowerOut

This is intended to supply attached equipment such as small audio amplifiers and the switching circuitry of ☞ Talk-Through Boxes. It is not intended to supply large amounts of power, e.g. for PAs or VHF radios in talk-through boxes.

At least the stated minimum current must be available. It must be impossible to exceed the stated maximum by applying a load of any impedance. The transceiver must not be damaged by the application of a load of any impedance, including short-circuit. These conditions can be met easily with a single-chip regulator such as a 7809 (which will work with internal supplies between about 10V and 30V). These are available in 750mA and 1A types; the stated current limits allow these with a small margin for error. The stated voltage limits allow other types (e.g. 7808, 7810, even with +10V supply) should these be preferred.

The stated figures imply that 5.5W can be relied upon.

Power must never be fed into the transceiver through this connector.

Operators should be aware of the extra battery drain imposed by any such equipment.

6.3.4.3.7 SigRx

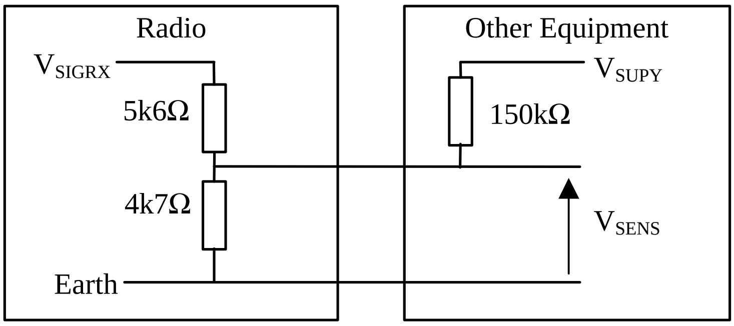
This is a binary signal to indicate whether 'the other end is speaking', i.e. whether an incoming signal is being received. It will have several uses, including in ☞ Talk-Through Boxes. If a signal is being received, the transceiver must provide a voltage in the range labelled On; otherwise, in the Off range. The transceiver must provide this signal with a source impedance no higher than that stated, whether SigRx is On or Off.. Equipment connected to the transceiver may not take more than the stated maximum current from this pin.

Note – this specification should be extended to stipulate reaction times to acquisition and loss of signal. This may be added later.

The impedance is relatively low to minimise the effects of partial short-circuits which might be caused by slightly conductive cave water wetting the connector. The transceiver enforces this low impedance: any equipment attached must have a high-impedance input, taking no more than the specified current.

In transceivers where this signal is not implemented, the pin must be disconnected.

With an FM radio, SigRx would be derived from the squelch line. With SSB its generation is harder; sub-audible tones applied by the transmitter are one option. (See the subsection on them in the ‘Specification of sundry facilities’ section.) These will probably wait for a future development, hence the Importance grade of D.



The diagram shows a possible implementation of this specification, where the Other Equipment might be (e.g.) a talk-through box. The transceiver either connects the line V_{SIGRX} to its power supply voltage (min: 10V less 0.5V Vce_{SAT} drop; max: 18V) or disconnects it. The Other Equipment has a power supply voltage V_{SUPY} also in the range 10V to 18V. It interprets the incoming voltage V_{SENS} as follows:

0 to 0.6V	SigRx is Off
0.6 to 3.5V	Invalid – should not be encountered
3.5V to 9V	SigRx is On
> 9V	Transceiver does not implement SigRx

The Other Equipment can put its SigRx threshold anywhere in the range 0.6V to 3.5V. It will be noted that this is TTL-compatible. The threshold to decide whether SigRx is implemented can be anywhere between 9V and 10V.

The maximum current drawn from the transceiver’s power supply is about 1mA, only taken when a signal is being received. This will be small compared with the current taken by the audio amplifier; it will have a negligible effect on battery lifetime.

6.3.4.3.8 Expansion

This is to allow for expansion. The direction is specified as I/O, i.e. bidirectional, there being only one pin left. On equipment where it is not used (which means everything at the moment), it must be disconnected. Other than that, no specification as to the nature, use or signal characteristics is made. This is intentional so as not to limit future development. It must not be used (this means you!) until some such specification is made.

