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speleonics 21

COMMUNICATION AND ELECTRONICS SECTION OF THE NATIONAL SPELEOLOGICAL SOCIETY

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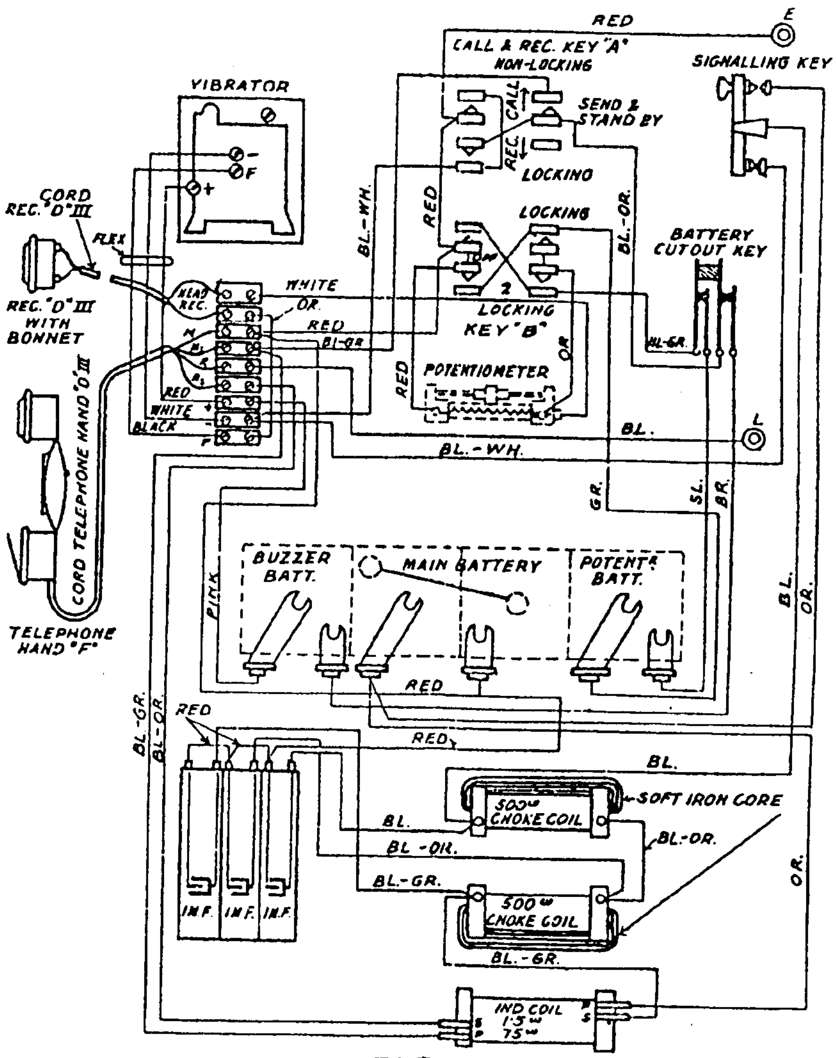

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CAVE RADIO RECEIVER PLANS ON PAGE 10

The British Army used the Fullerphone, an earth-dipole transceiver, for battlefield communication in World War I. Earth-dipoles might be useful in some caving applications. See the article by Frank Reid on page 3.

SPELEONICS 21

Volume VI, Number 1 March, 1997

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Editorship rotates among the officers. Volunteers are encouraged to guest-edit or produce an issue. A technical session, followed by election of officers, is held annually during the NSS Convention.

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CALL FOR PAPERS

If you are interested in presenting a paper at one of this year's NSS convention sessions, please submit an abstract up to 250 words in length, including title, author's name and author's address, to the appropriate session chairperson.

In addition to the traditional oral papers, the science sessions will include poster sessions at a separate time from the oral sessions. Please indicate whether you are submitting for a poster or oral paper.

The deadline is April 15, 1997 for abstracts to appear in the program booklet and official session schedules. Electronic submissions are strongly encouraged but please also send a paper copy to the appropriate chair person. Send 1997 NSS Convention Electronics Session abstracts before April 1 to:

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ANNUAL CAVERS' MEETING AT DAYTON HAMVENTION

Frank Reid W9MKV

Cavers and friends interested in cave-related electronics will hold our ninth annual meeting at the world's largest hamfest in Dayton, Ohio.

Time: 11 AM local time (EDT), Saturday, 17 May.

Location: Same as last several years: The 'grassy knoll' outside the southwest corner of the main arena building, just inside the fleamarket entrance by the "Pub," near the lowest-numbered fleamarket spaces (which are behind the bus stop). Look for a _Speleonics_ newsletter cover taped to the wall. In case of rain, meet inside nearest exit-door. Approximate GPS coordinates (D M.M): N39 49.35, W084 15.51

Frequency: 146.66 MHz simplex.

We always have had interesting discussions (and occasional demonstrations) of cave radio, cave-rescue communications, lights and batteries, highway ECM and other esoteric electronic things, and we exchange locations of cave-related equipment for sale.

For details of the hamvention itself, see any U.S. amateur-radio magazine published since January 1997, or view http://www.hamvention.org. The cavers' meeting is NOT on the official schedule.

SPELEOTARDINESS

Joe Hruska

Yes, this issue is long overdue. I apologize on behalf of all editors for the drought. _Speleonics 20_ was released in February, 1994. _Speleonics 22_ is planned for June, 1997, but more material is required. Please send me your articles soon. E-mail transfers are preferred, and U.S. mail works also.

The _CREG Journal_ (see below) covers the same subject material, and authors such as Ian Drummond and Brian Pease contribute to both publications. Potential authors are encouraged to forward their articles to either publication. _Speleonics_ and _CREG Journal_ will avoid printing the same information. Brian's D-Q Beacon Receiver is an exception.

RADIO CROSSLINK EXPERIMENTS

Paul Johnston KA5FYI

In reading about Ian Drummond's efforts to attempt to purchase a cave-radio-to-VHF crosslink in _Speleonics 20_, p2, I thought that I would relate my experience with crosslinking 80 meters AM to 2 meters FM, and 11 meters AM to 2 meters FM. For being able to do this I owe credit to the advice of WA5RON.

In helping to provide point-to-point communication for a small portion of the Texas Water Safari, a canoe race from Central Texas to the Gulf of Mexico, it became apparent that crosslinking would make the job much easier. Located on the riverbank about 60 feet vertically below the main roadway and about 300 feet horizontally, it was hard for the 2-meter signal to travel downstream through all the vegetation to the next communication point. However, if you used a 5/8-wave antenna and a couple of watts on simplex, you could easily talk with the other radio operators downstream while standing uphill at road level.

This happened in 1988 when crossband-repeat options were just becoming available for 2-meter radios. However, I wanted to use the equipment that I had available. WA5RON proposed to experiment with crosslinking 80-meter AM (3.8862 MHz) to 2-meter FM.

He had two BC611 walkie-talkies (a working set of World War II surplus that you see John Wayne use in the war movies). That part of the assembly was ready after assembly of two sets of batteries.

I had a Yaesu FT757GX, a 10-160 meter all-mode HF rig with external audio and PTT inputs and external-speaker output. Also, I had a Yaesu FT290R all-mode portable 2-meter rig with external PTT input and external speaker output. By building a simple transistor switch into each rig to key the other rig's PTT, and assembling four patch cords to connect the two radios, we were ready.

Both radios had squelches. By inspecting the circuit of each radio and finding a component which changes from voltage to no-voltage or vice-versa when a signal was detected, we could "steal" a little voltage and make a transistor switch to key the other radio's PTT. We brought this switch's output to the outside of each radio via a shielded cable that extended outside the radio by about one foot.

On the 2-meter radio, I also made a connection internally to the microphone audio input jack to an additional jack on the outside of the radio. On the two shielded audio cables that took the external speaker output of one radio to the audio input of the other radio, a 10k resistor was in line and a .001 uF capacitor was across the shield and inner conductor of each plug of each cable. The resistor and capacitor were built into the plugs. The resistor helped to keep the audio input from being overloaded and the capacitors were to keep RF from getting into the audio input. Both plugs of the PTT switch cables had .001 uF capacitors across the center conductor and shield to prevent RF from affecting the keying.

Here is how the radios were patched together: The PTT cables were plugged to the other radio's external PTT jack. The audio cables were plugged into the external speaker's output of one radio to the external audio-input of the other radio. The volume and squelch knobs of each radio then controlled the amount of audio input and the squelch sensitivity to the other radio. By using a 2-meter h-t and the 80-meter handheld, we could set the volume and squelch controls of each radio that were located in my truck at road level.

Down by the riverside, we would transmit up to my truck on 80-meter AM, and that was retransmitted downstream on-2 meter FM. Downstream, other hams would reply on 2 meters and that would be relayed to us on 80 meters. Because the 80-meter frequency happened to be a popular AM frequency, we monitored our own 2 meter output. If the HF rig in my truck retransmitted unwanted signals, we would know and could disable the crosslink. To prevent this from happening, we had the squelch turned up on my HF rig. Our nearby 80-meter signal would probably be stronger than a distant signal.

The above setup worked well. It was wonderful to see the World War II walkie-talkies in action more than 40 years after their day in history.

The next year, following the theme of trying to use available equipment, I crosslinked 11 meter AM (CB) to 2 meter FM. In the CB radio I built the PTT switch and brought its output to an outside jack; I also brought the microphone input to an external jack.

Patching the radios together was the same as already described. Adjusting the volume and squelch of each radio was done with the assistance of 2-meter and a 11-meter handheld radios.

I have used the above setup for several years and it has worked well. I do keep the 11 meter squelch tight to prevent unwanted CB signals from coming out on the 2-meter amateur radio band. Again, by monitoring the 2-meter output at riverside, I can be sure that only my own signals are retransmitted.

The thrill of the above experiments was in improvising with the equipment that was on hand.

Reference

"Cave Rescue Communications: Linked Systems", _Speleonics 3_, pp6-9.

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RESONANT-SPEAKER REFERENCES

Frank Reid

Narrow-bandwidth receivers are necessary for weak Morse-code signals (or cave-radiolocator pulses). One way to decrease bandwidth is to place a loudspeaker in a mechanically-resonant enclosure. Cave-radio builders might find these resonant-speaker references useful:

Jacobs, Glenn WB7CMZ, "The One-Note Pipe Organ", _73_ magazine circa 1980. Includes reference to _QST_ Sept. 1952, p66.

Millard, W., "A Resonant Speaker for CW", "Hints and Kinks" column, _QST_ Dec. 1987, p43.

"Hints and Kinks" column, _QST_ Jan. 1989, p37. Two short articles on resonant speakers.

Resources

Fair Radio Sales 1016 E. Eureka Box 1105 Lima, OH 45802 (419) 227-6573.	Mil-Com Exchange PO Box 982 Orange Park, FL 32067-0982 (904) 276-3568.

These suppliers of military-surplus electronics carry some items of World War II vintage. Field telephones and accessories are intermittently available.

HISTORIC EARTH-DIPOLE COMMUNICATIONS

Frank Reid

Introduction

An earth-dipole * transmitter injects current (usually baseband audio tones or voice frequencies) into the earth between pairs of widely-spaced electrodes. The current takes infinite paths through the conductive earth, and voltage can be detected at a second pair of grounds distant from the transmitting array (and preferably oriented parallel to it). The ill-fated inventor Nathan B. Stubblefield experimented with earth-dipole communication before the birth of radio [4].

Cavers have long experimented with earth-dipole techniques for underground communication, and have noted interaction between earth dipoles and inductive cave-radios. A recent series of articles by Rob Gill and David Gibson appear in BCRA *JCREG* issues 17, 19, 20, 23. Occasional articles in electronics-hobbyist magazines [1, 2] mention (usually without details) that telephone equipment was used during World War I for "wireless" communication through the earth, and that earth-dipole methods intercepted enemy telephone traffic. British VLF experimenter Mike Scrivener has obtained and shared copies of documents from the Royal Signals Museum [3, 6, 10] describing two wartime devices, the Power Buzzer and the Fullerphone.

* The expressions "earth dipole" and "earth current" are often used synonymously; some authors make the distinction that earth currents are naturally occurring, while earth dipoles are equipment used to detect them, or for communication.

The Power Buzzer

Radio was young at the time of World War I (1914-18). Radio equipment was bulky, expensive, delicate, and difficult to operate. Battlefield communication relied heavily upon field telephones and landline DC telegraph, both of which used single-wire lines with earth return. (Modern field-phones are usually used with paired wires but are capable of single-wire/ground operation.) Deploying wire was dangerous work, and artillery fire quickly damaged lines. Opposing armies developed methods of communicating through the ground without direct wire connections.

The British "Power Buzzer" was a large electric buzzer with a secondary step-up winding connected to a pair of bayonets stuck into the ground 100 yards (91m) apart. The receiver was a vacuum-tube audio amplifier connected to a similar pair of grounds, 2000-4000 yards away (1.1-2.3 miles; 1.8-3.7 km). To prevent interference, buzzers with different frequencies were manufactured; the operators' ears provided selectivity.

