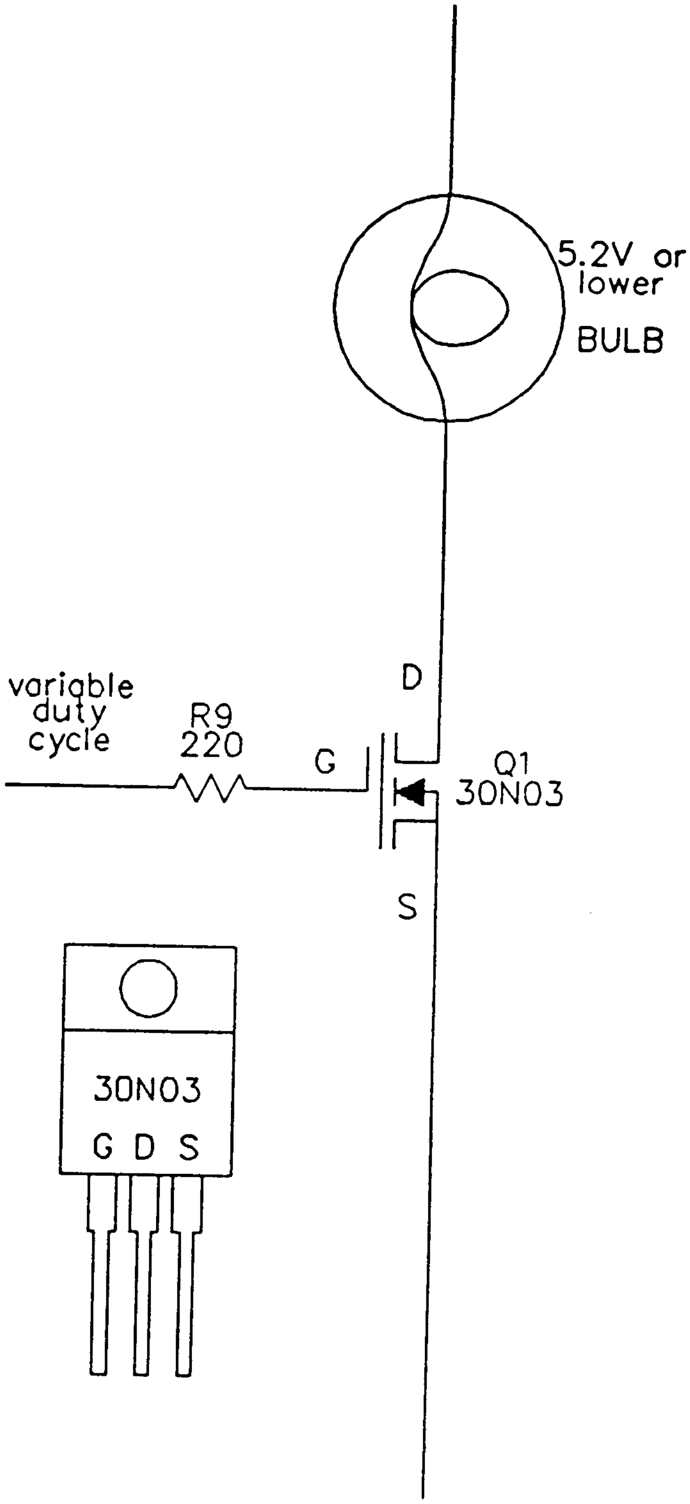
speleonics 20

Volume V, Number 4

FEBRUARY, 1994

COMMUNICATION AND ELECTRONICS SECTION OF THE NATIONAL SPELEOLOGICAL SOCIETY

CONTENTS



NOT ANOTHER LAMP-DIMMER! Efficient switching-regulator significantly enhances cave-lamp performance, including battery-energy usage, by maintaining bulbs at rated voltage. Kits are planned for this proven design. See page 9

SPELEONICS 20

Volume V, Number 4 February, 1994

SPELEONICS is published quarterly (sometimes irregularly) by the Communication and Electronics Section of the National Speleological Society (NSS). Primary interests include cave radio, underground communication and instrumentation, cave-rescue communications, cave lighting, and cave-related applications of amateur radio. NSS membership is not required for newsletter subscription. Section membership, which includes four issues of SPELEONICS, is $6.00 in USA/Canada/Mexico, $8 overseas. Send subscriptions to section treasurer Joe Giddens at the address below (make checks payable to SPELEONICS.) I you have a ham-radio callsign or NSS membership number, please include them when subscribing.

Foreign subscriptions can be paid in U.S. "paper" dollars in the mail; an international money-order may cost as much as the subscription itself. Many members have sent cash without problems. (No foreign currency, please.)

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.

Complimentary copies of SPELEONICS go to NSS offices and sections, the U.S. Bureau of Mines, U.S. Geological Survey, and the Longwave Club of America.

Chairman (and editor of this issue)
Ian Drummond VE6IXD
627 Varsity Est. Cres. N.W.
Calgary, Alberta
CANADA T3B 3C4
packet: ve6ixd@ve6yyc.#cgy.ab.can.na

Secretary (and editor of issue #21)
Frank Reid W9MKV
P.O. Box 5283
Bloomington, Indiana 47407-5283
internet e-mail: reid@ucs.indiana.edu

Treasurer (and editor of issue #22)
Joe Giddens N5IOZ
PO Box 891
Camden, Arkansas 71701

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Editorial:

Good Operating Procedures

In this edition of <u>Speleonics</u>, **Brian Pease** addresses the legalities of using cave radios without special licensing. His conclusions are very promising; it seems that caves radios as they currently exist are most unlikely to exceed the (US) FCC regulations on allowable emissions. However we need to remember a key provision of the regulations, that no interference can be caused to other users of radio-frequency devices.

How would we know if we have caused interference?

The best route would be if we were told immediately and through discussion were able to stop the interference.

Clearly a most undesirable way would be for the service which was receiving the interference to have to contact the FCC and have them go to the time and trouble of tracking the cave radio operation.

To avoid such a situation, no matter how unlikely it might seem, I would like to suggest that cave radio operators follow good operating practice, and in particular they identify themselves at the start and end of a cave radio session. This would allow anyone receiving interference to contact the operator with a minimum of fuss and presumably a maximum of goodwill to solve the problem. It would certainly help demonstrate a responsible attitude to use of the equipment.

How could cave-radio operators identify themselves? My suggestion is to use name and phone number.

I think it most unlikely that anyone other than the operator of the other cave radio will hear the call, but I think that as a group we cannot risk offending the authorities that regulate use of these frequencies. Articles such as Brian Pease's help us to design radios that do not exceed legal emission levels, and good operating practices will also help to avoid interfering with other users of the radio-frequency devices.

-- Ian Drummond

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ERRATUM

"Caver counter" circuit (Letters, <u>Speleonics</u> 19, page 1): **Pin 12 of 4047 must be grounded.** Contact Ian Drummond about availability of printed-circuit boards.

Announcements--

CALL FOR PAPERS: EQUIPMENT & TECHNIQUES SESSION

1994 National Speleological Society Convention
Brackettville, Texas, USA -- 20-24 June 1994

The technologies and techniques of cave exploration will be the focus of an all-day session that draws together many NSS Sections and other interested cavers. Before an interdisciplinary audience, both new developments and standard practices will be described, analyzed, and compared. Presentations by non-US cavers are especially welcome.

We solicit abstracts in the following areas:

Accident and Safety Analysis	Lighting
Communications and Electronics	Photography and Video
Computing	Survey & Cartography
Digging	Rescue
Diving	Vertical

There will be two formats for papers:

** Oral: a presentation before an audience, with time for questions (tentatively, between 15 and 25 minutes for each speaker)

** Poster: a show-and-tell presentation in which each presenter is provided a booth with poster boards and a table. This format is ideal for demonstrating wearable and hand-held equipment, computer applications, etc. The Poster session will not conflict with the Oral session, and should last 2 to 3 hours.

Please submit an abstract that includes title, name and address of the primary author, and a summary of the content of the presentation. The abstract should be self-contained and informative. For media, the order of preference is: (1) email; (2) Clear laser-quality printing, left-justified only, that can be scanned; (2) a DOS or Mac floppy disk with common word-processing formats or text file; (3) dot-matrix printouts or other text.

Abstract length is limited to 250 words.
Please indicate your preference for ORAL or POSTER format
Deadline for Abstracts is 15 April 1994.

The Equipment & Techniques Session will be co-chaired by **John Ganter** and **Bill Storage.** Please send your abstract to: John Ganter, 1408 Valencia NE, Albuquerque NM 87110 USA, Home: 505-265-5007, Office: 505-844-1304, FAX: 505-844-0244, Internet: jganter@ttd.sandia.gov

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[continued p. 5]

UPDATE ON THE CB TRANSVERTERS FOR CAVE-RADIO USE

Ian Drummond

Since the articles in Speleonics 19, the main piece of news about the CB transverters is that 24 commercially produced PC boards have been made. Various people have taken 10 pairs to build, so maybe the era of ready communication between cave and surface is at hand.

I hope that as units come into service, the builders and users will write in to Speleonics and let us know of the applications, the successes and failures.

The circuit used for the PC boards is the same as was published in Speleonics 19 with the exception of the power amplifier. (There are some small changes in component values to stabilize the oscillator.) The original circuit used an audio amplifier chip for the final stage. This chip was operating outside its specifications, and performance from one unit to the next differed badly. I redesigned the final stage to use a class-A FET amplifier. While this uses more power, the quality of performance is much better, being more consistent, and speech being more understandable as there is less distortion.

This modification cured the problem I was having with worse communication on the down-link than the up-link. I have obtained good 2-way communication at 250 m (820') depth, 300 m (1000') offset, which was as far as the surface party could get on the steepening mountain ridge above the cave.