6.3.4.4 Reasoning

The choice of connector here is a compromise. Other types such as XLR and the audio/microphone connectors used for power inlet suffer from problems: (1) they have bare pins on the panel-mounting connector, which is not acceptable with PowerOut on one pin; (2) they would be far harder to lock and unlock with cold or gloved hands; (3) their locking mechanisms are far more susceptible to mud. Better types are available only at costs of around £20 per connector.

6.3.5 RF Engine Connector

This shall be the only connection between the ☞ RF Engine and the rest of the transceiver. *Reasoning* – this (1) minimises the number of holes in the ☞ Bottom Box and (2) facilitates removal of the RF Engine for maintenance.

6.3.5.1 Connector

This shall be a D25 with the female on the RF Engine. These are the normal D25, not the sub-miniature. These are easily available from many sources. Suitable types are listed below, but many others are equally acceptable.

Gender	Maplins	Farnell	RS	Electrospeed	CPC
Male	YQ48C	616-853	465-390	17-43058A	CN00801
Female	YQ49D	617-003	465-407	17-43063J	CN00806

6.3.5.2 Mechanical fixing

The female for the RF Engine shall bolt into a hole in the Bottom Box. Note that, to allow the RF Engine to be removed without unsoldering, the connector must be fastened on the inside of the hole. It shall be made waterproof with a gasket, not sealant, to ease removal. See also the 'Note on waterproofing connectors', below.

6.3.5.3 Signals

To be specified. **John** – note that many of these (to which the RF Engine is meant to adhere) will refer to the signal levels on the Mic, Power inlet and Antenna sockets.

6.3.5.4 Reasoning

A 25-pin connector provides plenty of pins for expansion at negligible extra cost. D types are acceptable as even the RF frequencies are low; co-axial connectors are not needed.

6.3.6 Note on waterproofing connectors

None of the connectors used here are waterproof. They must be waterproofed after fitting to the case. There are two routes for water ingress:

1. Through the mounting holes. Sealant or gaskets must be used.
2. Along the pins. Sealant must be used.

Sealant. Run some sealant over the base of the pins and around the fixing nut. Sealant should not be allowed on the solder tags, but it might be wise to solder the wires on first. Suitable sealants are [**John Hey** - can you advise?]

Gaskets. [To be written]

If the socket is removed or replaced, this sealing must be repeated.

6.4 Specification of the RF Engine

This module shall be a transceiver with the following characteristics:

1. It shall use single side-band modulation on upper side-band (USB).
2. It shall carry audio signals at speech quality. The audio bandwidth shall be at least up to 2.1kHz.
3. The transmit and receive frequencies shall be crystal controlled or controlled by a frequency synthesiser.
4. The transmit and receive frequencies shall be accurate to [to be specified]
5. The notional carrier frequency shall be 87 kHz. (This might be changed in the future.)
6. The transceiver shall function to this specification with any power supply voltage between 10 V and 16 V.
7. When run from such supplies, the output shall be at least [to be specified].
8. All connections to it shall be via a single connector, the RF Engine Connector. This connector, its pin-out and the signal characteristics carried shall conform to the standard specified in the *Connectors Specification* section of this document. (Note that signals from external sockets will normally be connected via the RF Engine Connector to the RF Engine without intervening circuitry.)
9. It must also implement the levels of protection specified for all these, with one exception. It need not be proof against reversed polarity of the Power Inlet. (Reverse-polarity protection will be provided in the ☞ Top Box.)

If it proves difficult to fulfil the last two requirements, extra circuitry could be added in the Top Box. This might be necessary to avoid re-designing the PCB. In this event, it would be desirable to incorporate the requirements in any later PCB re-design.

No specification is made as to battery current consumption. For information, the RF Engine of the HeyPhone Mark 1 has the following measured figures:

Supply voltage	10V	12V	18V
Receive, no signal received		60 mA	
Receive, signal received			
Transmit, idling		150 mA	
Transmit, average speech		250 mA	

6.5 Specifications sundry facilities

By these are meant ones which do not fit conveniently elsewhere in the Specification. They are given an Importance grade of Essential, Desirable or Later (i.e. not to be implemented yet).

6.5.1 Beacon (Essential)

This is a facility to make the transceiver transmit an audible beep to help the adjustment of antenna position and orientation at the other end of the communication link. Typical practice is for an operator to ask the operator at the other end to provide 30 seconds of beacon just after communication has been established.