From reference 6 [6]:

"The Power Buzzer is a portable telegraph instrument designed for communicating with a distant point with which communication cannot be established by means of line telegraph or telephone. It... can transmit by passing an electric current into the ground through two lengths of field cable stretched out on the ground, each connected... to the apparatus, and at the other end to earth pins driven into the ground. The straight line joining the two points... is called the base, and must be at least 50 yards long,... preferably 100 yards. An amplifier... is connected to a similar base at the distant point. It is very important that these bases should be in certain definite directions relative to each other... A Power Buzzer squad should consist of 1 NCO and 2 men... In normal circumstances a range of 2000 yards may be obtained, and in favorable circumstances 4000 yards."

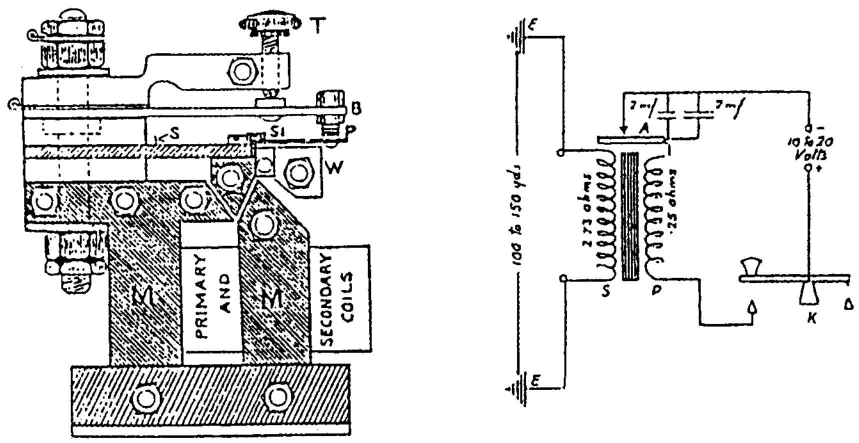
Fixed and variable-frequency buzzers operated between 300 and 800 Hz. The power source was a 10-volt, 20 ampere-hour rechargeable wet-cell battery.

Notes from Power Buzzer troubleshooting procedures:

"If a clear note is not obtainable and one only gets a spluttering, the following must be looked at :

(I) The line may be broken.
(ii) The earth connections may be of too high resistance...
(iii) Lower contact blade of wrong frequency may have been put in.
(iv) The condenser may be faulty."

British earth-dipole historian and experimenter John Taylor (G0AKN) forwarded an article [7] by Louis Meulstee (PA0PCR) of Holland, an authority on the history and technology of WWI communications. The article includes pictures and schematic diagram of the Power Buzzer:



Drawing and circuit of the French "Parleur" power buzzer, model "2 ter". Initially, British power buzzers were made to this design.

Like near-field magnetic induction, earth-dipole propagation has an inherent range limitation in that signal strength varies inversely as the cube of the distance from the source (in a uniformly-conductive earth). The relevant equation (from [5]) is:

$$v = \frac{I\ d1\ d2}{2\ pi\ s\ l^3}$$

where:
v = received voltage
I = transmitter current
d1 = transmitter electrode spacing
d2 = receiver electrode spacing
s = earth resistivity
l = distance between xmtr and rcvr
pi = 3.14

Reference 5 [5] is a caver's theoretical analysis of earth-dipole communication, and describes a practical data-transmission circuit.

Earth-dipole technology sank into obscurity as radio matured. Japanese forces in World War II used a system perhaps similar to Power Buzzer for communication between underground fortifications on Pacific islands (Speleonics 12, p.15). When amateur radio was suspended during World War II, disenfranchised hams rediscovered earth-dipole communication, using audio amplifiers as transmitters and receivers. "Ground wave" ranges greater than one mile (1.6 km) were claimed. We recall these techniques today for their historical interest, and because their principles are applicable to underground communication.

The opponents in WWI were sometimes able to intercept enemy telephone traffic by using battery-powered amplifiers and pairs of widely-spaced earth probes to detect the earth currents of single-wire phones. The listeners accidentally discovered the ionospheric VLF "whistler" phenomenon [8]. Whistlers were initially thought to be an effect of the war because they sound like falling bombs and shells.

The WWI battlefield was a harsh environment for electronics but it was probably electrically quiet. Today, ubiquitous power-line hum is a major limitation of earth-dipole communications, inductive "cave radio" and other VLF reception. Power-line harmonics extend well into ultrasonic frequencies. Cavers and others are experimenting with a variety of sophisticated weak-signal recovery techniques.

The Fullerphone

Colonel Fuller of the British Army developed an ingenious device which combined voice and telegraphy simultaneously on a single wire, without mutual interference. Fullerphone telegraphy could operate through wires having so much ground-leakage or resistance (up to 200k ohms) that they were unusable for voice. It could sometimes operate through a broken wire if both broken ends touched ground.

The Fullerphone's telegraph receiver is extremely sensitive, yet uses no amplifier. A high-impedance earphone is in series with the armature and normally-open contacts of a quiet electric buzzer. The vibrating contacts interrupt DC signals, modulating them into audio.

The telegraph transmitter is a 3-volt battery in series with a hand key. The telegraph transmitter and receiver are coupled to the line through an LC lowpass filter which prevents telephone signals from being shunted, and suppresses key clicks which would otherwise be audible in the telephone.

The voice circuit is a conventional local-battery telephone. It lacks a sidetone-suppressing hybrid network and other refinements found in WWII-vintage military field phones. Several models of Fullerphone were produced; the later "marks" did not contain telephone components and could be used with or without conventional field-phones.

Galvanic action between metals and soil chemicals produces small DC voltages. Other natural and manmade voltages may be present in the ground. Some Fullerphone models include an offset-voltage source for nulling unwanted signals: A 1.5-volt battery with polarity-reversing switch is connected across a potentiometer in series with the earphone.

Fullerphone telegraph signals are far weaker than those of the Power Buzzer or conventional DC telegraph. They caused no "crosstalk" interference in adjacent phone circuits, nor could they be detected remotely by earth-dipole receivers. Although not intended for "wireless" communication, Fullerphone had earth-dipole receiving capability. It could detect earth currents of nearby single-wire DC telegraph lines.

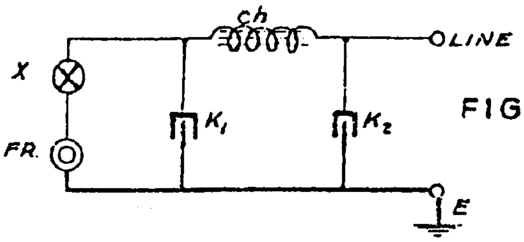


FIG. 1.

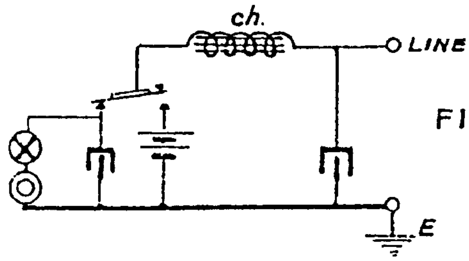


FIG. 2.

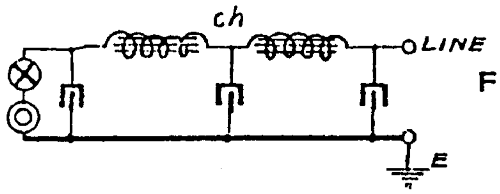


FIG. 3.

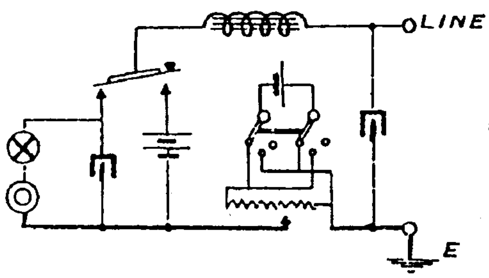


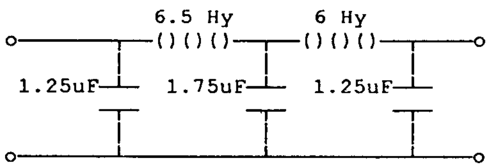
FIG. 4.

The figures above and the figure on the cover page are from reference [10].

Fullerphone's SPDT telegraph-key provides automatic send/receive switching ("QSK"). (Is this the origin of the traditional SPDT design of British keys?) Should one wish to duplicate the circuit, a compact and durable British-pattern hand-key of WWII vintage remains commonly available on the surplus market. It is made of black Bakelite, labeled "KEY W.T. 8 AMP No. 2 Mk III." A SPDT Microswitch(tm) would also suffice.

Fullerphones appear rarely at U.S. hamfests, often in nonworking condition at inflated collectors' prices. John Taylor sent me a Fullerphone Mark 4 model, apparently more recent than the 1917 literature; its buzzer module is dated 1941. It is a telegraph only. I was unable to fully restore it, but did measure component values of its lowpass filter.

Schematic of lowpass filter in Fullerphone Mk. 4. Inductors have 220 ohms DC resistance.



The inductors are large enough to block low-frequency, high-voltage telephone ringing current. Using the same inductors, the filter could be redesigned as an elliptic-function type, yielding 70 dB stop-band rejection with a deeper notch at 60 or 50 Hz.

Equivalent active-filters are more portable but have disadvantages of complexity, noise, power consumption, DC offset, intermodulation of strong signals, and susceptibility to high-voltage damage and radio-frequency interference.

Caving applications

Two Hz (slow Morse code) is approximately 5 octaves away from 60 Hz, greatly simplifying filtering requirements to reject power-line hum. A DC earth-dipole system which strongly rejects power-line interference suggests application in underground communications. DC penetrates the earth without skin-effect attenuation. Cavers might use DC earth-dipole equipment for communication by Morse code or low-speed data, or for cave-to-surface telemetry.

A digital voltmeter connected to the offset control could indicate signal strength directly (subtracting internal and ambient DC offset, measured when the transmitter is off). Signal-strength measurement is useful in propagation studies, and would also make the receiver a useful instrument studying naturally-occurring earth currents (interesting in the context of ionospheric, seismic and geochemical phenomena).

Galvanic effects cause errors if one tries to measure earth resistance with a DC ohmmeter. Special nonpolarizing earth-electrodes are used in resistivity measurements with DC instruments [13].

A member of Cave Research Foundation requested a design for an emergency beacon for cavers trapped by high water, etc. If a suitably-sensitive receiver could be built, an earth-dipole DC transmitter powered by a caver's lighting battery could be an inexpensive solution. A few prearranged signals could be used to communicate the urgency of the situation.

The old systems achieved remarkable performance with primitive equipment. Modern solid-state devices suggest numerous experiments. CMOS analog switches in bridge-inverter configuration (a form of balanced modulator) should produce twice the output of a simple interrupter (see also [9]). If the transmitter is bipolar, reversing its polarity instead of simply keying on and off, it would further double peak-to-peak signal strength. In the bipolar transmitter case, the receiver offset-control would be adjusted so that negative peaks of the transmitter signal produce no tone in the earphone. Balanced-modulator detection and bipolar keying together should yield a gain of four over the original Fullerphone, with no active amplification (theoretically improving earth-dipole range by 1.59, the cube root of 4). A high-voltage transmitter (perhaps a 12VDC-to-120VAC power inverter with rectified output) should yield appreciable range (albeit with shock hazard).

Discontinuities in the earth might enhance the range of earth-dipole communication. If each ground-rod of a transmitting and receiving pair were placed on opposite sides of a fault (e.g., between the walls of the main passage of Ellison's Cave in Georgia, USA). The fault would form a vertical plane of higher resistivity, forcing the current to take longer paths between the rods. Other types of faults might have lower resistivity than surrounding rock. In that case, one electrode could be placed in the fault plane, the other at maximum distance perpendicular to it on the side where communication is desired. Similar range enhancements might be achieved by inserting electrodes into selected horizontal strata, perhaps above and below a cave, or between surface and water table or cave stream.

It might be interesting to operate the modulator at 50, 72 and 80 Hz to try to synchronously detect European power lines or the U.S. Navy's ELF submarine-communication system. (ELF uses very low-speed FSK at 72 and 80 Hz. The transmitters are located at two sites in Wisconsin.)

References

[1] Maynard, Fred, "Terraquaphone", _Electronics Illustrated_ Sept. 1961, p41.

[2] Centore, Mike III, "Sounds from the Ground", _Elementary Electronics_ May-June 1972, p49.

[3] Royal Signal Museum, Maj. R. Picard, curator. Blandford Camp, Blandford, Dorset DT11 8RH, Great Britain.

[4] Reid, F., "Voices From the Past", _Speleonics 15_, p5.

[5] _An Evaluation of the Application of Current Injection Techniques to Underground Communications_ by Simon M. Mann, Dept. of Electronics, The University of York, May 1988. (61 pages)

[6] _Director of Signals Wireless Circular No. 16. Instructions for the use of the Power Buzzer._ G.H.Q., 24 April 1917, J. S. Fowler, Major General, Director of Signals. (12 typed pages)

[7] Meulstee, Louis, "Earth Current Telegraphy", _Morsum Magnificat_ issue #9, Autumn, 1988. _Morsum Magnificat_ is a British journal of telegraph history. See _Speleonics 18_, p11.

[8] Mideke, Michael, "Sounds of Natural Radio Part 2: VLF Emissions and a Bit of History", _Lowdown_ August 1989, p13. (Whistlers detected during WWI earth-dipole operations.)

