NOTES ON CONSTRUCTION AND USE OF THE

DQ RECEIVER AND BEACON

I suggest reading the CREG Jourtnal articles on my technical articles page before starting construction in order to understand how the units work and what you can do with them. The schematics and parts lists in the CREG articles are out of date, and the beacon design is obsolete, but the rest of the info is good. Refer to the schematics, layouts, parts lists, and notes included here for the final word. My old website http://radiolocation.tripod.com has information not included here, but is no longer being updated.

NOTE: These notes were updated in July 2020 to the current "2010" boards.

Information on measuring depth by absolute signal strength has been retained, but does not apply to receivers built without a 10-turn RF gain control with turns counter. Also, it is hard to get accurate results because many things can vary the receiver gain and beacon output. The primary variable is beacon output, which varies directly with battery voltage.

DQ RECEIVER NOTES

Detector Board notes

- The actual board is 3.5" square. 3 of the 4 corners must be grounded to the metal thru metal standoffs
- The simple version of the receiver is cheaper and easier to build (and use) if all you need is accurate Ground Zero location without depth measurement, such as cave divers. One can still use the "field angle" method for depth measurement, or an ACVM on "Test Point 2" to do a "Ratiometric" depth measurement when the signal is strong and interference is low. The receiver can be upgraded to the "complete" version by installing the rest of the parts on the board and doing a tuneup. Note that there will be a ~1.3 dB variation in the ACVM reading as beacon signal slowly drifts from one channel to the other. This variation is not audible and is inherent in the receiver design.
- The receiver is designed to be mounted in a metal box for proper grounding and shielding. The boards are designed to fit in the specified 3x4x5 inch "Minibox" or the "Antarctic" cast aluminum case. The cover and all of the standoffs must be grounded to the box. Remove paint if necessary. See the pictures on the Website showing receiver construction.
- "12v" in the lower left of the PC board is a misprint. It should just say "Battery in".
- The complete receiver uses two 9 Volt Alkaline battery. It can also be used with a 12 Volt sealed lead-acid battery if U20 is deleted or bypassed. The simplified receiver uses one 9 Volt battery or a 12 Volt lead-acid battery without modification.
- **Warning!!!** The metal crystal can must be raised above the board to avoid shorting out the traces that run under it! Note that a different crystal frequency can be used in countries that use 50 Hz power so that the operating frequency fits between two 50 Hz harmonics. See "The DQ Receiver - An Overview" on the website (near the end of the article).
- Trimmer C19 has its metal adjusting screw connected to one lead (which must be the ground lead).

- The RF amp board derives Vcc (+10V) from the output of the voltage regulator in the complete receiver, or directly from the on/off switch in the simplified receiver with no voltage regulator.
- The PM-128E DVM derives its power from the regulated +10V in the “Antarctic” receiver. If two 9V batteries are used with a 12V regulator, install a 9V regulator in the space provided to power the DVM.
- To save money in the complete receiver, the built-in DVM can be replaced by an external digital multimeter with a 200mV DC range. You must add R52, which is two 1Meg 1% resistors in series across C40. Connect the meter after the divider/filter R51, R52, C40. Because a separate battery is being used for meter power, U11A and its 4 100k resistors can be deleted. In this case, connect R51 directly to the S6 "arm" and the negative meter lead to the U3B pin 7 lead along with the "bottom" of C40 and R52.
- It is a good idea to use small coax to connect the volume control R34 to the audio amp U9. The center wire connects the tap of the volume control to R35 on the board while the shield connects the "bottom" of R34 to C28 on the board. Note that the shield is at V/2 and not grounded.
- Stereo headphone jacks are specified in the parts list because this is what most people will have. Any impedance will work, but 8 ohm phones may cause problems. For the simplified receiver I do not recommend headphones of less than 32 ohms, as they draw a lot of battery current and will cause distortion and instability with weak batteries. One solution is to use just the left or right element, which doubles the impedence. Changing C28 to 100 uF or more helps somewhat. Wire the "tip" and "ring" leads in parallel to use them as mono headphones. Lo-Fi mono headphones (intended for voice use) of the type that block all outside noise are really better in this application. Hi-fi phones have a somewhat annoying "hiss" that is not audible in the lo-fi units. High impedance phones have less risk of feedback than Low-Z units. My best phones are mono crystal "stethoscope" style. I also have some Telex 600 ohm mono headsets with full ear coverage for sale, probably intended for "language lab" use. With mono phones, connect only the "tip" lead to avoid a short circuit.
- <u>The receiver must be nulled before first use</u>. While using headphones, set both RF amp controls to Lo gain to get rid of RF amp Noise. Pre-setting both null controls to the center of their ranges beforehand will help. Alternately adjust the two null controls (R5 and R9) for a perfect audio null, turning up the volume control as the null improves, until only noise is heard. If you can't get a null then you should check the receiver to see that the correct resistor values were installed; the IC's are not backwards; there are no shorts or unsoldered connections on the board; the front panel controls are correctly wired; and the correct voltages are present. Each IC uses +V DC, and each op-amp output (and most circuits) operate at +V/2. The front panel null control will need adjustment from time to time (using low RF gain with no loop as before). The internal null adjust should only need adjustment after large changes in temperature (also for changes in battery voltage with the simplified receiver).
- In the complete receiver R42 can now be adjusted to align the DVM to exactly zero at the perfect audio null. See notes on the receiver mainboard schematic.
- After nulling, switch to Hi RF gain and 32 Hz mode, then turn up the RF gain. Noise from the RF amp should be audible.
- If a 1 turn pot is used for R9, it can be shunted with ~2k ohms to make nulling less "touchy". It may be necessary to add a small resistance in series with R10 or R11 to "center" the null on the pot. Placing an o-ring on the shaft of R9, then squeezing it by pressing down while installing the