No precise specification is made as to this signal. It should modulate the transmitter about as strongly as speech. The frequency should be somewhere in the audio band; 1 kHz is probably suitable.

It is probably helpful if the sound is pulsed on and off. The on and off times should be approximately equal. Times in the range 1/2 second to 2 seconds (i.e. 1Hz to 1/4Hz) are probably suitable. Such pulsing distinguishes the beacon from other whistles.

See also the specification of the beacon switch in the Controls section of this document.

6.5.2 Sub-audible tone (Later)

This is a continuous audio tone added by the transmitter whilst transmitting. It is at a fixed frequency and a very low signal level, too weak to be heard by the human ear. However, a suitable filter at the receiver can detect it and indicate that a transmission is being received. It allows a facility similar to Squelch (sometimes called Mute) as found in FM transceivers. It would make possible the implementation of the SigRx line as defined in the Connectors section of this document.

Implementation would require an oscillator to generate the tone in the transmitter and a filter to detect it in the receiver.

There is no intention to implement these at the moment. No specification is made; this section is currently for information only.

6.6 Specifications for add-on equipment

By add-on equipment is meant anything which connects to the transceivers. Most of the specifications are clear from the above sections, but there are a few points to clarify.

6.6.1 Battery packs

These will have a flying lead which terminates in a Power Inlet connector as specified above, and which plugs into the transceiver. It is essential that the flying lead is attached directly to the battery pack, rather than plugging into the same type of connector on the battery pack. Were this done, the connector on the battery pack would have two exposed pins with 12V on them. It would be very easy to short these out with metal objects such as the metalwork of other plugs.

Appendix D – Waterproofing – IP standards

How waterproof is waterproof? There is a formal set of standards which describe various degrees of resistance to water. These are the IP ratings, defined in a standard called **BS EN 60529 : 1992**. This is both a British Standard and a European Norm and was last updated in 1992 (these notes written in 2001). The ratings provide a way of describing how resistant an enclosure (such as the case of a radio) is against solids and liquids getting in.

IP ratings are of the form **IPnn** where each **n** is a digit, occasionally followed by other letters. In both cases, higher numbers mean better protection. An **X** for a digit is used to mean anything.

The first digit describes protection against ingress by physical objects. At the low-number end these are objects such as fingers (to describe whether a user can touch live parts inside, for instance). At the high-number end the number refers to dust. A rating of 6 means dust-tight, the highest for the first digit, and anything we are using should be to IP6X.

The second digit describes protection “against ingress by water with harmful effects”. The digit describes the equipment as being protected against water which is:

0 (No protection)
1 Vertically dripping
2 Dripping at 15^{o} to the vertical
3 Spraying
4 Splashing
5 Jetting
6 Powerful jetting
7 Temporary immersion
8 Continuous immersion

Ideally we would make all our equipment to IP68, but this has proved difficult or impossible, at least within reasonable cost limits.

The full standard BS EN 60529 is available from the British Standards Institution at a cost (in 2000) of £47. Details may be found on the British Standards Online website, http://bsonline.techindex.co.uk .

6.7 Hints for designers

The following hints and kinks come from several years of trying to build cave-proof electronics.

- Don’t trust the stated IP rating of boxes, switches, etc.. Test them for yourself.
- I have often been pleasantly surprised: boxes sold as IP67 or even IP66 have been totally waterproof.
- On the other hand, ones described as IP68 have sometimes leaked.
- Before you put the electronics in a box, fit all the controls and sockets and test it. Put it in a sink of water and weight it down. Leave it for half an hour or longer. Then remove it, dry the outside, open it up and look for water inside.
- Don’t pretend you didn’t see the water – the cave won’t have any such delusions!
- Can’t find the leak? Try filling the box with water, sealing it up, turning it with the controls (etc.) downwards and waiting for water to leak out.
- Rubber sealing gaskets round switches (etc.) can be improved by smearing them with a rubber-based glue such as Thixofix and wet-assembling.
- A poor seal round a box can be improved by putting insulating tape over the join. Best regarded as a temporary fix, but can be surprisingly long lasting. It’s the edges of boxes that get scraped across rocks, which is not where the joins are.