[9] Lancaster, Don, "Synchronous Demodulation", "Hardware Hacker" column, _Radio Electronics_ March 1990, p58.

[10] _The Fullerphone. Its action and use._ Issued by the General Staff, War Office, March 1917. Printed by Darling and Son, Ltd., Bacon Street, London. 29 pages, 30 schematic

diagrams.

[11] Reid, F., "Earth Dipole Communication Notes", Speleonics 16 (v4 #6) May 1991, p12.

[12] Manual of Caving Techniques. The Cave Research Group, Cecil Cullingford ed., Routledge & Kegan Paul, London 1969, pp219-231.

[13] Bevan, Bruce, "Self-Potential Surveys", Speleonics 15, p7.

[14] Stoleson, Harley N., "Design and Installation of Ground Systems", Philco Tech Rep Bulletin March 1955. Reprinted in LF/VLF newsletter Western Update #81 Sept. 16, 1991. [Western Update is no longer published, having merged with The Lowdown.]

[15] Null, Bob, "Earth Current Detector", Lowdown March 1988, p19. Microammeter and diodes. "This device responds to VLF solar flux modulations of the geomagnetosphere."

[16] Mideke, Michael, "Tree Probes and Earth Dipoles", Lowdown March 1992, p27.

The Lowdown is the monthly newsletter of the Longwave Club of America, 45 Wildflower Road, Levittown, Pennsylvania 19057. Subscription: $18/year USA, $19 Canada, $26 overseas. Highly recommended!

Additional Fullerphone reference not reviewed for this article:

Antique Wireless Association's (AWA) Old Timer's Bulletin vol. 3, p16, also in the 8th edition of their annual publication AWA Review.

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REPAIR YOUR MINI-MAG FLASHLIGHTS

by Earl Hancock NSS 24125

Doing routine maintenance on my caving gear, it became evident that all was not well with a double-AA-cell MiniMag(tm) flashlight. After cleaning the lens, the "O" rings, and burnishing all the electrical contacts that I could reach, the light still lacked the "factory fresh" bright light we expect, and sometimes needed a "whack" to turn it on. Looking at the plastic bulb-base/switch, I reasoned that there were more contacts that remain hidden. Seeing no evident method of removal (without hammer), I scanned the literature and found the solution for Mag Lites, Techna lights, Beckmann lights etc., but MiniMags seem to be permanently joined at the switch. Undaunted, I continued.

Remove the lens, bulb and batteries from your light. Take it outside in bright sun and peer into the tube and you will see the bottom of the plastic bulb-base/switch unit. It has a metal contact in the center for the positive end of the battery. Next to that are two small holes. Ah Ha! These holes are the secret! Insert a straight piece of wire* into one of these holes and push. The top (or bulb base) should pop out; it is a friction fit, and the switch will drop out of the battery holder. This plastic assembly is the switch and also holds the bulb. Note the positions of the tiny metal pieces that are the contacts. Clean the contact surfaces, especially the contact that touches the underside of the battery tube. The switch acts by the lens cover pushing the bulb assembly towards the battery and breaking the electrical circuit here. It may be necessary to scrape the aluminum tube here with a screwdriver to remove corrosion. After all is bright and shiny, reassemble in reverse order. A little silicone oil on the "O" rings will make your light dirt and waterproof once again.

Check or replace the spare bulb stored in the base under the spring. There are three sizes of bulbs; be sure to use the correct size: 2-AA, 2-AAA, 1- AAA (Solitaire).

* To remove the bulb/switch from a two-AA-cell Mini-Mag, use a 5-inch [13 cm] piece of coat hanger wire (.090 inch; 2.3 mm). For the single-AAA-cell Mini-Mags, use a straightened paper-clip (.035" [0.9 mm] wire).

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FOOT-CANDLES

David Gibson

Footnotes to David Gibson's article "Candlepower" in JCREG 26.

Despite what you may hear to the contrary, "traditional" high-brightness LEDs are not as efficient at turning electricity into light as are filament lamps.

That contentious statement needs some qualification. It depends, of course, on the devices with which you choose to make the comparison. LEDs are perhaps 100 times better now than early examples; and filament lamps can vary in efficiency by twenty times or more. A typical halogen or krypton flashlight bulb may be rated at 18-22 lm/W (the figure in Candlepower was a mistake!). A non-halogen bulb might be 6 lm/W, but even lower efficiencies, down to 1 lm/W, are possible for very small bulbs.

The "traditional" high- and ultra-bright LEDs are "bright" in terms of candela rating, but a power efficiency of under 3 lm/W is fairly typical (I explained the units of candela and lumen in Journal 26). A more recent "high power" LED, such as the HLMP-8100 is still only around 8 lm/W. To find an LED which is better than a good halogen lamp you need to look to the very latest LEDs – an example from Kingbright suggests 36 lm/W.

As for fluorescent lamps, the tiny 50mm 1W tubes are only 4.5 lm/W, but a typical 11W "compact fluorescent" is over 80 lm/W, and a high-efficiency 55W tube is almost 90 lm/W. The diffuse light does mean that it is difficult to compare like with like – LEDs do have their uses, but not (yet) as general cave illuminators.

The lumen output of an LED is the intensity [cd] 0.000242 (is beam angle). This gives an approximate answer because the light is not distributed evenly; but the spill outside the beam makes up for the -3dB drop-off at the beam edge and it is good enough for a rough comparison (over 2/3 of the light is in the beam unless the LED package is diffuse). A more accurate answer can be got by inspecting the polar diagram, but you have to remember to convert beam-angle into solid angle, so it gets a bit tricky.

Reference

Gibson, David (1996), "Candlepower", JCREG 26, Dec. 1996, p27.

The foot-candle is an obsolete unit of illumination, equivalent to 1 lm/ft2.

RECHARGEABLE ALKALINE CELLS

by Reno Lippold, N2WAS, January 28, 1997

1. **Purpose and Scope**. The purpose of this report is to make a comparison between the rechargeable alkaline cell manufactured by Rayovac Corporation, called Renewal, and some competitors, the alkaline primary cell, and the nickel-cadmium (Ni-Cd) secondary cell. The comparison is made in the context of use for a primary cave light. Information comes from the listed references, personal experience, and tests performed on C cells.

2. **Background**. Rayovac says rechargeable alkaline manganese (RAM) cells have been around for 40 years. They are making another attempt at promoting them and are investing plenty -- I saw them advertised during the 94 Super Bowl, and they were recently using Michael Jordan as a spokesperson. All alkaline manganese cells are rechargeable to a limited extent. Manufacturers provide warnings against recharging the standard alkalines and state they can leak or explode if charged. Still one company did market a recharger specifically for standard alkaline cells, though Consumer Reports indicated that with this charger, the best one could do is double the life of the cell. So apparently the RAM cells are designed in such a manner as to enhance their recharge characteristics.

3. Before getting into the results of my testing, I will cover some other areas important to cell comparison. Emphasis in the discussion is placed on the Renewal cell. Most information on the Renewal cell comes from a 1994 Rayovac product data sheet. It is possible that improvements have been made since then.

a. **Charge Retention**. Rayovac claims their Renewal cells will hold a charge for up to 5 years. I believe this is on par with standard alkalines. However, this differs radically from the Ni-Cd which will go dead in about four months at room temperature unless they are left on a trickle charge. Depending on your application, this may be one of the key advantages of the Renewal over the Ni-Cd.

b. **Earth Friendliness**. Rayovac's data sheet says their Renewal cells were 99.975 percent mercury free. Just recently I saw Renewal cells on the market which claim a mercury-free content. The contents of Ni-Cd cells (cadmium) are considered by some a serious environmental concern, although many communities have disposal facilities for this type of hazard. Some companies, like Sanyo, offer a mail in disposal program. Mercury free alkaline primary cells are now available.

c. **Temperature Affects**. Rayovac says their Renewal cell can operate from -20 to 130 degrees F. No further information was provided. While temperature undoubtedly effects the cell's characteristics, it seems that based on the wide operating range, they would not vary significantly in the temperature range cavers are normally subjected to.

d. **Cycle Life**. Rayovac rates their Renewal cells at 25 discharge cycles based on discharging to 0.8 V (with a 3.9 ohm load attached). Many more cycles are possible if the cell is only partially discharged.

e. **Charging**. The Renewal cell requires a special charger available only from Rayovac. To the credit of Rayovac, it is one of the nicest and well built cell chargers I have seen. The cells charge in 4 - 8 hours depending on the size and depth of discharge.

f. **Cost Data**. All prices are as of late 95 in New York State. All cells are size "C". Prices do not include tax. All Renewal items are manufactured by Rayovac.

Renewal 8 Cell Charger; Toys R Us; $29.99 each
Renewal Cell, 714-2; Toys R Us; $5.49 for 2
Deluxe Ni-Cd Charger; Radio Shack; $29.99 each
Hi Cap Ni-Cd, 23-141; Radio Shack; $6.99 each
Super Alk, 23-551; Radio Shack; $2.69 for 2

Rayovac provides a life-cycle cost comparison in their data sheet between one set of 6 Renewal AA cells plus a AA/AAA charger (~$10.00) and "regular alkalines". They show the Renewals running a Sega Game Gear at $0.16 per hour with regular alkalines costing $1 per hour. C and D Renewal cells require the more expensive battery charger, though it is a one time cost.

g. **Other**. The Renewal cell does not suffer from the memory effect, a problem often associated with Ni-Cds. I have never noticed a significant problem with my Ni-Cds and memory. Further, the problem can be easily avoided or corrected. Because of a fairly significant loss of capacity with each cycle, it is important to keep Renewal cells in matched sets, though I attempt to do this with Ni-Cd cells as well.

4. **My Testing**.

a. **Methodology**. Each test was performed using a battery of 3 cells. Unless otherwise specified, a voltage listed is the battery voltage. Average cell voltage can be obtained by dividing by 3. The ambient temperature was about 72 degrees F for all tests. Two different lamps were used as loads. The lamps are the Petzl Standard and the Petzl Halogen. Figures 1 and 2 provide the Volt/Amp characteristics of these two lamps. Several lamps were used and rotated during the testing to reduce characteristic changes caused by deterioration of the filament. The loads were applied continuously.

b. **Test Cell Specifics**.

(1) Radio Shack Super Alkaline. These are called "standard alkaline" in this report. In testing by Consumer Reports, the capacities of these cells were found to be close to the Eveready Energizer and Duracell Copper Top brands.

(2) Radio Shack High Capacity Ni-Cd. The set used for testing was three years old and had been through 20 to 30 partial cycles.

(3) Rayovac Renewal Power Cell. Two sets of 3 cells were tested to verify consistency of results though data on only one set is shown in the graphs. The cells tested had less than 3 cycles on them.

c. **Cutoff**. Cutoff is the voltage value at which a discharge is terminated. The cutoff one selects while discharging a battery can have a major impact on its performance and life. Of course cutoff used in a caving situation will vary by person, light source, and cave conditions. To aid in discussions and comparisons, two different cutoff voltages are used: 2.7 and 2.1 volts (0.9 and 0.7 volts per cell). 2.1 volts represents the voltage level at which I think nearly everyone would want to change to fresh batteries, especially if using the Petzl standard lamp. The choice of the 2.7 volt alternate cutoff is more arbitrary, but is the point at which some people may choose to change batteries, especially if using the standard lamp, and if using rechargeable batteries (I speculate many people won't feel so compelled to get every last drop of "juice" out if the cells are rechargeable.). I did not run all tests to the lower cutoff voltage. You could determine your anticipated cutoff level by applying an adjustable voltage to your lamp and approximating when you would feel the need to change batteries if in a certain cave or situation.

d. **Discharge Curves**.

(1) **Halogen Load**. Figure 3 shows the results of testing using a halogen lamp load. In my opinion, the results are rather striking. While Rayovac claims their cells have alkaline "power", this test certainly did not support this assertion. Due to a high internal voltage drop, they produced a dimmer light over the cycle and reached the 2.7 V cutoff very soon after test initiation.

(2) **Standard Load**. Figure 4 shows the performance of all cell types using a standard lamp load. The standard alkaline cells never reached even the 2.7 V cutoff before my data recorder reached its limit. While performing much better under the reduced load of the Petzl Standard bulb, the performance of the Renewal cell was still disappointing, lasting only slightly longer than the aged Ni-Cds. This point is even more significant when you realize that, according to Rayovac, the Renewal will loose on average about 2% of its original capacity on each cycle. What you are looking at is the best that they will do, since these were new cells.

e. **Capacity**. A common and simple comparison rating of cell capacity is the ampere-hour (Ah). The following table lists Ah ratings published for each cell and that which I obtained during testing. My Ah figures were obtained by creating a math model of current as a function of voltage for each lamp, using this to approximate the current for a given voltage, and then summing up each 10 minute current/time product.