The components for the transverters are available mainly from Mouser Electronics and Radio Shack, although I have used a number of other suppliers, particularly for the NE620A mixer chip. The components are all widely used and unlikely to become obsolete or unavailable in the near future.

The underground unit is mounted in a Pelican(tm) case (see photo). For voice communication the operator can simply open the case, switch on, and talk! For location work, a separate antenna is needed which must be laid out flat to give the correct geometry of the field. This unit was used in October 1993 to do four locations in the main passage of Overholt Blowing Cave in West Virginia. The case was successful at protecting the equipment while wading and crawling in the streamway.

One development I had hoped to report was the interface of the cave radio to an amateur 2m hand-held radio (or other VHF radio network such as the National Parks). Such a connection would allow a person in a cave to communicate over a wide area, to people in vehicles, to a rescue coordination centre, or to a hospital via a phone-patch.

The reason I cannot report such a development is commercial, not technical! The technology is available cheaply and commercially, but the supplier I chose to buy from (Box Products Inc, of Lexington, Tennessee) announced a redesign of the unit I ordered... after I sent my money! I am still waiting for the magic box, but do not anticipate any problems once it arrives, provided it does what the manufacturer says it does!

The November 1993 edition of 73, Amateur Radio Today, a magazine widely available in stores, has a home-brew version of a basic cross-link interface under the title, "Improved VOX mobile extender" by John Neeley, pages 20-24, which would do the basic job of cross-linking the cave radio (CB radio) to the VHF radio. The commercial unit I have ordered has the ability to control the interface remotely using touch-tones (DTMF) over the VHF radio. I feel this will be an important function if the cross-link is to be left unattended, for example over a camp in a cave for several days.

Mike Bedford, a cave radio and amateur-radio enthusiast in the UK has expressed a lot of interest in such links, and has proposed operating an amateur-radio station from a cave. I think the project is interesting, and have suggested such a link between caves in National Parks in Canada, the US, and possibly even the UK. Is there anyone out there interested in a project to link Nakimu Caves in the Canadian Selkirks to Lechuguilla in New Mexico, or Mammoth Cave in Kentucky, or Gaping Gill in the Yorkshire Dales? It won't happen next week, but if you are interested, either technically or because you would like an excuse to visit another country, drop a line to Mike Bedford, 4 Holme House, Oakworth, KEIGHLEY, W.Yorks, BD22 OQY, UK, or myself, Ian Drummond, 627 Varsity Est. Cres. NW, CALGARY, Alberta T3B 3C4, Canada.

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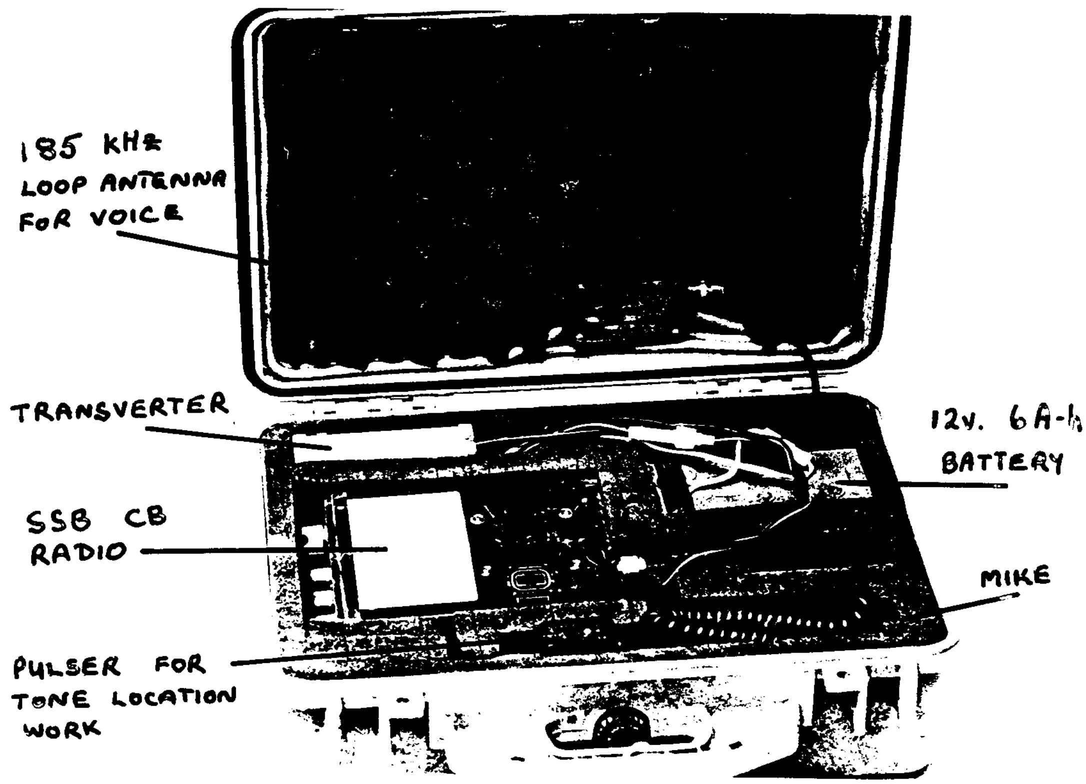

CAVE RADIOS AND THE LAW (in the USA)

Brian Pease, W1IR, NSS 7476 *

I have worked with cave radios on and off for more than 20 years. I am an engineer and not a lawyer, but I do work in the field of electromagnetics. I have carefully read the latest FCC regulations covering the unlicensed operation of radio-frequency devices and have concluded that homebuilt cave-radios employing loop antennas can be legally operated in the USA without license or approval of any kind. This includes voice radios operating at 9 to 50 kHz (or higher) as well as the common navigation-beacons operating at lower frequencies, and also at higher power levels than are used at present! I will show that typical cave radios generate electric fields far below the maximum limits allowed in the regulations.

The Law

A key word is "homebuilt." Units or kits offered for sale must either be tested for compliance, or data submitted showing that the unit meets the regulations. Legally, up to five units can be homebuilt for personal use. A "kit" includes any portion of the electronic parts needed to assemble the unit, usually with a schematic or PC (printed circuit) board. I believe that just a bare PC board plus a construction article does not constitute a kit and would be OK to sell legally without doing any testing. Homebuilders are only required to do their best to stay within the allowable field-strength limits, and are not expected to make actual measurements. The key regulation is Part 15.5 which says, in part, that you must not cause interference to others, including other unlicensed devices, but must accept interference from any source.

Operation below 9 kHz

The FCC has no jurisdiction here, so anything goes as long as you don't cause harmful interference to devices operating above 9 kHz. There are no rules. You could run a kilowatt into a long wire if you watch the harmonics! The FCC does recommend that you coordinate with other experimenters to avoid interference below 9 kHz.

Operation from 9 - 450 kHz

The maximum legal electric field allowed by the FCC is limited by the well-known expression

E_{max} = 2400 / (f kHz) microvolts/metre at 300 m range on the surface of the earth (9 kHz < f < 450 kHz).

In this frequency range the measurement must be made with a simple averaging detector (except for 90-110 kHz where the quasi-peak method is required due to the presence of LORAN-C). The stated intent is to make a far-field measurement, but the free-space wavelength varies from 33333 metres at 9 kHz to 3000 m at 100 kHz, which places the measurement well into the near field at the frequencies most likely to be used.

In the far field, the electric and magnetic fields are related by the free-space equation

Far field only

$$E \text{ (volts/m)} = H \text{ (amps/m)} \times 377 \text{ Ohms}$$

Both the E and H fields decrease linearly with distance in the far field.

In the near field (less than 1/6 of a wavelength from the antenna) the E and H fields are not related in this way, and may decrease with the square or cube of distance from the antenna.

The only way to measure the electric field at 300m from a device is to do so directly with an E-field antenna, which is usually a short dipole antenna with a high-impedance preamplifier located at its feedpoint. Measurements must be made up to the tenth harmonic frequency. The regulations specifically state that no FCC measurement procedure has been published for radiated fields below 30 MHz, although engineering groups such as IEEE have written some procedures which have been accepted by FCC in the past.

If the measurements are made at some distance other than 300m, then additional measurements must be made to determine the rate of decrease with distance. If a device is being tested so that it may be offered for sale, the FCC requires a documented procedure, with photographs, as well as the results.

The FCC regulations specifically state that radiofrequency devices used in mines and tunnels (i.e., caves) can operate on any frequency or power level as long as any leakage through the earth, water, entrances, or electric conductors such as power or telephone lines, complies with the regulations above ground.

For cave-radio use, this means that a transmitter used on the surface as in 2-way voice communication is the worst case to be considered. The same device used underground will give lower electric (and magnetic) fields on the surface.

Surface Electric Fields from a loop antenna

The Optimistic View

One approach to measuring the electric field radiated from a typical voice or beacon cave-radio is to place the loop antenna horizontally on the ground in an open field in limestone terrain (Figure 1), then measure the resulting vertical electric field 300 m away using a whip antenna. The vertical E_V field is the only electric field that can become part of a "normal" electromagnetic wave and propagate any distance.

The fact is that there is theoretically no vertical electric field at this range radiated from a horizontal loop resting on conductive ground! With this reasoning, any reasonable power on any frequency is acceptable as long as no interference results.

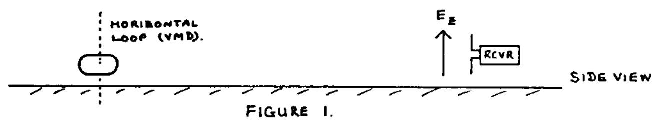

FIGURE 1.

FIGURE 2.

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* 567 Fire St.
Oakdale, Connecticut 06307

Figure 3.

Calculated maximum legal magnetic moment for a horizontal loop (VMD) on the surface of the ground, from 9 to 50 kHz.