knob, will help prevent the knob from being accidentally turned.

- The DVM should read "000" when the receiver is adjusted for a perfect audio null. If it does not (but is close!), you will need to apply a small DC offset to the DVM using R42, the 1-turn screwdriver trimmer on the detector board. If the DVM reading is negative, insert a jumper wire from the "0-adj" pad to the adjacent "V+" pad on the detector board, then adjust R42 until the DVM reads "000". If the reading was positive, jumper "0-adj" to "gnd". All 3 pads are located between R11 and C39. Once the correct connection is found, the jumper can be soldered.
- The completed receiver must be tuned very close to the frequency of your beacon in order to phaselock properly and give a steady DVM readout of signal strength. The beacon should first be adjusted to freq by either adjusting the crystal oscillator to 3.579545 MHz using the test point, or installing a fixed capacitor of ~24 pF. While receiving the Beacon signal from ~30m away, slowly tune C19 while watching the green phaselock LED, which will be blinking slowly on and off. Tune until the blinking becomes slower and finally stops with the LED ON. Now switch the DVM to "PLL Adjust" and continue trimming until the DVM reading is close to zero. The actual best "center" point is at about -300. This will seldom need readjustment, but can be done in the field during a Radiolocation if necessary.
- The simplified receiver must also be matched to the beacon frequency. With an analog meter, monitor the DC voltage at pins 1 or 7 of U2 while receiving the beacon signal. Slowly adjust C19 until the slow meter swinging almost stops.

RF Amp Board Notes

- There must be a metal shield between the RF amp and the detector board.
- For the simplified receiver, delete R20A, R20B, R21, and R55. Solder a jumper between X100 and S3 to connect the loop input directly to U0.
- Actual board size is 3.5" x 2.0"
- All 4 corners of the board must be grounded to the case thru metal standoffs.
- Use small coax such as RG-178 for the loop input and Sig Out lines.
- Wrap the 3 wires of R22 with an electrostatic shield which can be grounded to the output end of the RF amp board.

Receive Loop Notes

- Ultimate receiver sensitivity is determined strictly by the design of the loop antenna. Sensitivity is simply the ratio of the signal received on the loop to the thermal noise of the wire. Resonating the loop does not change the loop's sensitivity, but does increase the signal level and the impedance, which raises the thermal noise level above the input noise of the receiver.
- The 18" dia receive loop described in the CREG article "Constructing the 3496 Hz D-Q Beacon Receiver" in the Technical Articles is a very handy size for field work. A 22" dia loop gives about 6dB increase in actual sensitivity. I wound a second 22" dia loop and got 512 turns with 2 lbs of #28 wire. I measures 432mH with roughly 4600pF for resonance. Whatever frame is used for the loop should hold the loop rigidly in a plane. One possible frame is a used (ie worn-out) plastic wheelchair wheel with the tire removed. My receive loops are "frameless", wrapped in electrical tape, and sandwiched between plywood sheets in a rigid box. I have also constructed loops using a disks of rigid foam with a groove in their rims.
- My Antarctic loops are wound on aluminum bicycle frames of 25" physical outside diameter

with flat sides The rim is cut to provide a gap, which is reinforced with non-conducting epoxy board. The interior of the rim **must** be “padded” with duct tape on both bottom and sides to space the wire away from the rim at least 1/16” to reduce losses. I use 400 turns of #24 wire. The rim must be grounded to the coax shield. Try swapping the 2 loop wires to see which gives the highest “Q” (gain) when tuned. I have always found a significant difference.