Table of C Cell Capacities in Ampere-Hours (Ah)

Vc = terminal voltage at cutoff

Published Cell Capacities		My Measured Capacities			
		Halogen Lamp		Standard Lamp	
Type	0.9/0.75Vc	2.7Vc	2.1Vc	2.7Vc	2.1Vc
Std Alk	4.6/5.8	4.1	5	~5	~6
Ni-Cd	2	1.4	1.5	1.5	~1.6
Renewal	2.8	0.5	1.7	1.9	~2.5

(1) Published capacities came from sources other than my testing. For the standard alkaline, the two values are based on a load of 3.9 ohms and discharging to 0.9 and 0.75 V respectively. Radio Shack currently advertises their High Capacity Ni-Cd C cells as having 2.0 Ah. The same part number used to be advertised as 1.8 Ah. I don't think an improvement has been made. Rather, according to 1990 data, the 2.0 Ah value is based on a C/10 (C = rated capacity of the cell; in this case 2.0 Ah) discharge rate and 1.8 Ah is at a C/5 discharge rate. The 2.0 Ah value comes from discharging at a constant rate of 200 mA, much lower than would be required in most cave light applications. Higher discharge currents will lower the cell capacity. For comparison of Ni-Cd alternatives, the regular Ni-Cd C cell sold by Radio Shack has a published capacity of 1.6 Ah (also based on a C/10 discharge rate) and is half the price. The Renewal published value is based on a 3.9 ohm load discharging to a terminal voltage of 0.9 V. Rayovac says their Renewal cells will yield 48 Ah over their life.

(2) The remaining data came from my testing. The first number listed in each pair is based on a battery cutoff voltage of 2.7 volts. The second is based on a cutoff voltage of 2.1 volts. A value with a "~" prefix means I did not explicitly measure the value, but extrapolated the discharge curve to provide an estimate.

(3) Both the standard alkaline and Renewal yield significantly more energy (and give higher Ah ratings) if a lower cutoff voltage, and/or a lower current drain, is used. Note the capacity of the Renewal cell, with a halogen load and a 2.7 V battery cutoff, is so low because the terminal voltage quickly reaches the cutoff value due to a large internal voltage drop at this current level (0.5 A). But the battery is far from dead and will produce light for a much greater period if allowed to.

f. Discussion. The Renewal C cells fell far short in performance as compared to standard alkalines. Rayovac's claim that these cells "offer the high performance attributes of regular alkaline batteries" appears to be an exaggeration. The Renewals did provide reasonable performance with the lighter load, and I might be inclined to use them under these conditions. Using a higher voltage battery (say 4 cells) would allow lower current (at the same power level) which would improve performance. According to Rayovac, the Renewal cell performs better under intermittent loading (as do most cells) especially if the periods of heavy load are short. Thus the battery should perform better in a two-way radio, for example. The Renewal D cell provides more capacity and should perform better with the heavier loads. Consumer Reports found the Renewal AA cells perform much closer to their standard alkaline counterparts then do the C or D cells. I have had reasonable success with Renewal AAs in my daughter's electronic piano and my office pencil sharpener.

5. **Other Considerations and Open Issues**.

a. The Renewal cell is apparently very intolerant to being completely discharged. I had several cells go bad on different occasions after being left in a device with the switch on. While this is not recommended for your Ni-Cds either, I have never ruined them by such an event; they seem to be much more tolerant to accidents or abuse such as this. More information or testing would be required to make a more confident statement on this matter.

b. Rayovac suggests 0.8 V as a lower cutoff, but they do not discuss the effects of going lower. They state that partial discharges will yield many more cycles. But what effect does the cutoff have on total cell capacity (the Ah sum over all cycles)? During the testing, I made observations that suggested to me that cutoff at or below 0.7 V would significantly decrease the total capacity. Because it will be difficult to know your actual terminal voltage, and since individual cell voltages may be lower than the average, I recommend a cutoff of 0.9 V to ensure you do not enter the 0.7 V region. Unfortunately, I admit the use of a terminal voltage in determining cutoff is probably over simplistic due to the effect of internal voltage drop. This varies with load and means that terminal voltage is not a good indicator of "state of charge", which, I imagine, is the cutoff parameter that really determines future cell capacity. With greater loads, like the halogen lamp, a lower terminal voltage cutoff is probably equivalent in effect to a higher terminal voltage cutoff with smaller loads. More information from Rayovac or additional testing would be necessary for me to address the issue of recommended cutoff voltage with confidence. For now, I suggest you avoid deep discharging your Renewals and cut them off around 0.9 volts per cell.

6. **Conclusion**. The Renewal C cell is best suited for low power applications or where the periods of high power consumption are kept short and infrequent. If the load is kept below 0.25 A, it might be acceptable for caving lights. The Renewal may have practical use in other low current applications, especially where long charge retention is important.

References:

1. Rayovac Product Data Sheet, 1994
2. Radio Shack Enercell Battery Guidebook, 1990
3. Consumer Reports, Nov. 1991, pg. 720-723
4. Consumer Reports, Dec. 1994, pg. 784-5
5. Popular Photography, July 1994, pg. 56

(Figures 1 through 4 are on the following page.)

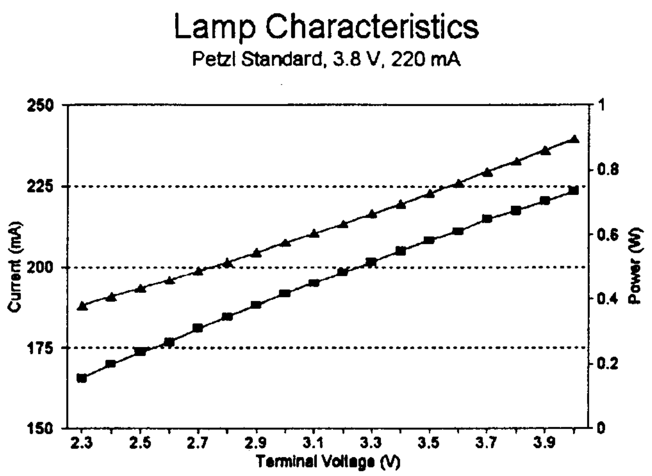

Figure 1

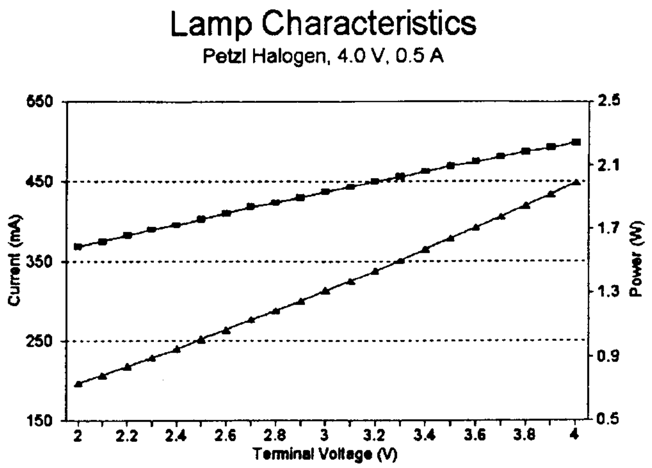

Figure 2

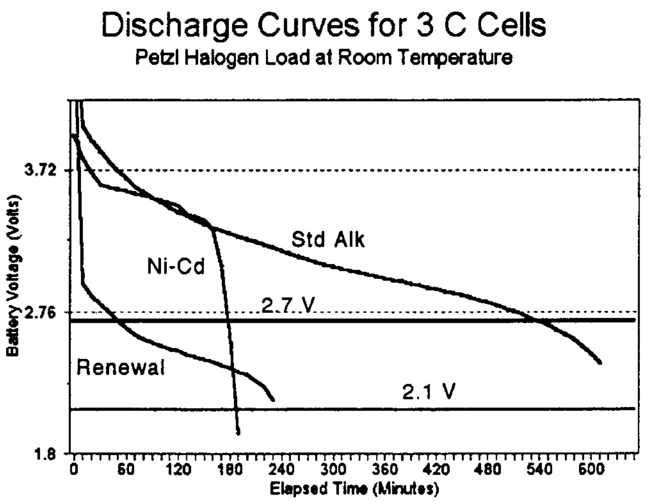

Figure 3

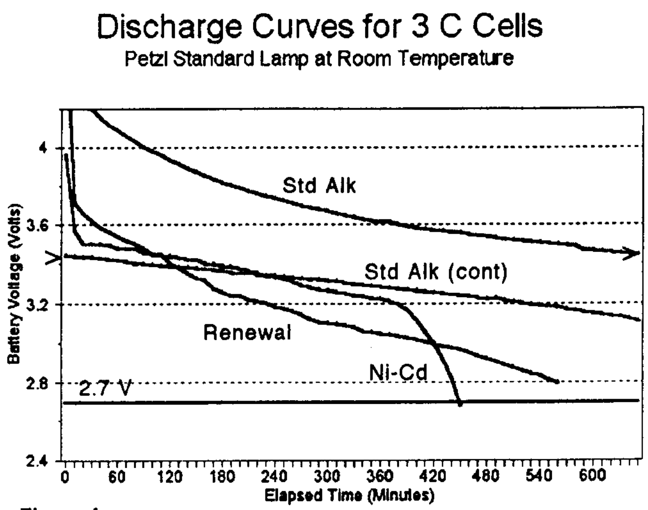

Figure 4

ALKALINE PRIMARY CELL FAILURE MODE UPDATE

Doug Strait *

In Speleonics 18 (July 1992) a failure mode of Eveready-brand alkaline cells was discussed. This failure mode was apparently related to the then-ongoing efforts to reduce the mercury content of these cells, and could be caused by subjecting the cells to shock or vibration. In subsequent discussion, Eveready engineering personnel now say that this problem has been resolved.

A less-positive battery development is that Eveready has redesigned their #529 alkaline lantern battery. These are the square 6-volt ones with spring terminals. I presume that the #528, which is the screw-terminal version, is also similarly redesigned but have not verified this. This redesign apparently occurred in 1991 or 1992. Eveready has abandoned the design which used welded intercell connections in favor of a (probably cheaper to manufacture) pressure connection design. When I called Eveready and suggested that this was a step backwards they sent me several cases of these batteries to test under conditions I considered relevant. I tested these batteries extensively and found that under some conditions their reliability is inferior to the old design. Specifically, if partially discharged under wet conditions and then stored for any length of time, they are prone to develop high resistance at the intercell connections. Also, if immersed for long periods the new design is more susceptible to mechanical damage. This is because the top and bottom of the new design is made from fiberboard, as opposed to plastic as was the case for the old design.

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THE D-Q BEACON RECEIVER

by Brian Pease

Introduction

This article gives theory and construction details of a simple high performance 3496 Hz long range "cave radio" Beacon Receiver which uses what I call a "Double Quadrature" detector to receive either a steady (non-pulsed) Beacon signal [1] for determining location and depth or CW (Morse code) for passing information to the surface. A conventional loop antenna is used to locate "Ground Zero". Searching can be aided by signal strength readings if necessary. Once Ground Zero is located, depth may be measured by the traditional "null-angle" method and/or by simply reading the signal strength on a digital voltmeter followed by a simple calibration on the surface after the trip or by the latest "ratiometric" method involving the ratio of two strength readings taken at different heights above the surface. The latter methods have allowed a complete “search-locate Ground Zero-find depth” sequence to be completed in 5 minutes by one person on the surface for depths of 50 feet in open terrain. This can result in a happy in-cave crew if a voice downlink is used, as I usually do.

Receiver sensitivity is limited only by the thermal noise of the loop, which will be overcome by atmospheric or power line noise much of the time. If needed, the narrow 1 Hz filter has 30 dB of attenuation only 17 Hz either side of the 3496 Hz carrier frequency, which suppresses 60 Hz power line interference. 3496 Hz is not a good frequency for the UK due to a very close harmonic of 50 Hz. The operating frequency can be easily changed if desired. Direct measurement of the transmitted H-field strength is also possible.

Knowledge of the conductivity of the rock can be used to improve the accuracy of the depth measurement for depths over 30-40 meters [2] [3]. By placing both the Beacon and receiver on the surface, a simple "depth-of-null" measurement allows easy rough estimation of average ground conductivity for any (approximate) depth.

The Loop Antenna

An article in *JCREG 24* [7] gives a more detailed circuit description than presented here. Referring to the block diagram (Figure 1) and the schematic/parts list (Figures 2a-2e), the loop antenna consists of one pound of #29 enameled wire wound 18.25 inches in diameter (I got 430 turns), wrapped with electrical tape and mounted on a board. I covered the winding with a (probably unnecessary) electrostatic shield. The second tuned circuit (I1 and C35, shown on this page) reduces RF amplifier overload from nearby transmitters and power lines, but should not be needed in most situations. The loop is resonated with a 1000 pF Arco trimmer plus polystyrene and/or silver mica capacitors. The thermal noise of this antenna determines the maximum sensitivity of the receiver. Appendix A gives all of the specifications for the loop and the receiver.

The RF Amplifier

The RF amplifier (U0 & U1) has been upgraded to a 3-stage design with a high impedance input using FET-input op-amps and a unique wide range gain control (R22) which varies the gain of U0 and U1A together. Counting the 40 dB input attenuator the gain can be varied from -4 to +100 dB. The circuit has low input noise compared to the thermal noise of the loop .

An RF overload LED (D6) utilizes an Exclusive-OR (XOR) gate to indicate saturation of the RF amp by atmospheric noise, power line EMI, or the beacon signal. The circuit was empirically designed but the prototype works fine.

The Local Oscillator

The local oscillator (U6) uses a common 3.579545 MHz color burst crystal which is binary divided in U6 to the 3495.65 Hz carrier and 437 Hz audio tone frequencies. It is tuned to closely match the Beacon frequency. XOR gates U7 A & B provide the 90 degree phase shifts required by the detector. If a different crystal frequency is chosen then the bandpass filter (U3B) must be changed since the audio frequency will no longer be 437 Hz.