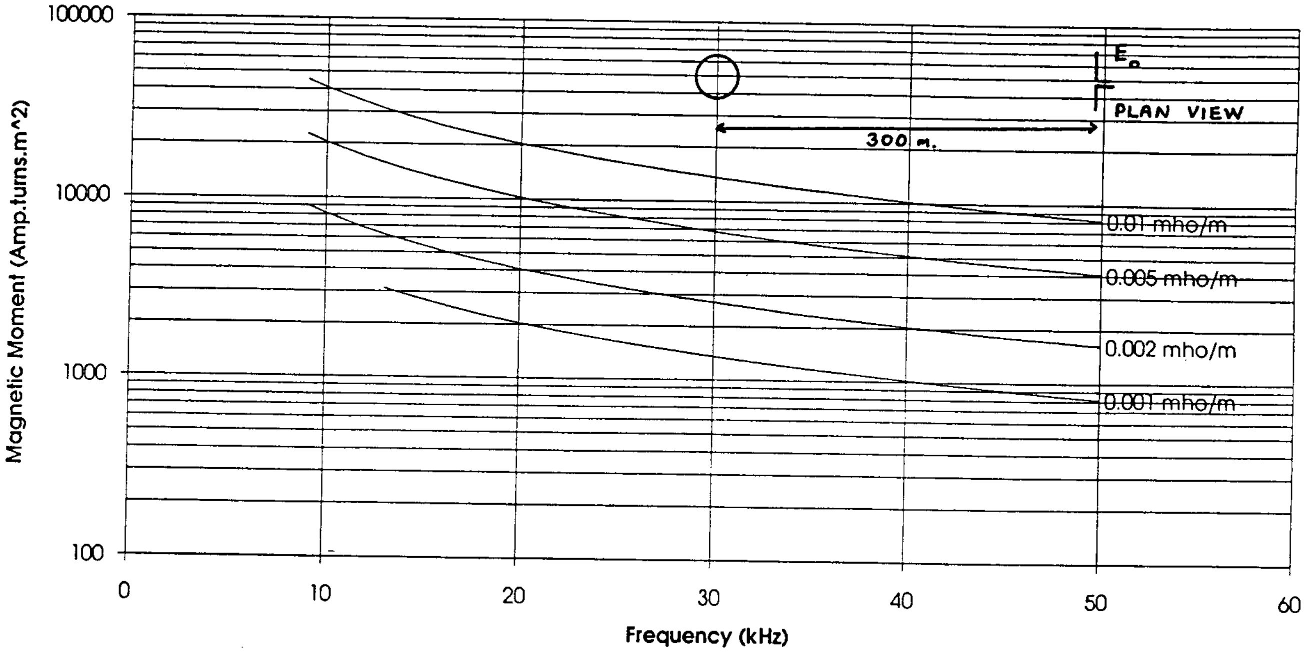
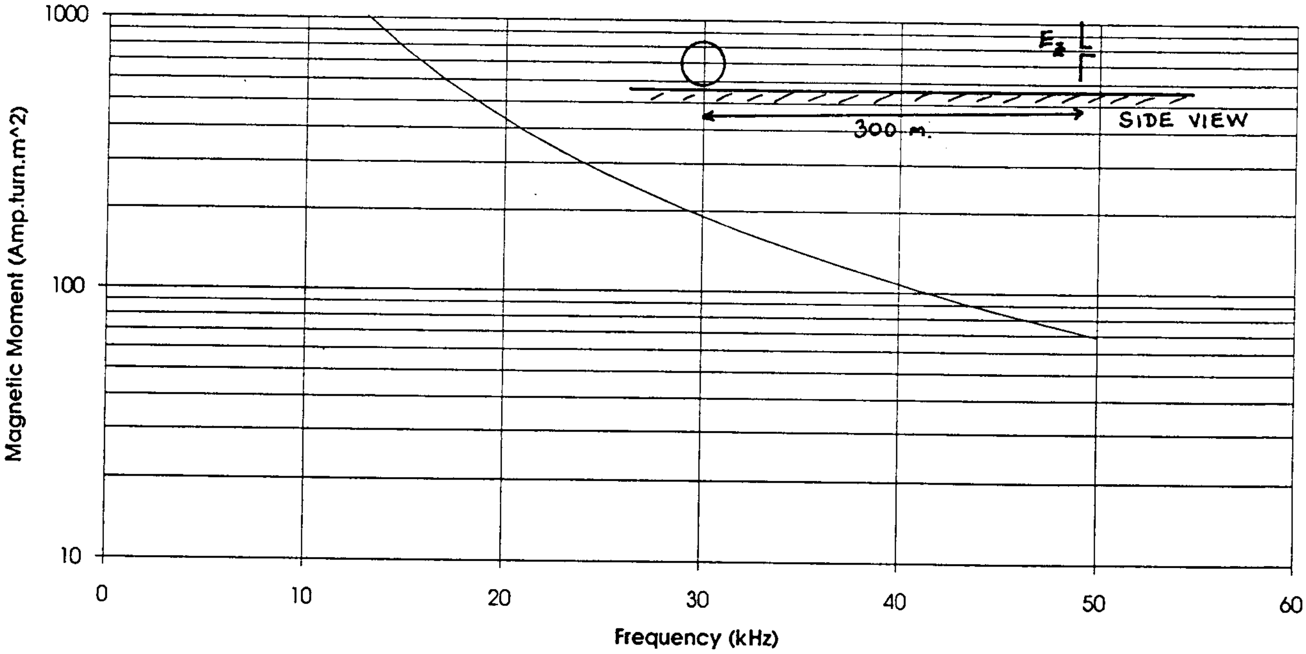


Figure 4.

Calculated Maximum legal magnetic moment for a Vertical Magnetic Dipole (VMD) on the surface of the ground, from 13 to 50 kHz.



The Pessimistic View

In this approach, electric fields of all orientations are considered, as well as the possibility of rotation of the loop antenna so its plane is vertical. At 300m range it is possible to use the "Quasi-static" field equations as tabulated by Bannister[2]. at least within the range of 9-50 kHz and ground conductivities of 0.001 - 0.01 mhos/m as found in much limestone terrain. (Unfortunately these equations do not extend to frequencies as high as the (US) license-free band of 160-190 kHz.

Ed. note: Brian would welcome assistance from someone who is able to do the numerical integration needed for the exact solutions over a wider frequency range. Anyone so interested please contact the author.

When the loop is lying horizontally on the ground (a vertical magnetic dipole, VMD) only a transverse electric field (E_o) is present. As shown in Figure 2, E_o can be measured with a horizontal E-field antenna located 300m away, and is predicted by the following equation:

$E_o = 3\ M\ /\ (2\ pi\ o_1\ r^4$ volts/m (Quasi-static model)

where M = magnetic moment of the VMD in amp·turns·metre^2
o_1 = the ground conductivity in mhos/metre
r = distance from VMD to measurement point (m)
pi = 3.1416

Alternatively, since we know that r must be 300 m and that the legal maximum electric field is given by

$E_{max} = 2.40 \times 10^{-3}\ /\ (f\ kHz)$ volts/metre

it is possible to calculate the magnetic moment of the VMD that would generate the legal maximum electric field E_{max} at 300m. These values are tabulated in Figure 3.

Even in the worst case of 50 kHz and a conductivity of 0.001 mhos/m, the magnetic moment of the antenna can be as high as 820 amp·m^2.

There are many configurations which could give such a moment, but an example could be an antenna 15' (4.6 m) in diameter with 4 turns carrying a current of 12.4 amps. Perhaps 60 watts of power would be needed to generate such a current.

These power levels and antenna size far exceed the capabilities of current cave-radios in the USA. There simply is no legal problem with cave radios in the USA!

Horizontal Magnetic Dipoles (HMD) - the real worst case

If the surface loop is turned so that its plane is vertical (HMD), then all three possible orientations of magnetic field are present.

Using the Quasi-static equations, it is possible to show that at 300 m, for the frequency range 9-50 kHz and conductivities of 0.001 - 0.01 mhos/m, that the vertical electric field E_z in the plane of the loop is the strongest of the three fields (Figure 4).

HMD, Quasi-static $E_{z(max)} = f\ u_o\ M\ /\ r^2$ volts/m

where f = frequency of operation (Hz)
u_o = 1.26×10^{-6} henries/metre
M = the magnetic moment of the HMD
r = distance from HMD to the measurement point (m)

As for the VMD, it is possible to rearrange this equation to predict the maximum magnetic moment which will not exceed the legal electric-field strength at 300 m. The graph is shown in Figure 4. This orientation of the loop is most likely to launch an EM wave. Even here it is legal to run 1.05 amps through a 4-turn loop of 15' (4.6 m) diameter at 50 kHz, or more realistically given the vertical orientation, 1.7 amps into a 40-turn 1m-square loop.

The vertical orientation might be tested for locating in the horizontal plane, conductivity measurements, or for voice communication while walking with the antenna.

Conclusions

The weak electric fields actually generated by loops at low frequencies allow homebuilt cave-radios to legally operate without licenses at much higher power levels (and frequencies) than commonly used. In particular, this will allow the development of 2-way voice cave-radios in the optimum 15-30 kHz range. A well-designed radio offered for sale should have no trouble passing any required radiated-field certification tests. No special license or field-strength measurements are required for homebuilt gear. Just keep the magnetic moment will within the limits presented in figures 3 and 4, and be especially careful not to cause harmful interference to anyone.

References
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1) The FCC regulations are found in Title 47 of the CFR which contains all federal regulations in a large number of volumes. Part 15 covers unlicensed radiofrequency devices with intentional or unintentional radiation.

2) The Quasi-static fields of dipole antennas - Part 1, P.R.Bannister, USL Report No.701, 3 Jan 1966, US Navy Underwater Sound Laboratory, New London, Conn.