- I now recommend using fixed 600 Volt mica capacitors for the receive loops. High voltage polypropylene also works and is cheaper. The high voltage rating is to prevent damage (shorted caps) when the loop is accidently placed close to an operating beacon (and it will happen!). The loops do not detune by themselves. The fixed caps help keep the receiver gain stable for depth measurements.
- Adding a grounded electrostatic shield (with a gap of course) to the loop winding is worthwhile if you are doing precision Radiolocations where wells will be drilled, depth measurements, or are doing conductivity measurements where signal strength at the bottom of deep nulls must be measured. The shield eliminates small variations in signal strength when the loop or receiver are touched. The shield lowers the Q of the loop slightly. All of my loops have shields, but they work well enough for most purposes without them.
- <u>You MUST mount a sensitive cylindrical bubble level (not a round one) on the top edge of the receive loop, set to be centered when the loop is PRECISELY vertical. This is an absolute MUST for accurate Ground Zero location!!!!!!!!!!!</u> These are available as inexpensive plastic "line levels" at Home Depot or other hardware store
- A useful addition to the loop is a 6 ft (2m) low stretch line attached to the center of the loop on one side, with a "T" bar of thin wood or fiberglass on the loose end to stand on. This allows one to make rapid Ratiometric depth measurements by raising the horizontal loop over ones head a precisly known distance above the ground. The reasonable depth limit for accurate measurement with this short line is about 120 ft (40M), but I have made reasonably accurate measurements at twice this depth. For the best results at larger depths, I use a rigid pole to raise the loop as much as 25 ft in the air. See the electrostatic shield notes above.

Beacon Notes

- If only one beacon will be used, C2 can be replaced by a ~24pF fixed cap. Otherwise, insert C2 without soldering then connect a freq counter to C1 (using a x10 scope probe for isolation if available) and adjust C2 for 3.579545 MHz. Measure C2 then replace with fixed ceramic or mica caps. Multiple beacons need to be on the same frequency so that the receiver will be able to phase-lock on them for depth measurements.
- Actual board size is 3.5" x 2.0".
- <u>The metal crystal case must be raised above the board to avoid shorting out the traces underneath.</u>
- Caps C1 - C4 are all in parallel to resonate the loop. A capacitance decade box is very helpful in loop tuning. With the loop away from all metal objects, momentarily key the beacon with an analog current meter in series with the battery, and tune for maximum current. Once tuned, current should be roughly 0.5 amps for most of my loop designs. Most of the installed capacitance should be low loss 250V (or higher) polyproplyene, although smaller trim caps can be Mylar.
- Note that the LED will only light if all 3 connections to the loop are intact and a real signal is being transmitted. It is real "BITE"!

- The laws of physics dictate that the Magnetic Moment (beacon field strength) increases linearily with loop diameter if battery power drain and the weight of the wire in the loop remain constant. The exceptions are ferrite rod loops, which can be very small but also very heavy. I now use a collapsable frame with the 4 ft loop to make it easier to level (with a line level) and obtain a repeatable output. The beacon loops must be precisely leveled in order for the axis of the magnetic field (ie Ground Zero) to be precisely overhead.

Locating Ground Zero

Radiolocation requires practice. Even though this gear often gives a useable signal close to 1 km away, always try to position yourself as close as possible to the expected location by using topographic overlays, GPS, compass course and distance from an entrance, etc. Try to always be higher than the cave passage, ie wait uphill rather than downhill. If you are within a horizontal distance of about 1.4 times the expected depth of the beacon, the locating will be very quick and easy.