The Double-Quadrature Detector

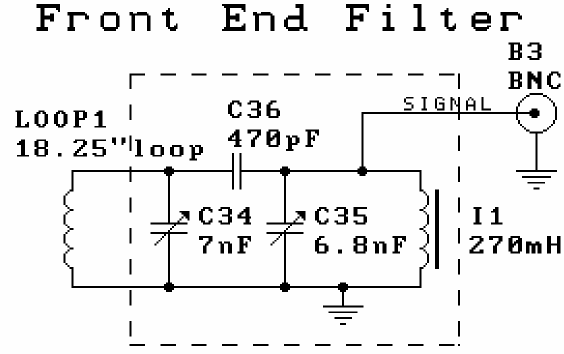
The narrow band frequency converting detector in this receiver is an improvement on the 8-pole commutating filter/ mixer (my idea) used in Ray Cole's "Organ Cave Radio" [4] [5] [6]. It was built to solve the operational problems of my "synchronous" receiver which was used for earlier location, depth, and conductivity measurements [2].

This detector uses a 2-channel in-phase/quadrature direct conversion mixer (U5A & B) whose DC (baseband) outputs are low pass filtered and then up-converted (by U5C & D) to a pair of audio tones whose algebraic sum is proportional to signal strength. The great selectivity results from the fact that the 1 Hz BW mode rolls off at -20 dB per decade based on the 0.5 Hz BW of the RC filters (R1, C1, C3 and R2, C2, C4). Without the PLL the DC outputs of the two low pass filters will drift slowly with time (one is maximum when the other is zero) but in theory their RMS sum will remain constant. In practice there is about 1 dB variation which is inaudible but is annoying for field strength measurements. The combination of the second mixer stage, summer (U3A), and 437 Hz bandpass filter (U3B) provide an audio output and allow signal strength measurement with an ordinary AC DVM. The output remains a sine wave even when the input is seriously overloaded which more or less eliminates the need for AGC, limiters, or LOG amplifiers while searching for ground zero.

The Audio Amplifier

The audio amplifier in the prototype was just a conventional non-inverting op-amp designed for use with my 2000 ohm high efficiency headphones. For the usual low impedance (8-30 ohm) "stereo" phones a better amplifier is needed so I designed the LM-386 circuit shown (U9). The new circuit may be more prone to feedback due to the higher currents involved.

Front End Filter



Minibox on loop.

The Phase-Locked Loop

A phase-locked loop can be easily added to the D-Q detector to solve the drifting problem by locking the receiver's local oscillator to the Beacon. The PLL's main purpose is to improve the signal strength readout by allowing the use of a DC meter. It also allows for a "lock alarm" that will alert the operator when a signal is present. It has no other effect on normal receiver operation.

The baseband signal from one channel of the D-Q detector is connected to the input of the high gain DC coupled amplifier U4A (+60 dB) whose output drives variable capacitance diode V1 which can slightly shift the frequency of the 3.57 MHz crystal. The total shift at 3496 Hz is only 0.14 Hz but this is more than enough. Once locked, the SIN (quadrature) signal is nulled out while the COS (in-phase) channel carries a steady DC voltage proportional to the Beacon signal. Extremely narrow loop filtering allows the PLL to lock on signals that are well below the noise and interference in the receiver's 1 Hz BW and to give a steady readout on a DC DVM. The DC meter has two desirable features: 1) There is an inherent 3 dB improvement in SNR over the AC DVM (for the same receiver and meter bandwidth) since the DC meter only sees noise from one channel and 2) the DC bandwidth can be narrowed with a simple RC low pass filter almost without limit to steady the readout. R38 & C33 give a bandwidth of 0.15 Hz for an additional 8 dB improvement in SNR. This steady (positive polarity) reading is the best proof that the receiver is phase-locked. In poor conditions, the DC readout is superior to the AC meter, although neither exhibits "drift" while the receiver is locked.

My prototype has a built-in digital panel meter that shares the receiver's power source, but requires a differential amplifier to isolate the grounds.

Lock Indicator and Audio Alarm

To make waiting on the surface less boring I added a circuit to indicate when the receiver phase-locks on a beacon. U8B is an op-amp integrator with a differential input that monitors the baseband (DC) output of both channels. When the in-phase channel rises a few millivolts (positive) above the Quadrature channel and holds for several seconds then the integrator output will rise high enough to trip XOR gate U7D and light the "locked" LED, and sound a loud alarm if desired. Its threshold is set higher than the minimum PLL lock-on signal in order to reduce false alarms. It is not foolproof but it has worked fine in field tests so far.

Circuit Construction

Ian Drummond laid out a 3-part printed circuit board containing the Beacon, original Receiver RF amplifier, and Receiver. Four boards were made and three are actually working. We may offer some updated boards for sale if there is enough interest. I plan to construct an experimental 874 Hz receiver with my board since my prototype 3496 Hz unit works just fine.

For this receiver to work properly, digital noise, especially the 3496 Hz LO signal, must be kept out of the analog circuits, particularly the RF stage, otherwise adjusting the RF gain will affect the detector null. With the PLL circuit, any 3496 or subharmonic leakage may cause "lock-up" on the receivers own LO signal at high RF gain settings and possible variation in accuracy at different gain settings. The entire radio must be shielded to prevent feedback to the loop antenna. I don't know if the loop's electrostatic shield is necessary, but I do get extremely deep nulls at close range (>70 dB) and have no "hand" effects. The second tuned circuit (if used) should be shielded and mounted on the loop to isolate it from the digital circuitry. I can place the entire receiver, including my 2K ohm headphones, at maximum RF and audio gain, into the center of the loop without feedback or noise of any kind.

I built the RF prototype amp on its own Radio Shack board and shielded it, along with the input connector (which is not grounded to the case), attenuator, and RF gain control, from the rest of the receiver. The bypass capacitors for +VCC and V/2 (C15 & C16) are also included. I used a 10 turn pot with calibrated dial for RF gain. As a precaution all analog grounds are brought individually to a single ground lug bolted to the partition separating the RF amp from the main board. Oscillation is always a potential problem with 100 dB gain. I placed a shield of grounded foil between the input circuits (B1, S3, etc) and the RF amp circuit board to eliminate some obvious feedback at maximum gain. I also used a very short coax to connect pin 3 of U0 to the input circuits, with the shield connected only at the input end.

The layout of the main board is not critical except to keep digital signals away from the audio amplifier. Again, in the prototype all analog grounds are brought individually to a lug on the same bolt holding the RF amp ground lug. The prototype used a RS 2x3x5 inch aluminum minibox for overall shielding, and a belt clip for hands-free operation. Ian's custom PC boards require a larger box.

If the PLL circuits are not being installed then C20 is replaced by a 30 pF capacitor connected from pin 11 to ground. V1 along with all parts associated with U4A, U7D, U8B, and the DC DVM output are not installed.

The D-Q detector circuit must be carefully adjusted to null out the 437 Hz tone (when no signal is present). If the PLL is not installed then you may have to replace R8 & R12 with a pot to equalize the gain in the two channels to minimize fluctuations in the AC output level when drifting phase causes the signal to shift from one channel to the other. I put the "null" control (R9) on the front panel with a knob and the "null balance" pot (R5) on the circuit card but accessible from outside with a screwdriver. "Null balance" should only need touching up once or twice a day when temperature changes. It will pay to use 1% resistors (or matched pairs) for all three DC divider networks. The actual values are not critical. The "null balance" pot should be centered before installation to aid in the initial tune-up.

The receiver will work directly from a single 9 volt battery without a voltage regulator if desired, but there will be significant drift of the null as the voltage drops along with small changes in gain.

Initial Tune-Up

1) If the PLL circuit is installed, break the loop by removing the 100k resistor (R28) from pin 1 of U4A and connecting it to V/2.

2) Turn on the receiver while monitoring current drain from the battery. Mine is 35 mA at 12 volts DC. Do not connect the antenna.

3) Check all three voltage divider circuits for a nominal value of 1/2 the supply voltage.

4) The output of each op-amp should also be about 1/2 of the supply voltage. If the PLL circuits are installed, the output of U4A is OK if it is within 1-2 volts of V/2 and varying.

5) You should hear a 437 Hz tone in the earphones. With the RF gain switch in the "low" position and the RF gain control at minimum, alternately adjust "null" and "null balance" controls until a deep null is found, leaving only noise. If you run out of adjustment range, it may be necessary to trim one of the voltage divider resistors.

6) Now put the RF gain switch in the "low" position and the RF gain control to maximum. The output noise level should increase, especially in the 32 Hz BW mode. Now connect the antenna.

7) Tune up the loop tuned circuits by using your Beacon signal while monitoring the AC output of the RF amp directly (if possible). Keep RF amp output below 1 volt RMS to avoid saturation. The 437 Hz audio tone will be steady if both channels are working. With the Beacon off, in the 1 Hz mode at high RF gain you should now be able to detect individual lightning strikes. Atmospheric noise is loudest at night and least in the morning. It is also loudest in the summer and least in the winter.

8) Match the receiver to the Beacon frequency by first receiving a fairly strong Beacon signal. If the PLL circuits are installed simply monitor test point T1 with an ANALOG DC voltmeter while adjusting C19 to lower the beat frequency as close to zero as possible. Without the PLL circuits, monitor one of the DC outputs of U2 or temporarily disconnect R8 and monitor "pulsing" audio.

9) Reconnect R28 and/or R8. A receiver with PLL should lock on the beacon signal. C19 can be touched up to "center" the voltage at test point T1 at V/2. The lock LED (L1) should light. The sensitivity of the lock indicator is adjusted by R32. Raising it's value increases weak signal sensitivity but will increase false triggering from noise at high RF gain.

10) A small "offset" will exist between the audio and DC DVM nulls with the receiver adjusted as in step 5. Adjust R42 to null the DVM. It may be necessary to move the connection of R43 from B+ to the analog ground to make this adjustment depending on whether the offset is positive or negative.

Calibration of the RF gain controls and "absolute" calibration is beyond the scope of this article. Calibration of the controls is necessary for measuring conductivity as the relative strengths of a peak and a deep null must be recorded. Absolute calibration allows depth by field strength to be measured in "real time" and allows one calibration point to be used for widely different depths. No calibration is necessary for the "ratiometric" method of depth measurement as the two numbers will always be similar enough to be recorded without changing the gain settings.

Operation

After several minutes warm-up, I carefully null the Receiver, using both null controls, at minimum RF gain and without the antenna. The front panel null control will need adjustment occasionally during the day using the same procedure. With the PLL Receiver I just set the loop on the ground; turn on the alarm; switch to 1 Hz BW; then increase the RF gain as much as possible without false alarms. I am then free until the alarm sounds when the continuous Beacon signal comes on. If the signal is strong I will use the wide BW mode while searching due to its fast reaction time.

The details of locating a "Ground Zero" and measuring depth by the "Null angle" method have been given too many times to repeat here. I use a table giving depth-to-horizontal distance ratios for each 0.5 degrees of loop tilt from vertical [8]. Null angles of 25-40 degrees from vertical should give the best results. With this receiver one has the option of measuring the relative strengths of the horizontal and vertical fields separately, and calculating the null angle as an arc-tangent. This seems to give more accurate results than direct measurement when the null is very shallow (<20 dB).

In its simplest form, depth-by-absolute-field-strength requires calibrating the Beacon and Receiver on the surface after the trip. It also requires some sort of rigid frame for the Beacon loop. After locating "Ground Zero", set the Receiver's loop horizontally on the ground and switch to the 1 Hz mode. Connect the DC DVM and set the RF gain controls so that the RF overload does not light. Record the maximum reading and the exact RF gain and switch settings. Later, set up both loops "coaxially" on the surface as shown in figure 3. With this geometry the ground has little effect on the signals (at moderate spacing over limestone anyway) so the result will be close to the "free-space" value. Use the same receiver settings recorded earlier. Now simply adjust the spacing to duplicate the reading obtained at ground zero and measure the distance to obtain the depth.

"Coplanar" surface calibration, with both loops lying on the surface, is possible, but is restricted to short spacing (perhaps 30-50 meters) as the ground has more effect on the signal than in the coaxial arrangement. Remember that the received signal strength is exactly 1/2 what is obtained with the coaxial arrangement.