Similar information will be found (perhaps more accessibly) in P.R.Bannister, Quasi-static fields of dipole antennas at the earth's surface, Radio Science, vol 1, no 11, 1321-1330, 1966 or in "The Electromagnetics Problem Solver," a book reviewed elsewhere in this edition of Speleonics.

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Announcements-- [continued from page 1]

ANNUAL CAVERS' MEETING AT DAYTON HAMFEST

Cavers and friends interested in cave-related electronics will meet again this year at the world's largest hamfest in Dayton, Ohio.

Time: 11 AM local time (EDT) Saturday, April 30.

Place: Same as last few years: Grassy area outside southwest corner of main arena building, just inside the fleamarket entrance near the lowest-numbered fleamarket spaces. Look for a Speleonics cover taped to the wall. In case of rain: Meet inside nearest exit door.

Frequency: 146.66 MHz simplex.

In past years we have had interesting discussions (even demonstrations!) of cave radio, cave-rescue communications, lights and batteries, radar-detector zapping, pyrotechnics, and exchanged locations of cave-related equipment for sale.

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THE NSS CONVENTION, PENDLETON, OREGON August 2-6, 1993

Several items of electronic interest were discussed in presentations at the NSS Convention.

The Communications and Electronics Section started off with a presentation by **Skip Withrow** on using Global Positioning System (GPS) equipment in Mexico. Skip emphasized the benefits of some advanced planning when doing surface survey work. In particular he showed how a computer program provided by the manufacturer (Magellan) could be used to select the time of day which would give the best geometric arrangement of satellites, and hence the quickest, most accurate fixes. He also showed how the data being generated could be collected by a portable computer and evaluated for reliability. Examples were shown of position data where the apparent position wandered within an approximate circle (acceptable), and where it continually slid away in one general direction (unacceptable). Skip also strongly recommended the use of an antenna mounted on a tripod about 10' (3 m) away from the operator and other objects. He showed the plots obtained in a school yard with kids playing near the unit, which seriously degraded its performance. Cavers could take note, as so far all GPS units I have seen have been in the centre of a group of people bent over the unit with their heads just about touching! Anyone contemplating using GPS on an expedition could well benefit from the ideas that Skip presented. (Skip Withrow, 5404 S. Walden St., Aurora, Colorado 80015, USA. 303-693-0997)

Doug Strait demonstrated his fluorescent (helmet-mounted) caving light. I thought the quality of the light, not to mention its quantity, looked great. Doug has had a number of lamps made professionally, and the unit he passed around was certainly very well crafted. The discussion was wide ranging. Doug has designed the power supply to be very efficient at the low input voltages typical of caver battery packs (i.e., less than 6v), and to provide constant power on a very wide range of input voltage. This has been achieved through careful design of the switching power-supply which incorporates a feedback loop. The specifications of the transformer, which has large leakage inductance, are critical. Doug showed us the circuit diagram, and discussed it in detail, but he is reluctant to publish the circuits, as he feels reproductions will not work properly due to the critical nature of the circuit values. Doug still has some units left, and is a fund of information about fluorescent lights. (Doug Strait, 17 Pinehurst Dr., Caswell Beach, North Carolina 28461, USA.)

Ian Drummond (your reporter) followed with a demonstration of his CB transverters (described in <u>Speleonics 19</u>). A comparison was made to a specification suggested by **Gene Harrison** at Frankfort, Kentucky in 1985 at the first meeting of the Communications and Electronics Section. Gene had wanted a cave radio for rescue purposes, that had the following features.

Gene's Specs:

* 2-way voice, plus emergency location.
* Range of 1000' (300m) extendable to 1 mile (1.6km) horizontally.
* Simple operation.
* Easy to build (circuit board and common parts).
* An underground unit which was less than 1 cubic foot (<28 ltr) and less than 25 pounds (<11kg).
* A standard frequency.
* Run on 4-12v power supplies.

The transverters meet many of these specifications.

* They certainly provide 2-way voice and location;
* The range is over 300m vertically and could be extended past 1.6km horizontally by use of a crossband repeater to a VHF link.
* Operation is simple (the same as a CB single-sideband unit).
* A circuit board is available; parts can be mail-ordered and are unlikely to become obsolete in the near future.
* The underground unit, complete with antenna, packaged in a Pelican(tm) case meets the size and weight specification.
* While a standard frequency has not yet been agreed upon, the transverters are easily changed over a wide range, so they will not become obsolete. Several people are using 185 kHz, within the (US license-free) 170-190 kHz band.
* Sorry, the transverters need a 12-volt supply capable of delivering 3 A, such as a 6 A-h lead-acid battery!

A couple of pairs of circuit boards (with 10 pages of documentation) are still available: Ian Drummond, 627 Varsity Estates Crescent NW, Calgary, Alberta, T3B 3C4, Canada. ph: (403) 288-4034.

The photography Section meeting had a couple of items of electronic interest.

Cave photographers are becoming increasingly concerned about light sources as the last of the flash bulbs are used up. Cave divers have always favored "strobes" (as electronic flash units are called in N. America). A small group including **Ron Simmons** and **Bill Storage** have designed and constructed a high-powered electronic flash gun. It produces 50% more light than an M3B bulb and is housed in a waterproof enclosure for use when diving. I would "guestimate" the size as 3" x 3" x 4" long [8 x 8 x 10cm] with a removeable solid 6" [15cm] reflector mounted on the end. While the xenon flash tube is readily available from Mouser Electronics, the power-supply capacitors are part of a special production run that Bill Storage persuaded Panasonic to make! There was some confusion in the meeting about their actual capacitance, either 1.5 mFarad, or 1.5 Farads. In any case there are two of them, charged to 360 volts. Later in the meeting it was mentioned that the energy per flash was 160 watt-seconds. This is consistent with the capacitance being 1.f mF; it is also a potentially lethal punch, as defibrillators for emergency medical use are often only 100 watt-sec.

I did ask Bill Storage if he would consider an article for Speleonics, but he was feeling cautious, given the potentially lethal power stored in the units. For further information on the capacitors or the flash, try Bill Storage, 2 Bayside Village Pl. #421, San Francisco, California 94170, USA. ph: (415)-512-1886.

Chris Howes, a well-known British photographer was asked to show his photographic equipment. His methods rely heavily on the use of slave units to synchronously fire flashes (bulb or electronic) that are remote from the camera. While this is not a new technique, Chris was full of praise for a new design by **Dave Gibson**, who is secretary of the (British) Cave Radio & Electronics Group. Dave's design has several very attractive features. The unit can be plugged into flash guns of any voltage or polarity; it is very sensitive to electronic flash, yet is not triggered by cavers' lights or ambient light. It is powered by a lithium "coin" cell, and the current draw is so low that no switch is needed.

A startling feature is the ability to trigger it with infrared light. Chris demonstrated how an ordinary electronic flash-gun can have a piece of unexposed, developed slide film (the black stuff) taped over the flash tube so no visible light is seen, yet the slave is still reliably triggered. The major benefit is complete elimination of the mist that obscures so many photos taken with a (visible) flash near the camera.

For information on the slave units, see RESOURCES.

********** Radio Amateurs with 160 m Privileges **********

Challenge - Challenge - Challenge - Challenge

Any amateur-radio operators who can operate on the 160-metre band (1.8 - 2 MHz) have the opportunity for some interesting and useful experiments.

Larry Jack reported in an article published in 73 magazine ("Underground Radio is a Dirty Business," Larry Jack, September 1975, pages 57 - 59) that he had best success at communicating between the surface and a "large West Virginia cave" at frequencies between 1 and 2 MHz. He was using portable radios operating at 2 to 10 watts into wire antennas ranging from a few feet to over 60 feet in length (up to 18 m). The range achieved was over 1000 yards (800 m).

Nevin Davis provided both practical and theoretical reasons why voice communication in the amateur 160m band is possible. ("Optimum Frequencies for Underground Radio Communication," Nevin W. Davis, Nat.Speleo.Soc.Bull. Vol 32, #1, pp 11-25, 1970). Using military walkie talkies with 125 milliwatts output, Nevin was able to obtain 2-way voice communication at 2000' (600 m) from an antenna buried 120' (36 m).

The underground antenna was a 120' (36 m) horizontal wire. With a similar horizontal antenna on the surface only 300' (90 m) was achieved, but with a vertical wire supported by a balloon the full range of 2000' (600 m) was obtained, as the surface EM signal is vertically polarized.

The final piece of the puzzle, which is needed for a practical 160 m communication system, is contained in The ARRL Antenna Handbook published by the American Radio Relay League, Newington, Connecticut 06111 in 1991.

Work over the last few years has developed practical transmitting loop antennas for use in the amateur bands. Chapter 5 of the ARRL book (21 pages) is on Loop Antennas. These loops are different from the usual cave-radio loops. They are electrically large, used with the loop in a vertical plane, and are designed to launch a vertically-polarized EM wave. According to Nevin Davis this is exactly what is needed to communicate with an underground station.

The loops are excellent for normal amateur contacts on 160 m, so would have application to an amateur-radio operator aside from cave-radio experiments.

They are constructed from a single turn of 3.4" (18 mm) copper tube and are used with the plane of the loop oriented vertically. Full construction details are given in the ARRL Antenna Handbook.

I would be most interested to hear from any amateurs who consider pursuing a project to develop voice communication to the underground on 160m.