- The best time of day for radiolocations is during the morning, from about 8AM to 1-2PM. The worst time is during the night when "skip" brings the noise of far distant thunderstorms. This assumes no local storm activity. For this same reason, winter is much quieter than summer. Even so, it is possible to do moderate depths on a summer evening. I find it hard to get cavers moving before the "crack-of-noon"!
- Coordinate times with the underground party so you know the earliest time they will "turn on". In smaller caves or with experienced cavers, you can have them operate on a schedule. At first, plan to have the beacon turned on for 30 minutes or more. With careful planning, I have used a little as 4 minutes with divers in springs. You go to the first location, turn on the receiver a little ahead of time, and null the receiver (after disconnecting the loop, set the switch to low gain and the dial below 5.0), then reconnect the loop using quite high RF gain, 1 Hz bandwidth, and the loop on the ground. Carry a small screwdriver in case you have to adjust the internal null adjustment or the frequency (if it won't phaselock for depth measurement). Don't wait directly under a noisy power line or close to a metal fence line! The receiver should be kept out of direct sunlight, as the heating will cause the null to drift, which may make it impossible to null the receiver until it cools.
- When the beacon is heard, hold the loop vertical and slowly rotate it for a null, adjusting volume as desired. RF gain should remain high enough to give deep nulls. Ground Zero lies along the null line. Gamblers can simply walk in one direction along the null line while continually rotating the loop thru the null to update direction. If the signal gets weaker, then simply go the other way. In an open field, one can walk perpendicular to the original null line a short distance and then null again. If you walked far enough, the two null lines will not be parallel and will intersect near Ground Zero. This is the 2-LOP method. If all else fails, you may be very far from the Beacon. In this case make a quick signal strength measurement with the loop on the ground then walk 50-100m along the null line and measure again to see of the signal really is getting stronger or weaker. Note that this method will fail if you are within roughly twice the estimated depth of the beacon where the field lines are not vertical.
- It is easy to "overshoot" Ground Zero. As one gets close, within 1.4 times the estimated depth of the beacon, the best way to check progess is to occasionally rotate the vertical loop perpendicular to the null line that you are walking along, then tilt the top of the loop towards yourself. At first this null may occur with the loop nearly horizontal, but as Ground Zero is approached this null will occur with the loop closer and closer to vertical. Very close to ground zero the loop will null while rotated in any direction, but the signal will become incredibly

strong when the loop is tilted even slightly from vertical. At this point, for highest accuracy, it is a good idea to re-null the receiver.

- Now the vertical loop is rested on the ground, rotated so the axis is pointed at you, then tilted back and forth to find the null. At any nearby location except exactly at Ground Zero, the magnetic field will tilt away from Ground Zero as it exits the ground. The cylindrical bubble level shows loop tilt. If the loop nulls when it is tilted slightly towards you, then move the bottom of the loop slightly away from you and re-null, repeating until the loop is precisely vertical when nulled. The plane of the loop is now precisely on a line of position that passes through Ground Zero. With practice, and perfect conditions, it is possible to detect a 6 inch (10cm) change in the position of a beacon at 300 ft (90m) depth! Mark this line at the loop, then rotate the vertical loop 90 degrees and repeat the process to obtain a second line, which should cross directly over the first line. Mark the intersection of the lines as ground zero.
- To cancel out most of the errors in the receive loop and its bubble level, repeat each measurement in the last step with the vertical loop rotated 180 degrees from its original position. This will usually give slightly different positions. The result will be a small square box of marks with ground zero at the center.

Depth Measurement

A SIMPLE WAY TO START DOING DEPTH MEASUREMENTS

For a start, you can do the fast Ratiometric measurement without any calibration at all. Make certain that the RF overload LED on the receiver is not lit! If is is lit, back off on the RF gain. With the receive loop horizontal on ground zero, just set the receiver dial to give a reading of 1000 or more (if you can), then raise the horizontal loop an accurately known distance for the second reading, without changing any receiver settings. You then use the equation to calculate ratiometric depth. For shallow depths (say <100 ft [30m]), this is all that you need to do.

Calculating Ratiometric Depth

- The two DVM readings and the 6 foot spacing are used to calculate the "free space" Ratiometric depth using the equation below. V1 is the DVM reading with the loop on the ground and V2 is the reading with the loop raised the distance H above the ground. The cube root requires a scientific calculator such as the one in Windows. The calculated Ratiometric depth will normally be equal to, or less than the actual depth, with the error growing rapidly as the depth gets greater (beyond roughly 30 meters).

$$D = \frac{H}{\left(\sqrt[3]{\frac{V_1}{V_2}}\right) - 1}$$

- You can also use the traditional field-angle method, which is covered on this website on the Basic 1 & Basic 2 Radio page.

The following information is primarily for receivers built using 10-turn RF gain controls with numerical readout dials.

"Ratiometric" and "absolute"(signal strength) depth measurements are discussed in "Operation" in the CREG article *Constructing the 3496 Hz DQ Beacon Receiver* in the Technical Articles, and are discussed in more detail in *Depth by Radiolocation: an Extreme Case*. Using 2 independent depth measurement methods helps to give confidence (or lack of it) in the results. The only missing information is the receiver amplitude calibration for depth by absolute signal strength. The procedure given here is based on a calibration table (which follows) generated for the first receiver I built using the new circuit boards. It allows one to adjust the receiver RF gain for a reasonable DVM reading, without overload, with the receive loop horizontal at ground zero, and calculate depth by absolute signal strength later.