"Ratiometric" depth measurement is perhaps the simplest method overall with no calibration or angle measurements required. Once at Ground Zero (precise location is not essential) one simply records the field strength (V1) with the receive loop horizontal then raises the loop a known height (h) (5% of expected depth is a good minimum) and records the strength again (V2). Since it is not necessary to adjust the receiver's gain between readings, and only the ratio of the numbers is used, no calibration is required. The RF amplifier must not be overloaded and the beacon signal must remain constant for accurate results. The calculation is a variation of the "free-space" cubic fall-off equation:

Depth = h / ([cube root of (V1 / V2)] - 1)

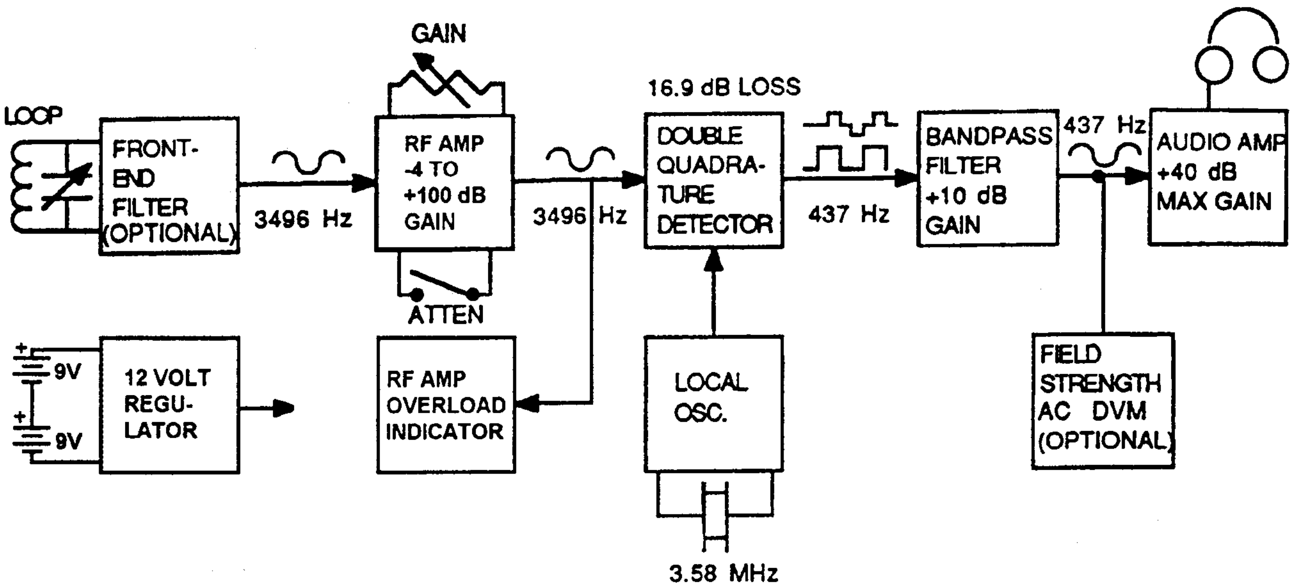
The conductivity of the rock will cause errors in all three of the depth measurement techniques, but good results should be obtained up to a depth of 30-60 meters with any of the methods. In homogeneous (uniform) earth, the Null-angle and Ratiometric methods should always give a value LESS than the actual depth, while the field-strength method should always give a value GREATER than the actual depth. As depth increases, the spread between the Absolute and Ratiometric methods will increase, but the actual depth should always lie between them! At great depths the average of the two values will be closer to the actual depth than either value alone. I have successfully simulated these effects by using a computer program that calculates the effect of conductivity on the strength and direction of the Beacon's magnetic field [9]. Using two or three methods is also a good way to pick up careless errors, even at shallow depths!

Feel free to contact me for any details of construction, calibration, or operation. Most of my parts came from Digi-Key. LF-353 or TL-082 op amps will function in all of the circuits, but current drain and DC offsets are higher. I also have an idea for improving skirt selectivity which I will try when I build my 874 Hz unit. I am also available to do locating work using this gear.

(Editor's note: The Beacon Transmitter schematic and parts list has been included for reference. An article in JCREG 23 [1] describes the transmitter in detail. See references on page 19.)

Figure 1 Beacon Receiver Block Diagram

BASIC BEACON RECEIVER



DOUBLE-QUADRATURE DETECTOR AND LOCAL OSCILLATOR USED IN ABOVE RECEIVER
(Dashed lines are the optional PLL circuits)