--Ian Drummond

Note: The new Ten-Tec(tm) "Scout 555" amateur-band SSB/CW transceiver appears especially interesting for 160 m caving experiments because of its small size (2.5 x 7.25 x 9.75", 5.2 lb.) [6.4 x 18.4 x 24.7 cm, 2.4kg]. Output: 50 watts (variable). Power source: 12vdc. Price: US$495. See reviews in CQ (Nov. 93) and QST (Dec. 93) magazines. Another small-sized candidate is the Kenwood(tm) TS-50S (100 watts max, aprox. US$1000). -- Frank Reid

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BOOK REVIEW by Ian Drummond --

The Electromagnetics Problem Solver
by the staff of Research and Education Association, 505 Eighth Ave., New York, NY 10018; 1983 (revised edition 1987) ISBN 0-87891-550-8, soft cover 947 pages. Canadian $34.00.

To people interested in cave radios, the second part of the book is an unexpected and interesting bonus. Indeed the final 115 pages are perhaps worth the price of the book on their own. Section II is "Summary of Electromagnetic propagation in conducting media" by Martin B. Kraichman.

It is written in the style of a review paper. Four chapters cover the following topics: Basic equations and theorems, Plane waves, EM fields of dipole sources (such as cave-radio loop antennas), and EM fields of long-line sources and finite-length electric antennas. Chapter 3 on the dipole sources covers many solutions to this problem, including Bannister's approximations, used to such good effect by **Brian Pease** in measuring conductivity, and in estimating the electric field produced by loop antennas (see Brian's article on Cave Radios and the Law, elsewhere in this edition of Speleonics).

The article includes 82 references, and 4 appendices on topics including the parameters of conducting media, ELF and VLF atmospheric noise.

The first part of the book is a compilation of questions in the field of Electromagnetics, along with detailed solutions including all-numeric calculations. Indeed the text of this section contains almost as many numbers as English letters, and Greek letters run a close third!

Fourteen chapters, containing about 540 questions, cover a progression of topics starting from the basic concepts of charge and potential, through magnetic fields, and antennas. The selection of problems ranges from basic concepts through very practical questions, and liberal use is made of figures and graphs to describe the problems and solutions.

While this book is certainly not a textbook to explain concepts, it is a great help in applying the theory to obtain numeric answers to real problems.

Indeed to someone who is interested in why cave radios work, and in designing better communication systems, this whole book is very useful.

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RESOURCES

CBC International Inc. fax (602)-996-8700
P.O. Box 31500
Phoenix, AZ 85046 USA

Operated by **Lou Franklin [K6NH]**, this small company specializes in CB radio stuff; books and kits for modifying CB radios, including shifting the frequency of operation into the 10m amateur band, and changing the mode of operation to FM.

Several books, most authored by Lou Franklin, are offered for sale. They cover the range of possible audiences from a source-book on where to buy CB stuff, through "The screwdriver expert's guide," to "Understanding & Repairing CB radios for the professional technician." There are also specialized data books and service manuals.

Coverage is not restricted to US models, but covers the various aspects of CB around the world, including the European FM-only models, and the various frequency allocations. Both the current (US) 40-channel and older 23-channel models are addressed.

I purchased the "Understanding & Repairing CB Radios" book. It is 384 pages, with lots of diagrams, graphs and circuits. The text is very clear in explaining how stuff works, and the symptoms of malfunction. Lou also explains the most common failures and how to fix them. Examples from specific radios are used. In short a very useful book if you are using CB radios and are curious about what goes on inside them. -- Ian Drummond

(continued p. 14)

Magnetic Moments #10:

A PROBE TO MEASURE RF MAGNETIC FIELDS AND THE MAGNETIC MOMENT OF A TRANSMITTING LOOP

Ian Drummond

Before describing the magnetic field probe, some background material on measurement of AC voltages may be useful.

Most voltmeters have a setting to measure "AC Volts." When making a measurement, the test leads connect the circuit to the meter, where a diode rectifier converts the AC voltage to DC, which is measured and displayed. This arrangement works well at low frequencies, such as 60 Hz household power frequencies, but becomes increasingly inaccurate as the frequency rises. By 100 kHz, most meters will have errors of at least 50% in the indicated voltage, but depending upon the meter, significant errors may happen at frequencies as lows as 1 kHz.

There are several sources of error, but two of the most important are loading the circuit under test, and signal pickup by the test leads.

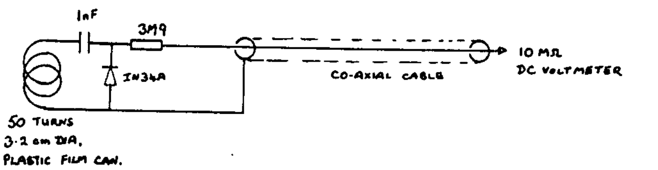
For accurate measurement the meter must not draw significant current from the test circuit. When measuring DC voltages this means using a high-input-resistance voltmeter, often 10 MegOhms. For AC voltages the input capacitance must also be small, otherwise significant AC currents can flow.

With AC voltages and currents, the test leads can act as small antennas, and totally spurious signals can be coupled into the test circuit.

The solution to these problems is to move the rectifier diode to the circuit end of the test leads, and use shielded leads to connect the meter to the circuit. The meter is set to read "DC Volts," as it is measuring the rectified voltage. Such a device is called an "RF Probe."

RF probes can be purchased for many voltmeters, or easily constructed. The American Radio Relay League (ARRL) Handbook for Radio Amateurs has construction details, and states that the finished probe is accurate to +/- 10% over the frequency range of 50 kHz to 250 MHz with an input impedance of 6000 Ohms shunted by a capacitance of 1.8 pF. My Heathkit probe states that it is useful down to 1 kHz.

The RF magnetic-field probe is built on the same principles as the RF voltage probes. The rectifier circuit is located at the test site, and a shielded cable carries a DC voltage back to the meter. The circuit diagram is shown here:



I wound 50 turns of 32 AWG (0.203 mm dia) wire onto a plastic 35 mm film canister, and mounted the capacitor, resistor and diode inside the canister. A length of 1/4" (6mm) wood dowel was inserted through the diameter of the canister to act as a wand, and the coaxial cable was run down the wand and connected inside the canister.

It is important that the DC voltmeter must have an input resistance of 10 MOhms, as this resistance forms half of a voltage divider to indicate RMS voltage, and hence RMS magnetic field strength.

The intensity of the magnetic field is given by

$$H\ (\mathrm{Amp/m})\ -\ 1.27 \times 10^{5} \cdot V / f \cdot A \cdot n$$

Where V = measured DC voltage
f = frequency (Hz)
A = area of RF probe loop (m^2)
n = number of turns on RF probe

For the probe described above, 50 turns on a film can, this becomes

$$H\ (\mathrm{Amp/m}) = 3.2 \times 10^{6} \cdot V / f$$

The magnetic moment of a cave-radio transmitting antenna can be calculated directly from the strength of the magnetic field at the centre of the loop. The magnetic moment of a transmitting antenna is a very important parameter in determining the range of a radio. Normally it has been estimated by calculation (see a computer program in Speleonics 2 by Ian Drummond, 1885), or by a multi-step measurement procedure where the current in the transmitting loop is calculated from knowledge of the power and AC resistance of the loop at the operating frequency (which is often several times higher than the DC resistance of the loop).

The magnetic field at the centre of a circular loop of n turns of wire carrying a current of I amps is given by the following expression:

$$H\ (\mathrm{A/m}) = n \cdot I / 2a$$

where a = radius of transmitting loop (m)

Since the magnetic moment of the transmitting loop equals n·I·a we can derive that the magnetic moment is equal to:

$$M\ (\mathrm{amp\text{-}turn \cdot m^2}) = 2 \cdot pi \cdot H \cdot a^3$$

$$pi = 3.142$$

Thus if the RF magnetic-field probe is used to measure the magnetic field at the hub of the transmitting loop (the RF probe must be small in diameter compared to the transmitting loop), the magnetic moment of the transmitting loop can be directly estimated.

Example:

Consider a 1-metre-square, 3-turn loop antenna operating with 2 watts of power at 185 kHz.

The Direct Measurement Method

The RF probe gave a reading of 105 mV at the hub of the loop.

The magnetic field at the hub is

$$H\ (\mathrm{Amp/m}) = 3.2 \times 10^{6} \times 0.105 / 185000 = 1.8\ \mathrm{A/m}$$

The effective radius (radius of a circle with the same area) of the 1-metre-square loop is 0.564 m, so the magnetic moment of the antenna is given by:

$$\text{Magnetic moment}\ (\mathrm{A \cdot m^2}) = 2\,pi \cdot (0.564)^3 \cdot 1.8 = 2.0\ \mathrm{A \cdot m^2}$$

The Calculation Method

To calculate the magnetic moment, the following information is needed, either by measurement or further calculation.

L = 39.h microHenries   f = 185 kHz
Q = 43   P = 2 watts

$$\text{AC Resistance} = R_{(AC)} = 2\,pi \cdot f \cdot L / Q = 6.28 \times 185000 \times 39.6 \times 10^{-6} / 43 = 1.07\ \text{Ohms}$$

$$\text{The current in the winding} = I\ \text{amps} = \mathrm{sqrt}\,(\text{power}/R_{(AC)}) = \mathrm{sqrt}\,(2 / 1.07) = 1.37\ \mathrm{A}$$

$$\text{The magnetic moment} = \text{Turns} \times \text{current} \times \text{area} = 3 \times 1.37 \times 1\ \mathrm{Amp \cdot m^2} = 4.1\ \mathrm{A \cdot m^2}$$

The agreement between the two independent methods of estimating the magnetic moment is not particularly good. The RF probe opens the way to much easier and more accurate testing of antennas, of their efficiency at converting electrical power into magnetic moment.

Incidentally, the computer program from Speleonics 2 mentioned above also predicts a value of 4.1 $A \cdot m^2$ for the experimental antenna.