- After locating Ground Zero, place the loop horizontally at ground zero and level it with a round bubble level.
- In the 1 Hz mode, adjust the RF gain switch and pot for a high resolution reading on the DVM, say 900-1500. Now adjust the gain pot precisely to the nearest "1/2", ie 7.0, 7.5, 8.0, 8.5. For highest accuracy, it is best to avoid the extreme ends of the pot near 0.0 or 10.0 if possible. These are the points where gain is calibrated in the table that follows. Make certain that the RF overload LED on the receiver is not lit! If is is lit, back off on the RF gain.
- Record 3 pieces of info: The position of the gain switch (High or Low); the position of the gain pot (1-10 in increments of 1/2); and the DVM reading (>900 if possible). For Ratiometric depth, without changing the receiver settings, raise the horizontal loop an exactly known distance (say 6 feet) and record the new (lower) DVM reading and the distance the loop was raised.

Calculating Ratiometric Depth

- The two DVM readings and the 6 foot spacing are used to calculate the "free space" Ratiometric depth using the equation below. V1 is the DVM reading with the loop on the ground and V2 is the reading with the loop raised the distance H above the ground. The cube root requires a scientific calculator such as the one in Windows. The calculated Ratiometric depth will normally be equal to, or less than the actual depth, with the error growing rapidly as the depth gets greater (beyond roughly 30 meters).

$$D = \frac{H}{\left(\sqrt[3]{\frac{V_1}{V_2}}\right) - 1}$$

- Next look up the gain pot setting in the following table and record the corresponding "inverse ratio". These numbers are accurate for my receiver and probably OK for yours, but are not guaranteed. Contact me if you are interested in custom calibrating you own receiver. I used a precision 3-decade 50 ohm step attenuator.

RF Gain Pot Setting	Inverse Ratio	RF Gain Pot Setting	Inverse Ratio
10.0	1.000	4.5	50.12
9.5	3.273	4.0	60.26
9.0	5.754	3.5	73.28
8.5	8.610	3.0	90.16
8.0	11.61	2.5	112.2

7.5	14.96	2.0	146.2
7.0	18.84	1.5	197.2
6.5	23.44	1.0	285.1
6.0	28.51	0.5	478.6
5.5	34.28	0.0	1259
5.0	41.69		

- Use the DVM reading, switch setting, and inverse ratio to calculate Vz, the normalized receiver input voltage, which will be used to calculate "free space" absolute depth. Vz=(DVM reading)(100 for Lo, 1 for Hi Gain setting)(Inverse Ratio). Example: if DVM=900; Lo Gain mode; Pot Setting=7.5; Vz=1346400

Calibration for Depth by Signal Strength (Absolute Depth)

- The beacon/receiver system must be calibrated, with both units on the surface, before or after the trip. The best location to do it is a level area with low conductivity ground, such as the granite in my backyard since you are trying to do a "free space" calibration.
- Set the Beacon loop exactly vertically with its axis aimed exactly at the receive loop exactly 100ft (or exactly 30m for metric) awayat distance "Dcal". Likewise, the receive loop is also set up exactly vertically with its axis aimed at the Beacon. This is called "coaxial" alignment.
- Turn on the receiver, disconnect the loop, set to 1 Hz BW, Lo RF Gain, alarm off, meter Fast and connected to the receiver output. Now null the receiver for exactly "000" on the DVM (the audio doesn't matter). Reconnect the loop, then turn on the beacon with a fresh battery and let it warm up.
- Adjust the RF Gain pot to a setting listed in the table above that gives a DVM reading of at least 3 digits, preferably above 500. Record the RF gain setting, Hi-Lo Gain setting, and DVM reading for use in the 100 foot (or 30m) absolute depth calibration. Calculate Vcal exactly as Vz was (or will be) calculated using the actual Ground Zero readings.

Calculating Absolute Depth

- Use the following equation to calculate Absolute Depth, which will normally be equal to or greater than the actual depth, with the error growing as the depth gets greater.

$$D = D_{cal}\sqrt[3]{\frac{V_{cal}}{V_z}}$$

- At shallow depths (say under 30m), the two calculated depths should be similar. At greater depths, the Absolute depth should be somewhat greater than the Ratiometric Depth. If it is, then one can add the two numbers and divide by 2 to get an average which should be quite close to the true depth if you have uniform rock from the surface to well below the cave passage. See the CREG article "Determining Depth by Radiolocation, an Extreme case". My deepest reasonable result was 550 feet at Jewel Cave, South Dakota, which meets the uniform rock requirement.