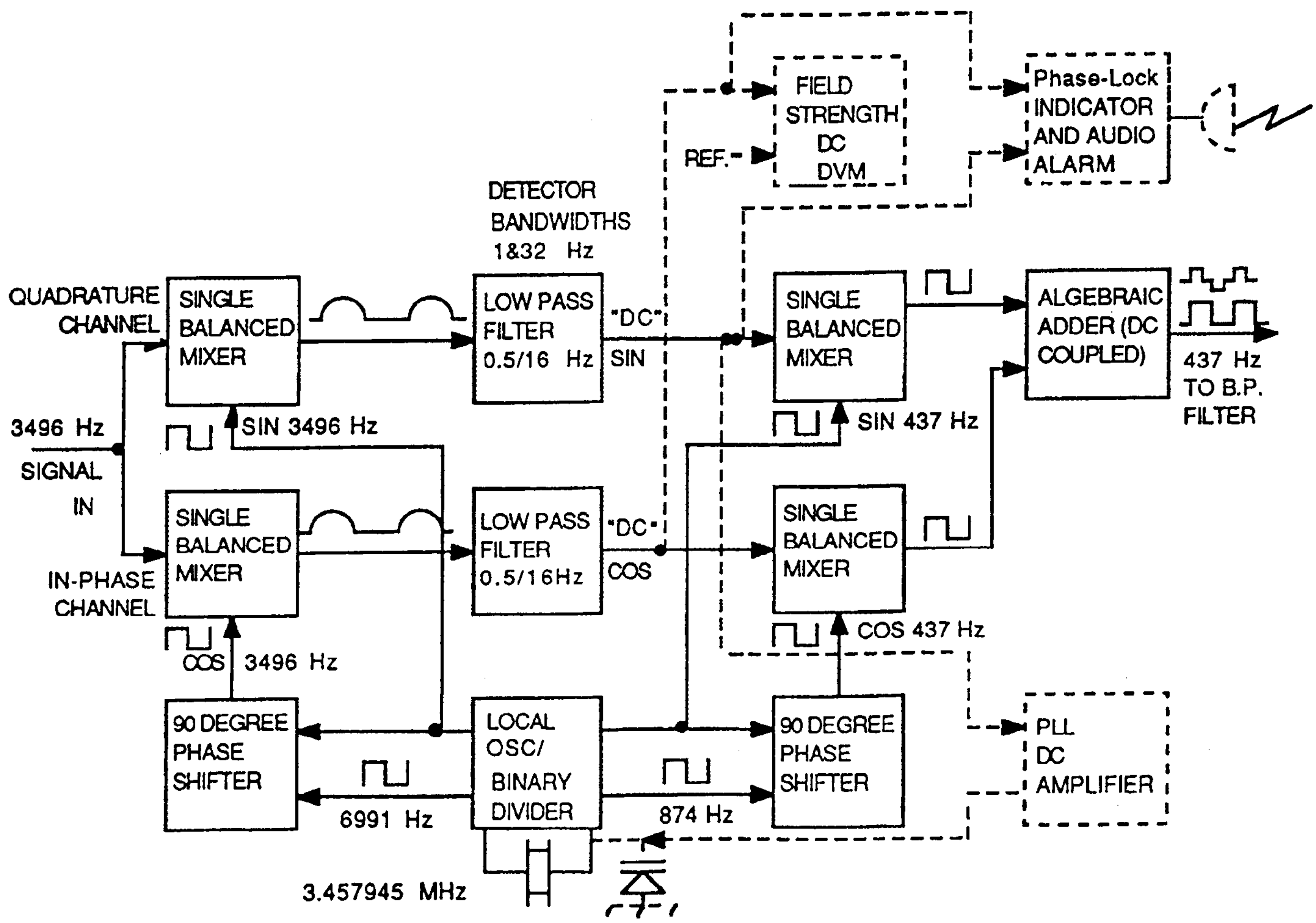


Figure 2a Beacon Receiver Schematics

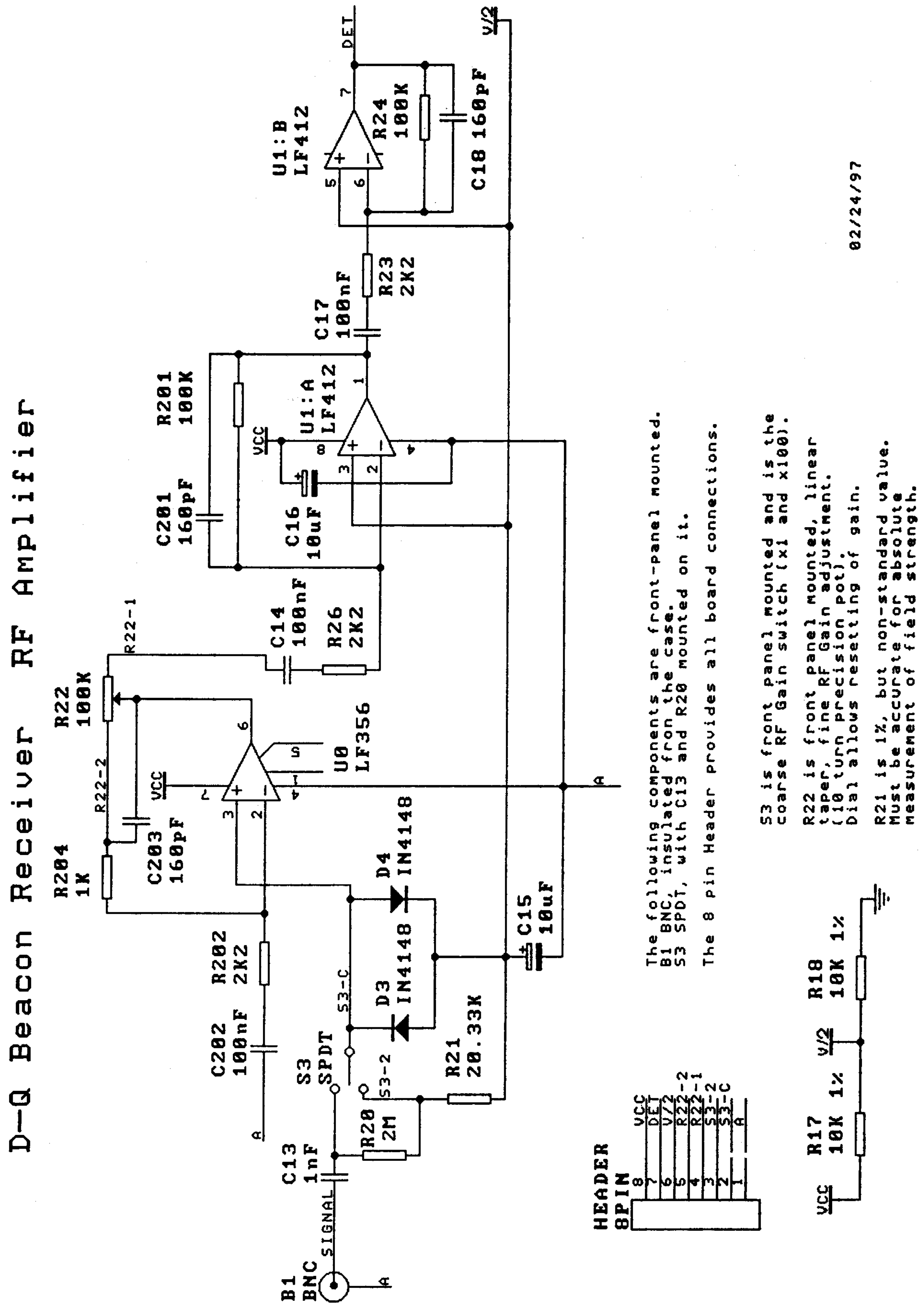


Figure 2b Beacon Receiver Schematics

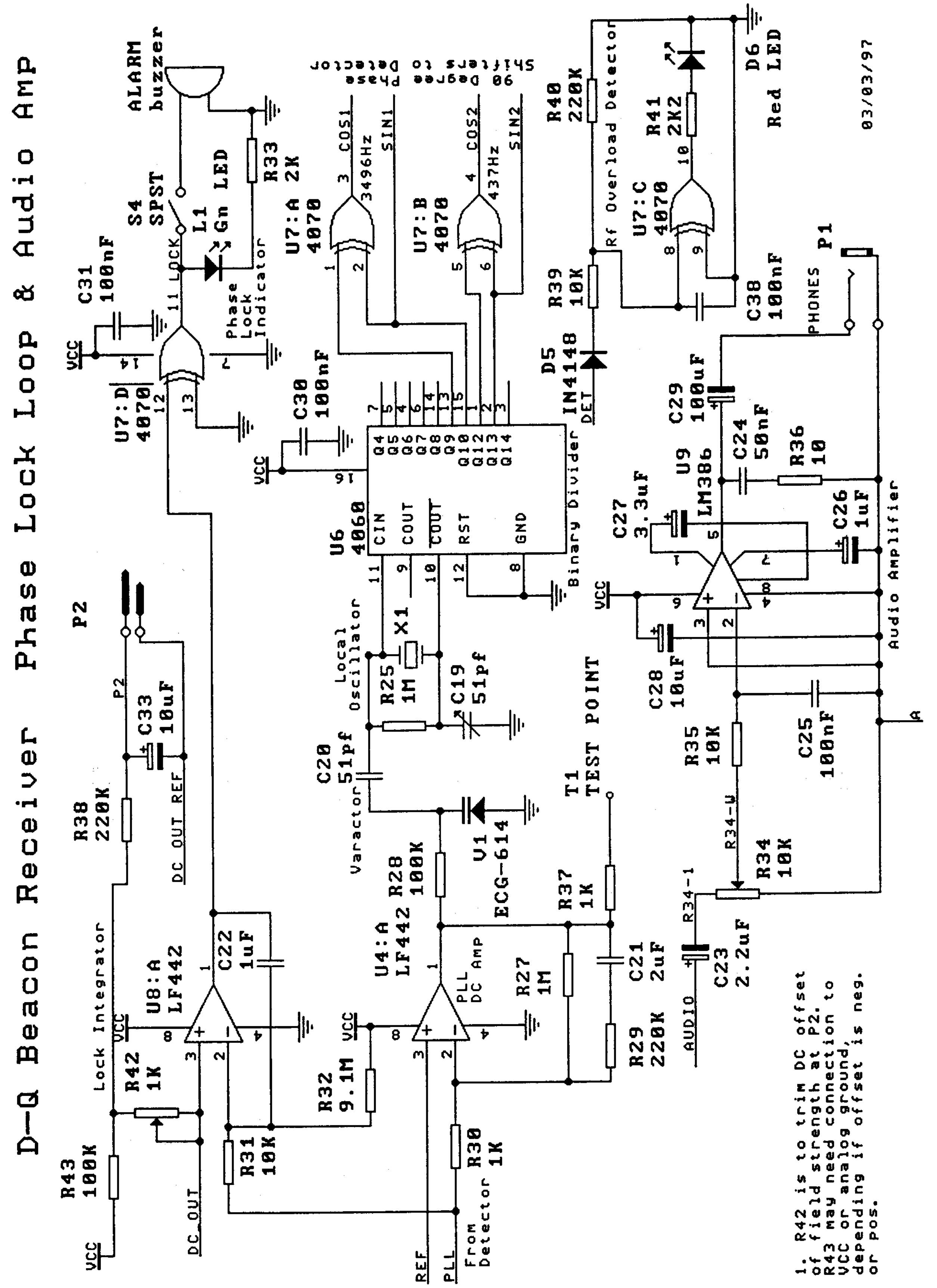


Figure 2c Beacon Receiver Schematics

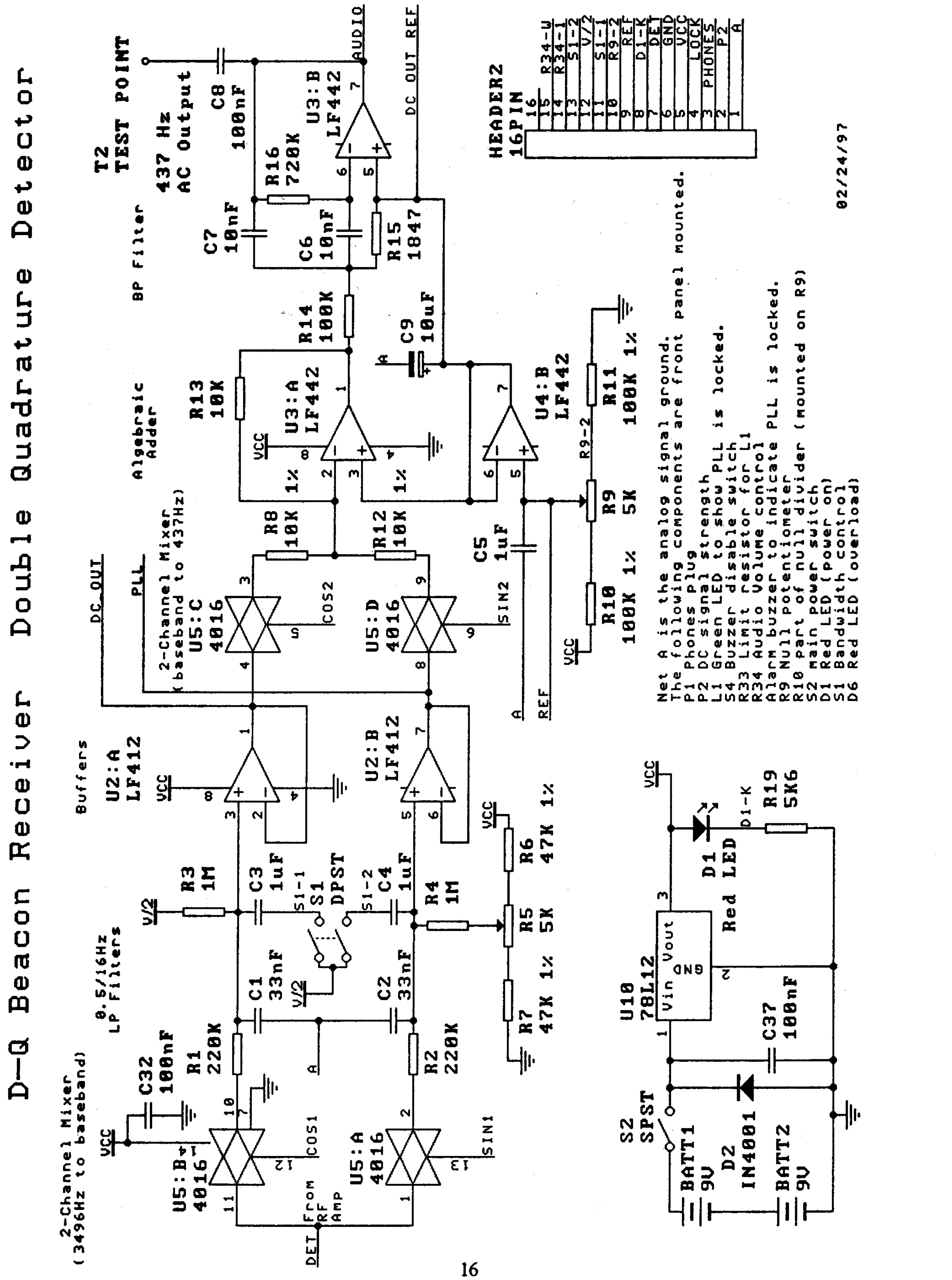


Figure 2d Beacon Transmitter Schematics

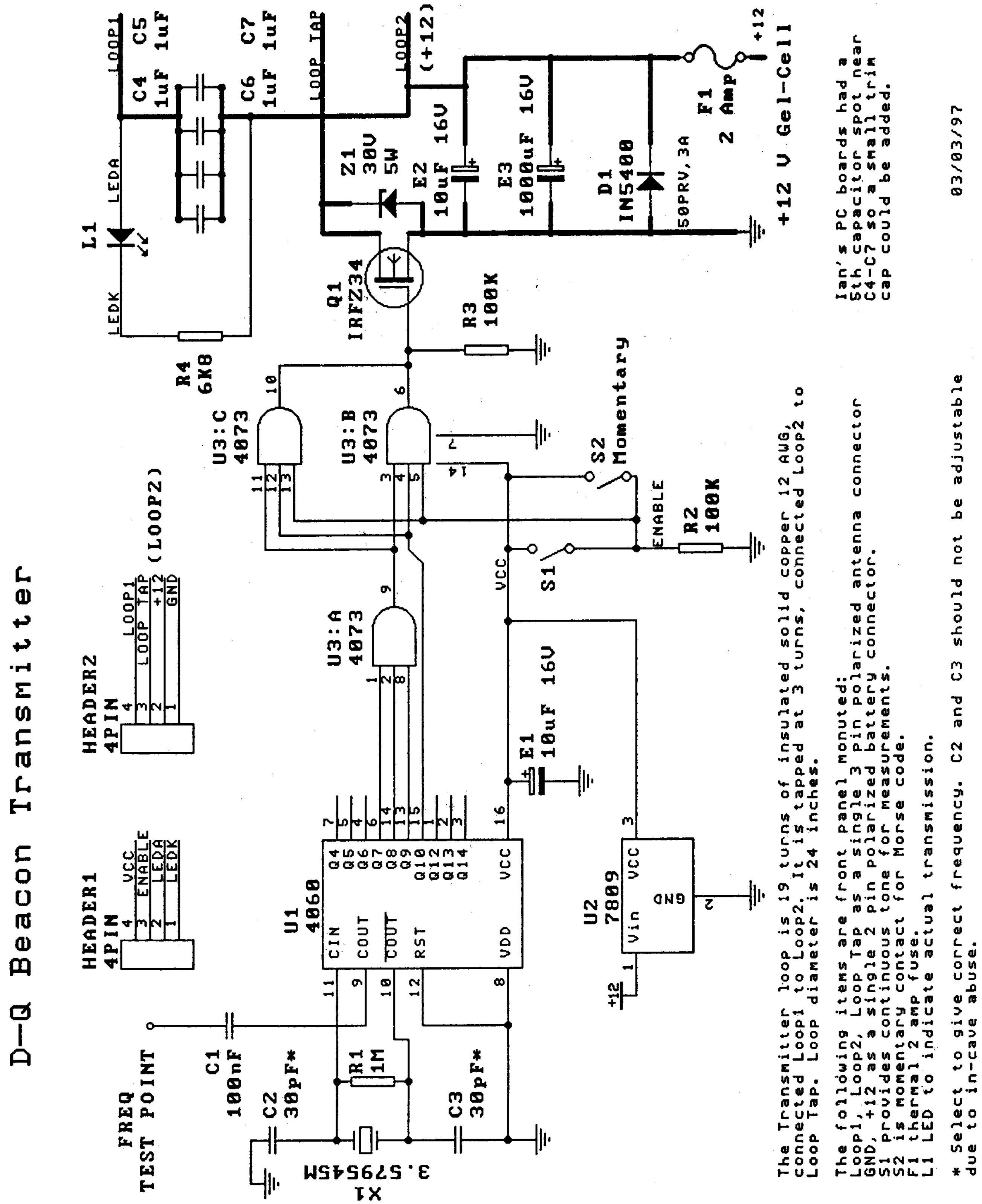


Figure 2e Beacon Rx and Tx Parts Lists

Parts list for D-Q Beacon Receiver 03-Mar-1997

Capacitors are monolithic ceramic 0.1" spacing, except as noted.
Resistors are 1/4w, 5% carbon film except as noted.

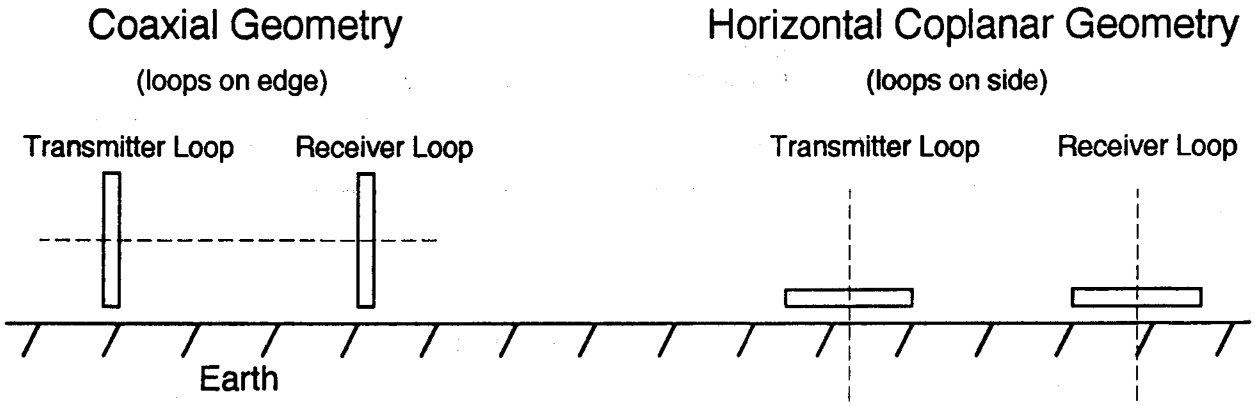
DESCRIPTION	QTY	COMPONENT NAME(S)
1/8" phone jack	2	P1, P2
1K	4	R30, R37, R42, R204
1M	4	R3, R4 , R25, R27
1nF	1	C13
1uF	4	C3, C4, C5, C22
1uF Tantalum 16V	1	C26
2.2uF Tantalum 16V	1	C23
2K	1	R33
2K2	4	R23, R26, R41, R202
2M 1% metal film	1	R20
2uF ceramic	1	C21 (two 1uF in parallel)
3.3uF Tantalum 16V	1	C27
3.579545 Mhz	1	X1 (Color burst crystal)
5K potentiometer	1	R5 (trim pot)
5K potentiometer	1	R9 (linear, multiturn)
5K6	1	R19
6.8nF	1	C35
7nF	1	C34
8PIN	1	HEADER
9.1M	1	R32
9V	2	BATT1 , BATT2
10	1	R36
10K	4	R13, R31, R35, R39
10K audio taper pot	1	R34
10K 1% metal film	4	R8, R12, R17, R18
10nF	2	C6, C7
10uF Tantalum 16V	5	C9, C15, C16, C28, C33
16PIN male header	1	HEADER2
18.25"loop	1	LOOP1
20.33K	1	R21 (1% metal film trimmed to exact value)
33nF	2	C1, C2
47K 1% metal film	2	R6, R7
50nF	1	C24
51pf	1	C20
20 to 60 pF trimmer	1	C19
78L12	1	U10 (could be ECG-950)
100K	5	R14, R24, R28, R43, R201
100K	1	R22 (10-turn linear pot with a calibrated dial)
100K 1% metal film	2	R10, R11
100nF	10	C8, C14, C17, C25, C30, C31, C32, C37, C38, C202
100uF electrolytic	1	C29
160pF	3	C18, C201, C203
220K	5	R1, R2, R29, R38, R40
270mH shielded	1	I1 (Mouser)
470pF	1	C36
720K	1	R16
1847	1	R15
4016	1	U5
4060	1	U6
4070	1	U7
BNC	2	B3, B1 (B1 shield insulated from case)
DPST	1	S1
ECG-614 (1N5470A)	1	V1 (Varactor diode about 33pF at 4V reverse)
Gn LED	1	L1
IN4001	1	D2
IN4148 or IN914	3	D3, D4, D5
LF356	1	U0
LF412	2	U1, U2
LF442	3	U3, U4, U8
LM386	1	U9
Red LED	2	D1, D6
SPDT	1	S3
SPST	2	S2, S4
buzzer	1	ALARM

Parts list for D-Q Beacon Transmitter 03-Mar-1997

Capacitors are monolithic ceramic 0.1" spacing, except as noted.
Resistors are 1/4w, 5% carbon film except as noted.