PULSE-WIDTH MODULATED VOLTAGE REGULATOR FOR ELECTRIC CAVING LAMPS

by William Hunt

Problem History. A simple electric caving light using disposable alkaline batteries running a vacuum bulb works fine, but has many disadvantages. Since alkalines have a steep voltage-discharge curve, the difference in lamp brightness over the battery life can be great. Caving regularly requires spending significant money on non-reusable batteries. Vacuum bulbs do not provide as much light per watt of input as krypton or quartz-halogen lamps. Of course, krypton and halogen lamps can be and are used with alkalines, but since they tend to be relatively high-current bulbs they cause significant voltage drop of alkaline batteries because of the high cell-impedance. This drop becomes wasted power inside the batteries, which reduces the total watt-hours available, thus reducing the number of hours of light. Also, halogen bulbs perform well only if supplied with power at a small range of voltage. If the voltage is too high, the lamps burn out very fast because halogens normally operate at higher filament temperature than krypton or vacuum bulbs. If the voltage is too low, then the halogen bulb's cycle does not work properly and the bulb blackens prematurely.

Since lithium batteries have a flat voltage-discharge curve, they are much better than alkalines at providing constant bulb power. However they are very expensive, non-reusable, and pose significant safety risk if a cell is ruptured in a cave. Rechargeable lithium batteries are available but are also very expensive.

To overcome the cost problems with alkaline and lithium, two types of rechargeable batteries are normally used, nickel-cadmium (NiCad) and lead-acid. NiCads work well since they have a flat voltage-discharge curve and low cell-impedance. Thus, NiCads can run high-current bulbs at nearly constant brightness until almost depleted. However NiCads do have disadvantages. They are more expensive, especially at higher capacities, than lead-acids, and they need to be cycled completely to prevent memory problems which reduce their capacity. Lead-acids are relatively inexpensive and have a low cell-impedance. They have a steep voltage-discharge curve, but not nearly as steep as that of alkalines. This discharge curve makes them difficult to use with halogen bulbs.

Another problem with most systems is properly matching the bulb voltage and battery voltage. For example, a 5.2-volt halogen matches poorly with any 6-volt lead-acid. The off-the-charger voltage above 6.8 will burn out the bulb immediately. Most of the power comes around 6.0 to 6.5 volts which is much too high. On the other hand, a 4-volt lead-acid is much too low. Even four NiCads produce voltage on the low side of what that bulb needs, after an hour or two of use. Often it is a game to find a bulb with the desired voltage and current to match the batteries and desired number of hours.

One solution to the steep discharge curve of lead-acid batteries is to use a variable resistor (rheostat) in series with the bulb. The resistance can be decreased by the user as the battery drains. This works as a manual voltage-regulator where the user is part of the feedback system. When the bulb get noticeably dimmer, the user simply turns the knob. This solution does not conserve battery power, since power is wasted in the variable resistor.

Electronic Regulator. A better solution to many of these problems is to use an electronic voltage regulator. An ideal regulator would take power at any voltage and convert it to the desired voltage with no loss of power. Practical regulators can approach the ideal, with some limitations. By using a regulator between the battery and the lamp, constant brightness can be achieved over almost all of the battery's capacity. This is especially good for lead-acids and alkalines, since the battery voltage drops significantly from start to finish. For example, a 6-volt lead-acid can range from 7.2 to 5.2 volts, but run through a regulator it can produce a constant 5.2 volts RMS to run a 5.2-volt halogen lamp.

Since the regulator can provide a different output voltage with the Same battery, it is possible to run a 3.75-volt halogen or a 2.3-volt krypton bulb from a 6-volt lead-acid battery. Because of the regulator's high efficiency, almost all the battery power is delivered to the bulb, even though the bulb voltage may be far less than the battery voltage. This allows greater flexibility when choosing lamp-power to burn-hours for a given caving trip.

Of course all good things have a down side. Regulators do cost money. They add complexity which undoubtably reduces reliability of the lighting system. If not properly protected from water, they will fail to work correctly. However, a well-built regulator should be trouble-free and last a lifetime.

Regulator Designs. In designing a regulator for low-voltage lamps there are many aspects to consider. High efficiency must be obtained or much of the benefit is lost. Thus, the power to run the regulator itself must be small. The cost should be low, and size of the parts should be small. The output need only maintain the bulb brightness, not necessarily be DC. It would be nice if the output voltage could be higher or lower than the battery voltage.

Given these criteria, it was obvious that a pulse-width modulated waveform should be sent directly to the lamp. This requires only an electronic switch between the battery and the lamp. The only requirement of the waveform is that the RMS (root mean square) voltage be constant. In simpler terms, the power can be turned on and off at a high enough rate so that bulb averages the power, providing constant heating of the filament. As the battery voltage drops, the duty cycle (on time divided by the sum of the on and off times) increases so the bulb gets the same power (RMS voltage) but not the same peak or average voltage. When the battery voltage drops to the same voltage as the bulb, the duty cycle reaches 100%. Below that point the bulb will get dimmer, since the duty cycle cannot go beyond 100 percent. This means that the regulator cannot produce a higher output voltage than its input voltage. Thus, bulb voltages must be lower than the lowest battery voltage.

The trick is knowing what duty cycle to use as the input voltage varies. In the first-generation design, the regulator samples the bulb resistance during the off-time. The regulator then increases or decreases the duty cycle to maintain constant bulb resistance. Since bulb resistance relates to filament temperature, this works very well. However this regulator is quite complex. The 2nd-generation design tries to approximate the desired mathematical function (reciprocal of the input voltage squared). It is too simple and does not provide a wide enough input voltage range. The 3rd-generation incorporates a refinement in the approximation function. It works well enough to provide a small-percentage variation from ideal over a wide input range. Also, it is simple enough that it can be built inside most headlamps.

Regulator Operation. Figure 1 shows the schematic of the 3rd-generation design. U1 makes a 650Hz oscillator with a 99-percent duty cycle. R1, R2, D1 and C1 are the timing components of this oscillator. R3 pulls the output of U1 all the way up to the battery voltage: the

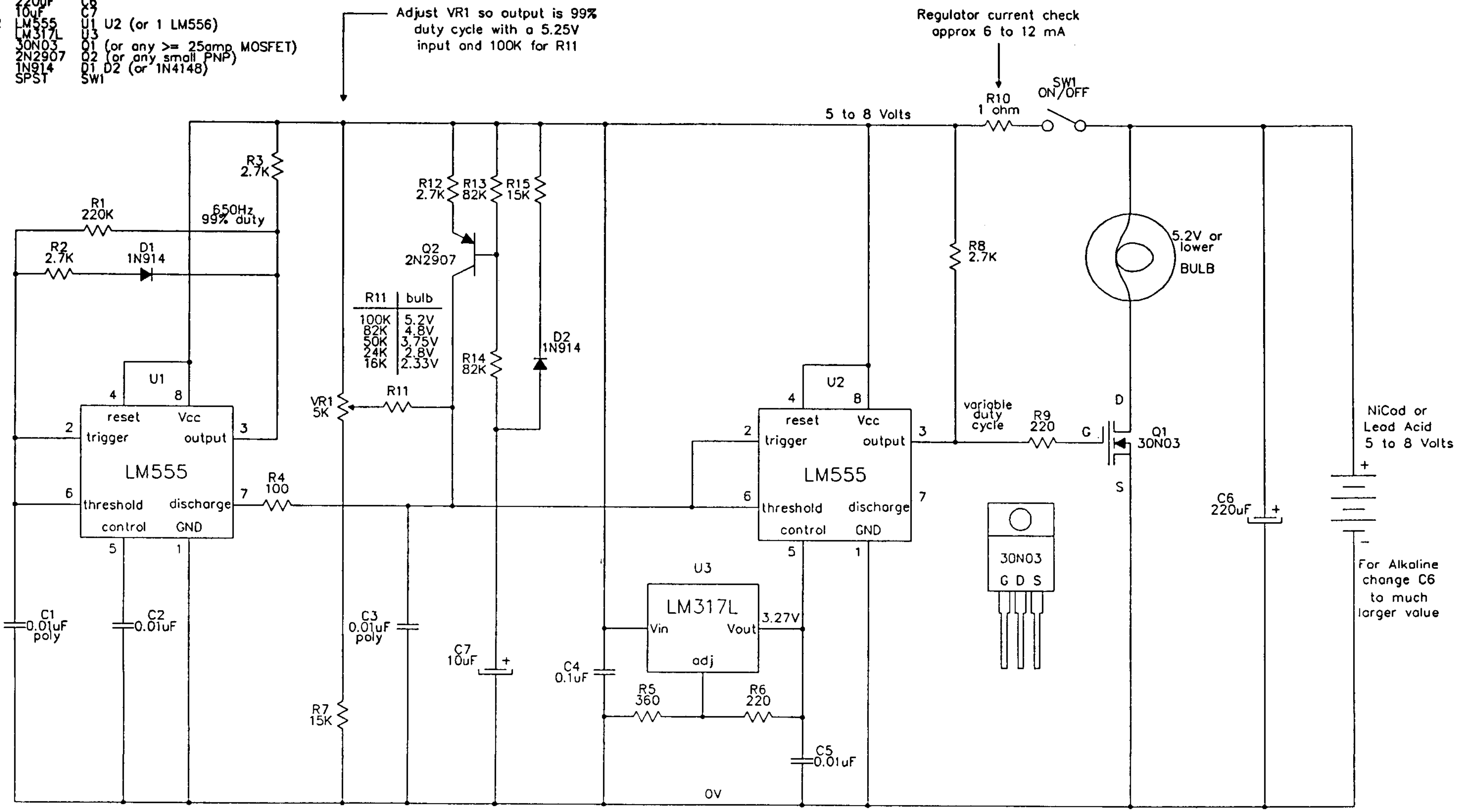
PWM light bulb regulator

8/16/93

PARTS LIST

1	1 ohm	R10
1	100	R4
2	220	R6 R9
1	360	R5
4	2.7K	R2 R3 R8 R12
1	5K VR	VR1 (use a small trim pot)
2	15K	R7 R15
2	82K	R13 R14
1	100K	R11 (or different value, see chart)
1	220K	R1
2	0.01uF	C1 C3 (poly or temp. stable)
2	0.01uF	C2 C5
1	0.1uF	C4
1	220uF	C6
1	10uF	C7
2	LM555	U1 U2 (or 1 LM556)
1	LM317L	U3
1	30N03	Q1 (or any >= 25amp MOSFET)
1	2N2907	Q2 (or any small PNP)
1	1N914	D1 D2 (or 1N4148)
1	SPST	SW1

This circuit approximates a constant power duty cycle with a log function.
Version 2 dims up lamp to prevent filament shock.