DESCRIPTION	QTY	COMPONENT NAME(S)
1M	1	R1
1uF	4	C4, C5, C6, C7
1N5363B 30V 5W	1	Z1 (or ECG5141A, NTE5141A)
2 Amp	1	F1
3.579545 Mhz	1	X1 (Color burst crystal)
4PIN	2	HEADER1, HEADER2
6K8	1	R4
10uF Tantalum 16v	2	E1, E2
30pF*	2	C2, C3 (selected for correct frequency)
100nF	1	C1
100K	2	R2, R3
1000uF 16V	1	E3
4060	1	U1
4073	1	U3
7809	1	U2
IN5400	1	D1
IRFZ34 or equiv.	1	Q1 (60V, Ron=.05 ohm, 30A cont., gate threshold < 4V)
LED	1	L1
SPST	1	S1
SPST momentary	1	S2

Figure 3 Beacon Operation - Loop Geometries



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[1] Pease, Brian, (1996), "3496Hz Beacon Transmitter & Loop", *JCREG 23*, March 1996, pp22-24. (*JCREG* is the journal of the Cave Radio & Electronics Group of the British Cave Research Association.)

[2] Pease, Brian, "Measuring Ground Conductivity With a Cave Radio", *Speleonics16*, May 1991, pp4-6.

[3] Drummond, Ian, "Ground Conductivity by Electromagnetic Methods", *Speleonics12*, April 1989, pp4-6.

[4] Cole, Ray, "Organ Cave Radio", *Speleonics 3*, Fall 1985, pp2-5.

[5] Cole, Ray, "Correction", *Speleonics 4*, Spring 1986, p1.

[6] Stevens, Paul J., "Caves of the Organ Cave Plateau", Greenbrier County WV, "Cave Radio", Appendix G, 1988.

[7] Pease, Brian (1996), "The D-Q Beacon Receiver - Overview", *JCREG 24*, June 1996, pp4-6.

[8] This table and any other information desired is available from the author for a self-addressed stamped envelope.

[9] Pease, Brian (1997), "Determining Depth with a Cave Radio, an Extreme Case", *JCREG 27*, pp?-?, March 1997. (Describes all 3 depth methods and quantifies the effect of conductivity)

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Appendix A
Specifications of the D-Q Receiver Including PLL

Theoretical ultimate range of this receiver (using headphones for searching) with my Beacon with its small 2-foot diameter loop is 885 meters in "free space" assuming coaxial loops, 1 Hz BW, 10 dB SNR, and no atmospheric or power line noise. The "real world" range may be quite a bit less, however the PLL and DC meter will work BELOW the noise in the 1 Hz BW!

Measured Specifications (12 VDC):

- Sensitivity (equivalent noise H field) is 1.3 nA/meter in a 1 Hz BW.
- Sensitivity of the RF amp (noise at input) is 20 nV in a 1 Hz BW.
- Bandwidths are 1 Hz and 32 Hz at the -3 dB points.
- Selectivity is 12 Hz at -20 dB points in 1 Hz mode.
- Loop parameters:
  Q=29 (25 with electrostatic shield)
  Resonant Z = 125k ohms (215k with 2nd LC circuit)
  Thermal noise = 54 nV/1 Hz BW with 2nd LC circuit
  E-field effective height = 0.12 meters
- Phase-locked loop bandwidth (-3 dB) is 0.16 Hz.
- PLL capture (lock) range is 0.14 Hz.
- Threshold for phase-lock is about 3 mV on the DC DVM.
- Threshold for the lock indicator/alarm is about 60 mV on the DC DVM
- Maximum RF linear RF amp output is 2.75 VRMS.
- Maximum DC meter reading is approximately 1 VDC without RF overload.
- Maximum AC meter reading is approximately 2 VRMS without RF overload.
- DC meter bandwidth (-3 dB) is 0.15 Hz with 10 uF.
- Settling times: The Receiver takes about 2 minutes to stabilize at turn-on. The DC meter takes 10 seconds to fully settle with 10 uF.
- Power: Draws about 35 mA from two 9-volt alkaline batteries in series, which will give several hours of life.

WIDEBAND PORTABLE ANTENNA

Danny Britton KB4TEP

There exists on the ham-radio market an antenna priced around $20 which is very portable, versatile, has moderate gain, and will function as a wideband antenna from the 2-meter band to approximately 157 MHz. It is the MFJ model 1714 telescoping end-fed 1/2-wave antenna with a BNC connector. Because it is a 1/2-wave antenna, it does not need a ground plane for proper operation.

Mike Doughty (KD4BYA) and I discovered this antenna's wideband capabilities while playing with his new MFJ VHF SWR meter. We found that by adjusting the last telescoping section of the antenna, we could adjust its natural resonant frequency and SWR. We found that at its fully-extended length, it was resonant at the middle of the 2m band (for which it is manufactured). After collapsing the last section to half its extended length, we found that it was now resonant at approximately 151 MHz. When the last section was fully collapsed, the antenna was resonant at approximately 155 MHz.

I tested a second antenna of the same model to verify the earlier discovery. This time I used a SWR meter with a length of coax, and found the same results. I then installed a different length of coax and found that the SWR measurements were the same. The antenna functioned extremely well at the end of a length of coax.

For remote locations, you could easily carry a length of 50-ohm coax, a small ball of string, and a piece of tape to attach the string to the next-to-last telescoping section. With a lead weight propelled by a slingshot, this antenna could be hoisted up a suitable elevated object. Frequency changes could easily be made by lowering the antenna and changing the length of the last section.

I have not tested the angle of the lobes radiating from this antenna. My opinion is that for its simplicity and capabilities, it would be hard to beat.

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NiCd MEMORY EFFECT EXPLAINED

Joe Hruska

The following text excerpts were copied from the _Maxim Engineering Journal_, Volume Twenty-Five, page 8. The schematic is on the back of this issue.

"If left undisturbed, the microcrystalline cadmium in a NiCd battery's anode slowly changes. Tiny crystals in the metal coalesce into larger ones, producing an increase in battery resistance that lowers the terminal voltage. This effect can become noticeable when repeated partial discharges leave the lowest layers of cadmium unaffected. On the other hand, an occasional complete discharge converts the entire cadmium anode to cadmium hydroxide, which allows the anode to revert (during recharge) to the desired microcrystalline state.

"Thus, a full discharge eliminates the reduction in terminal voltage sometimes (erroneously) called the memory effect. The circuit of Figure 1 'preconditions' a battery by fully discharging it (to approximately 1V per cell) before initiating a charge cycle." ...

... "The circuit requires about 10 hours to precondition (fully discharge) a fully charged battery. It then recharges the battery automatically, in about 2 hours."

"A similar idea appeared in the 1/22/96 issue of Electronic Design."

UPDATE ON HIGH-BRIGHTNESS LEDS

Doug Strait

Speleonics 18 (July 1992) contains an extensive discussion of Light Emitting Diodes (LEDs). At that time the Hewlett-Packard company was distributing pre-production samples of an amber LED based upon AlInGaP technology with a luminous efficiency of 5 lumens/watt. Full production was planned for 1993. Full production of these devices was achieved in 1993 by which time the luminous efficiency had been increased to 8 lm/watt. These devices are identified as the "HLMA" series.

Hewlett-Packard has now introduced its next generation of high-brightness LEDs which are also based upon AlInGaP technology. This series is identified as the "HLMT" series. Pre-production samples are currently available and full production in the T1 3/4 size is scheduled for June of 1995. Production of T1 and subminiature surface mount packages is planned but at least a year further into the future. The HLMT series have luminous efficiencies of 20 lm/watt. These are the first LEDs whose luminous efficiencies significantly exceed those of incandescent lamps used by cavers. For example, the popular 1- amp Wheat Lamp bulb, BM30A, has a luminous efficiency of 12 lm/watt. These LEDs even beat the popular Halogen bulb, HPR-55, which has a luminous efficiency of 18.5 lm/watt. Specifications for T1 3/4 devices which are to reach full production by June 1995 are given below:

LED_Part_#	Intensity (Cd@20mA)	Viewing_angle (deg)
HLMT-CL00	6.5	8
HLMT-CL15	4.0	15
HLMT-DL00	1.5	23

All parts have a color dominant wavelength of 590 nm (yellow) and a maximum forward current of 50 mA. There are also parts available with a 615 nm wavelength (reddish-orange) with part numbers similar to the above except for "H" substituted for "L" in the part number. Pricing is on the order of $0.75 each in quantities of 1000.

While the narrow color-bandwidth of LEDs continues to make them unattractive as primary light sources, the high efficiency of the new HP HLMT series further enhances their attractiveness as high-reliability backup sources. Driven at 40 A these LEDs have a light output equal to that of the 2 AAA cell MiniMag bulb under rated conditions.

If you plan to experiment with these LEDs it will be worthwhile to request a datasheet from HP. The graph of forward current vs. voltage looks somewhat different from other LEDs I have examined. It appears that if one were to remove the first 15% of capacity by other means, it would be possible to operate these LEDs from a pair of AA or AAA alkaline cells without a ballast resistor. If 2 alkaline cells are to be used without prior discharge of the first 15% of capacity, a ballast resistor of at least 10 ohms is indicated.

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(Editor's note: This article is almost 2 years old.)

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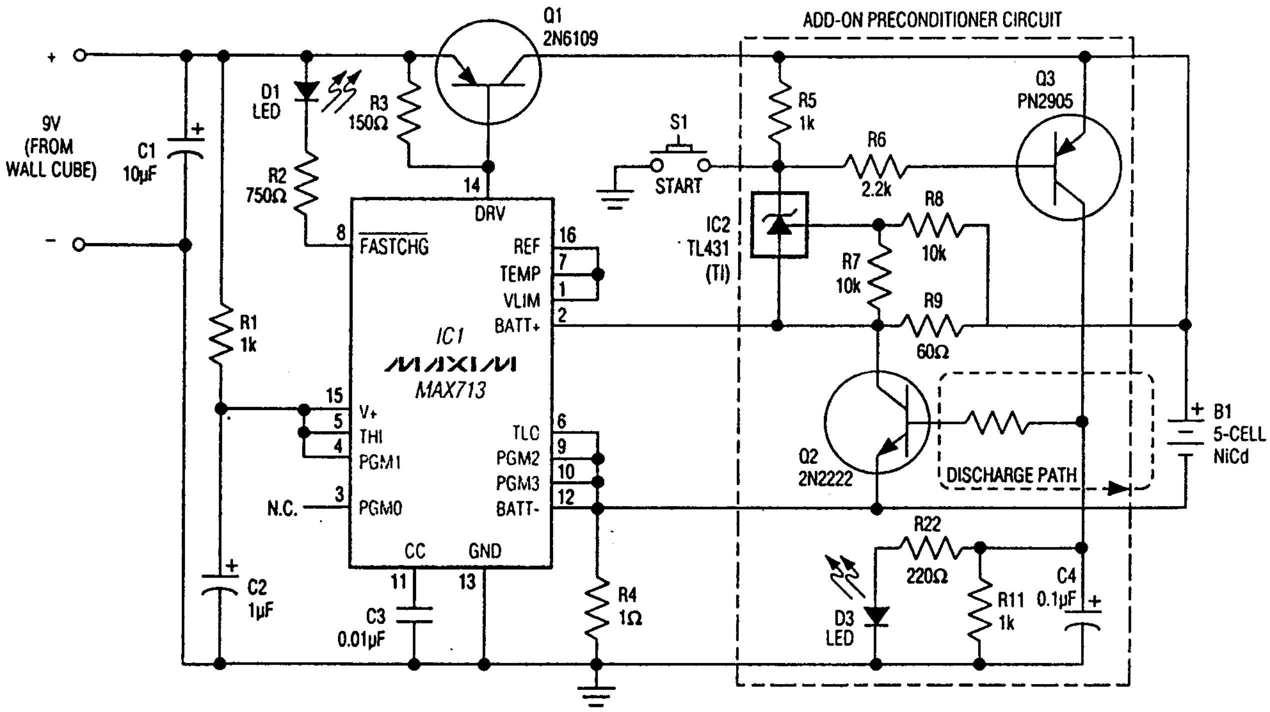

Figure 1. This add-on preconditioner circuit for NiCd battery chargers eliminates the so-called "memory effect" by fully discharging a battery before recharging it.