555's output does not go all the way to V_{CC} because of transistor voltage-drop. The discharge pin of U1 is connected to the pulse-width modulating (PWM) timing components VR1, R7, R11 and C3. Since the discharge pin is an open-collector output, it behaves like a switch to ground. Every 1.5 mS (1/650 Hz) the discharge pin of U1 turns on for 25 uS, completely discharging C3. VR1, R7, and R11 then charge C3 back up. U2 compares the voltage of C3, and the reference voltage coming from U3. U3, R5, R6, C4 and C5 make a 3.3-volt reference that does not vary until the battery voltage drops too low. When the voltage of C3 is less than 3.3 volts, the output of U2 is high, which turns on Q1. Conversely, when the voltage of C3 is greater than 3.3 volts the output of U2 is low, which turns off Q1. When Q1 is on, the bulb is connected to the battery which heats the filament, and when Q1 is turned off the bulb has no power, so the filament cools. Being a high-current power MOSFET, Q1 has little voltage drop because of an "on" resistance of less than 30 milli-ohms. Q1 takes no DC gate power, unlike a bipolar power transistor. R8 like R3 pulls the output of U2 up to the battery voltage. R9 prevents Q1 from oscillating in the 100+ MHz range during switching. C6 lowers the high-frequency impedance of the battery. If alkalines are used, C6 will need to be much larger. See the later section on use with Alkalines. SW1 turns the power on and off. Notice that the bulb current does not run through the switch. This prevents power loss in the switch due to bulb current. Leakage through Q1 is so small when the regulator is off that it will not affect the shelf life of the battery. R10 (1 ohm) is used to check the regulator current and prevent switch-contact pitting from charging C4. The regulator current is approximately 12 mA.

Version 2 adds components Q2, R12, R13, R14, R15, C7 and D2. These components provide a temporary faster charging of C3 so that the bulb dims-up slowly to full brightness. This should help extend the life of the bulbs, since bulbs normally burn out when power is first applied. Because a cold filament has a much lower resistance than a hot one, the initial current is quite high. This high current can overheat and fuse a thin spot in the filament before the rest of the filament heats up. If this feature is not desired, these components can be left out.

By adjusting VR1, all the timing components can be compensated for tolerance variations. R1, C1, VR1, R15, R11, C3, R5, R6, the trigger and theshold voltage of U1, and the reference voltage of U3 have the most effect on the PWM duty cycle. Of course all the values could be calculated, but component tolerances, particularly the LM555 (U1) and LM317 (U3) are much wider than desired output tolerance, thus making adjustment necessary.

Regulator Timing Theory. This section is included for those who like math or are just curious how the component values were obtained. Calculated timing values are all based on the solution to the standard RC differential equation:

$$\frac{v(t)}{R} = i(t) = C \frac{d\,v(t)}{dt}$$

which has the solution:

$$v(t) = V_{init}\, e^{\frac{-t}{RC}}$$

For the oscillator U1, the C1 charges from 1/3 to 2/3 V_{CC} with a final voltage of V_{CC}. This is a ratio of 1/2 of the final voltage of V_{CC}, thus:

$$\ln(0.5) = \frac{-t}{222.7K * 0.01uF}$$

This results in a time of 1.54 mS. Similarly, C1 discharges from 2/3 to 1/3 V_{CC} with a final voltage of 0.6 because of the diode. For a 6.0-Volt V_{CC} the ratio would be 0.412. This results in a time of 24 uS. The sum 1.57 ms makes a 638 Hz oscillator. C3 charges from zero to the voltage from U3 before the output switches off. At exactly 100% duty cycle C3 charges in exactly the time it takes C1 to charge. U3 has a nominal 1.25 volt internal reference across the R6, and 50 uA of current from the adjustment pin across R5 results in a 3.31 volt reference. Given that R11 will be 100K and the duty cycle will be 100% with a V_{CC} of 5.2 volts, the ratio of V_{CC} that VR1 should produce can be calculated approximately as:

$$V\ ratio = e^{\frac{-1.54\ mS = \ln(0.5) * 222.7K * 0.01uF}{(100K + 2K\ aprox.\ imped.\ of\ VR1) * 0.01uF}}$$

This results in a ratio of 0.220. So the reference voltage of 3.31 is (1 - 0.220) = 0.780 of the final voltage. Thus, the final voltage is 4.25 volts, which is 0.817 of the 5.2-volt V_{CC}. This means that VR1 should be 27% from the lower voltage end. Of course, component tolerances will make this vary greatly. It is interesting to note that a change of C1 and C3 values will not affect the duty cycle provided that both change the same amount.

Now, suppose that V_{CC} is raised to 6.5 volts. The output should maintain a 5.2 volt RMS. This implies the duty cycle should be 0.64 given this equation:

$$duty\ cycle = \frac{V\ RMS \wedge 2}{V_{CC} \wedge 2}$$

Working backward through the above timing calculation, the voltage of VR1 would be 5.31 volts. That makes the voltage ratio 0.376. Solving:

$$\ln(0.376) = \frac{-t}{102K * 0.01uF}$$

results in 0.997 mS plus 24 uS on discharge time, which is 0.65 of the 1.57 mS cycle time. Thus the calculated value 0.65 implies that the regulator will be very close to the theoretical value of 0.64. The only question now should be how was the 100K for R11 selected? This was done by the above calculation at 24 different voltages from 5.2 to 7.5 volts. Different values for R11 were tried and all 24 calculated duty cycles were compared with the theoretical duty cycles. Iteratively, a best-fit R11 was found. Thanks to a computer, this was a quick process. Of course, the user need not understand any of this math to build and use the regulator.

Regulator Adjustment. To adjust VR1, the regulator needs to be hooked up to a 5.25v power source, and connect a 5.2 or greater voltage bulb to the regulator. Set R11 to 100K and adjust VR1 until 100% duty cycle is achieved on the output. Back-off VR1 very slowly until the output just starts pulsing and thus is around 99 to 100%. It is easy to see when the output starts pulsing with an oscilloscope or with a logic probe. If neither are available, use a digital voltmeter on the AC scale across the bulb. The meter will read zero when the output is not pulsing, and jump up when it starts. After this adjustment R11 can then be changed to whatever value is needed to match the bulb voltage being used. The adjustment of VR1 only needs to be done once regardless of changes in R11 later to match different voltage bulbs. Table 1 shows some values for R11:

Bulb Voltage	R11
5.2 V	100K
4.8	82K
3.75	50K
2.8	24K
2.33	16K

Table 1.

```
      .----R16------------.
      |                   |
  ----*----R17---o\       |
      |            \o----*----
      '----R18---o

      Multi-bulb R11 substitute
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Figure 2.

R11 can be switched to select different values. A SPDT center-off switch can be used to select three different bulb voltages, using the circuit in figure 2. For example, if R16 and R17 are 100K, and R18 is 19K, then a 5.2, 3.75, or 2.33 volt bulb can be used by switching the switch. Table 2 lists the theoretical duty cycles for various input and bulb voltages. This can be used to check the regulator operation and to trim the value of R11. Other values for R11 can be selected empirically by using the formula given in table 2.

$$\text{Theoretical Duty Cycle} = \frac{(\text{bulb voltage})^2}{(\text{battery voltage})^2}$$

battery voltage	bulb voltage 2.33	2.80	3.75	4.80	5.20
8.00	8%	12%	22%	36%	42%
7.90	9	13	23	37	43
7.80	9	13	23	38	44
7.70	9	13	24	39	46
7.60	9	14	24	40	47
7.50	10	14	25	41	48
7.40	10	14	26	42	49
7.30	10	15	26	43	51
7.20	10	15	27	44	52
7.10	11	16	28	46	54
7.00	11	16	29	47	55
6.90	11	16	30	48	57
6.80	12	17	30	50	58
6.70	12	17	31	51	60
6.60	12	18	32	53	62
6.50	13	19	33	55	64
6.40	13	19	34	56	66
6.30	14	20	35	58	68
6.20	14	20	37	60	70
6.10	15	21	38	62	73
6.00	15	22	39	64	75
5.90	16	23	40	66	78
5.80	16	23	42	68	80
5.70	17	24	43	71	83
5.60	17	25	45	73	86
5.50	18	26	46	76	89
5.40	19	27	48	79	93
5.30	19	28	50	82	96
5.20	20	29	52	85	100
5.10	21	30	54	89	100
5.00	22	31	56	92	100

Table 2

Construction. This regulator can be built on a small piece (1 x 1.5 inches) [2.5 x 4cm] of perf board by careful placement of components and standing-up resistors. A LM556 will save space since it is two LM555's in a 14-pin package. Since capacitors tend to be much less temperature-stable than resistors, it is critical that C1 and C3 be of good quality. Polycarbonate or polyester work well. Most modern 5% resistors are stable enough for this regulator, but 1%'s can be used for better stability. If the regulator is put inside the headlamp then temperature stability is more of a concern. With a high-power halogen bulb inside a plastic headlamp the regulator may be subjected to high temperatures. Conversely, a low-power bulb in a metal headlamp will not heat up much at all.

Power MOSFET Q1 may be any N-channel MOSFET with sufficiently low on-resistance. The 30N03 ratings are 30 volts, 30 amps, and on-resistance less than 0.03 ohms. Most MOSFETs below 60 volts and greater than 25 amps will work well, as they have appropriately low on-resistance. The 30N03 loses only 0.5 percent when running a 5.2 volt, 0.88 amp bulb. MOSFETs with higher resistance will work, but efficiency will be reduced and the bulb will get less power unless R11 is adjusted. What percentage constitutes a reasonable efficiency is debatable. A simple procedure to select a MOSFET would be to keep the ratio of the MOSFET on-resistance to the bulb resistance as low as practical. Table 3 shows various bulbs and their resistance, and table 4 shows various MOSFETs. Note that the bulbs with the * are particularly demanding on MOSFET selection. Also, the bulbs with the + will require a battery voltage higher than 6 volts.

bulb		volts	amps	watts	ohms	
K-18	Krypton	7.2	0.7	5.0	10.3	+
HPR50	Halogen	5.2	0.88	4.6	5.9	
K-12	Krypton	6.0	0.65	3.9	9.2	+
K-15	Krypton	4.8	0.7	3.4	6.9	
605	Vacuum	6.0	0.5	3.0	12.0	+
K-3	Krypton	3.6	0.8	2.9	4.5	*
425	Vacuum	5.0	0.5	2.5	10.0	
HPR52	Halogen	2.8	0.85	2.4	3.3	*
Petzl	Halogen	3.75	0.5	1.9	7.5	
K-2	Krypton	2.4	0.8	1.9	3.0	*
PR-3	Vacuum	3.57	0.5	1.8	7.1	
K-1	Krypton	2.4	0.6	1.4	4.0	*
K-222	Krypton	2.33	0.6	1.4	3.9	*
PR-2	Vacuum	2.38	0.5	1.2	4.8	*
K-4	Krypton	2.33	0.48	1.1	4.9	*
Petzl	Vacuum	3.75	0.22	0.8	17.0	
243	Vacuum	2.33	0.22	0.5	10.6	

Table 3

Paralleling MOSFETs is another option. Two 0.18-ohm MOSFETs in parallel make 0.09 ohms. Drains and sources can be connected directly in parallel, but separate gate-resistors must be used. If the gates are connected directly in parallel, a push-pull oscillator will result in the 100+ Mhz range. This often kills the MOSFETs, and at a minimum will waste power.

MOSFET	volts	amps	ohms
IRFZ40	50	51	0.028
30N03	30	30	0.03
IRFZ42	50	35	0.035
IRFZ30	50	30	0.05
35N05	50	35	0.055
35N06	60	35	0.055
25N05	50	25	0.08
IRF540	100	27	0.085
IRF541	60	27	0.085
15N05	50	15	0.16
15N06	60	15	0.16
IRF530	100	14	0.18
IRF531	60	14	0.18

Table 4

The finished board will fit inside a metal Justrite (tm) headlamp. The switch on the headlamp must be replaced with a subminiature toggle switch. The switch can be soldered in for a watertight seal. The cord coming into the headlamp should also be sealed by using sealant or a grommet or both. Jacketed cord will seal better than zip cord. The front lens can be glued to the metal ring and teflon tape used on the ring threads to complete the sealing job. This is by no means watertight but will suffice for temporary immersions.

There are many other headlamps available and most are much more water-resistant than the one shown. If there is not sufficient space to put the regulator inside the headlamp then a separate box with watertight wiring through the box will be needed. If the regulator is built into a small pressure vessel it can be used diving but the user should be convinced of the construction reliability before using it for a real dive.

Lead-Acid Batteries. This regulator is designed for use with 6 volt (3 cell) starved-electrolyte sealed lead-acid batteries. There are many companies who sell these batteries in a range from 2 to 65 amp-hours. Many companies have thin packages in the 4 to 8 amp-hour range which are nice for caving. Recommended charging is constant voltage of 7.2 to 7.3 volts with an initial current limit. Most of these batteries have charging instructions printed on the batteries. Gelled types can be used although their general performance is not as good as the starved-electrolyte type. As with any rechargeable battery, be careful when discharging them fully not to reverse voltage on any one cell. The best way to prevent this is as soon as the light starts getting dim, stop using the battery.

NiCad Batteries. NiCads can also be used. A pack made of 5 cells will work best. This gives an initial voltage of less than 7 volts and an ending voltage greater than 5. AA, C and D cells are readily available, but only the high-capacity variety are worth using. The cells are rated at 0.85, 2.0, and 4.3 amp-hours, respectively. 7.5 and 10 amp-hour cells are available but are very expensive.

Alkaline Batteries. As shown, this regulator will not work properly with alkalines because they have a much higher impedance than NiCad or lead-acid batteries. The high impedance causes so much voltage ripple that the regulator will not produce the correct duty cycle. One solution to this problem is to change C6 to a sufficiently large value to reduce this ripple so that the regulator can work properly. For a 3.75 volt 0.22 amp bulb using 5 AA's, 6000 uF is sufficient. For other bulb and battery combinations the ripple should be checked and capacitance added until ripple is less than 200 mV peak-to-peak.

With high-current halogen bulbs it may be impractical to put enough capacitance in parallel with the battery, even using parallel sets of D-cells. One solution is to increase the switching frequency. This reduces the size of C6 needed for a given ripple amount. This can be done by changing both C1 and C3 to a smaller value. This has its limitations, because capacitors used for C6 will have internal resistance which will dominate the reactive capacitance if the frequency is high enough. There are low-ESR capacitors made for switching power-supplies which will work better than standard types. Also, if the frequency is increased the switching losses will start to become significant.

Further Refinement. If low-power bulbs are to be used, then the user may want to modify the circuit to reduce power consumption, thus increasing overall efficiency. If the regulator uses 80 mW with a 4.5-watt bulb, then regulator power is less than 2% of the bulb power, resulting in a 97% overall efficiency. However if the same regulator is used with a 0.8-watt bulb, then regulator power is 10% of the bulb power, resulting in a 89% efficiency. This is still high, but almost 10% more of the battery power could be used for light instead of heat.

To reduce the regulator power, construct the regulator using a CMOS version of the LM555, and modify the resistor and capacitor values. Scale-up R1, R2, R7, R11, and VR1 by a factor of 10. Scale-down C1 and C3 by a factor of 10. Scale-up R5 and R6 by a factor of 3 to 4. The LM317 will have to be tested to make sure it still regulates properly with the larger values of R5 and R6. Remove R3 and R8, since the CMOS LM555 will pull up all the way to V_{CC}. Also, Q2, R12, R13, R14, R15, C7, and D2 can be removed since low-power bulbs will probably not burn out from initial current inrush. If the dimming is still desired then scale-up the resistors by a factor of 10 and scale-down C7 by a factor of 10. These modifications will reduce the regulator current to 2 mA, which equates to 13 mW at 6.5 volts. This is 1.6% of a 0.8-watt bulb, thus efficiency will be increased to 98%. Of course, these modifications, along with paralleling two 30N03's, can be used with a 4.5-watt bulb resulting in greater than 99% efficiency. This is perfect for those who need something to brag about.

Recent Notes: I have used this regulator for caving for over a year now, and mountaineering since last summer. For mountain trips I find it invaluable, since it more than doubles what I consider the usable capacity of 5 alkaline AA-cells running a 0.8 watt bulb. I get 13 hours of light vs. about 4 hours for 3 AA's running the same bulb. For caving, I use 6 volt 6.5 AH or 10 AH rechargeable lead-acid batteries with a 4.5 watt halogen bulb. I get 9 hours from the 6.5 AH pack and 16 hours from the 10 AH, of constant-brightness light. I am so spoiled by the brightness that anything less just doesn't let me enjoy the cave as well.

The schematic (in PostScript) and documentation (in ASCII) are available by Email. This article has previously circulated via the Cavers' Forum and Internet newsgroups. Due to a large number of requests from cavers and climbers, I plan to make the headlamp voltage-regulator available:

Bare printed-circuit board	$10
Kit: pcb plus parts	$20
Assembled and tested	$30

Shipping can be done via US mail for $1 for the pcb and $2 for the kit or A&T in the US.

The kit will include all parts for the pcb but no external pieces like wiring, power switch, box, battery holder, etc. Since this regulator can be used with many types of batteries and bulbs, it is also up to the user to select the battery and bulb combination that suits his needs. I can help with this selection via Email.

The assembled and tested unit is just the kit put together, tested, and calibrated. The user must put the board inside the headlamp or other box. If the unit will be immersed in water, the box must be watertight or the unit will have to be potted.

The above items should be available by March, 1994. Prices could decrease, depending on quantity produced. Contact:

William Hunt Internet Email: willie@cs.indiana.edu
Department of Computer Science
Lindley Hall
Indiana University
Bloomington, IN 47405

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1993 CAVE-RESCUE COMMUNICATION NOTES

Frank Reid W9MKV

* A field-telephone with amplified handset (Speleonics 19) was used to good advantage during the Crossroads Cave (Virginia) rescue in June. Lightweight TA-1 military sound-powered phones were deployed underground. These have weaker signals than battery-powered types, and the staging area was extremely noisy due to gasoline-powered generators deployed by a local fire department.

Brad Bason and I also ran 1200 feet [400 m] of wire over the surface to a nearby church, and connected it (with permission) to the commercial telephone line, for long-distance medical communication. We connected this extention to a lineman's test-set, which has a dial but no ringer; we used the bell in an EE-8 field-phone set to common-battery mode.

* The rescue at Triple-J Cave (Indiana, August) required intensive surface-communications because numerous caves had to be searched for the missing persons. Many radio-amateurs (cavers and non-cavers) participated, and quickly amassed enough handheld 2-meter FM transceivers for the searchers.

An autopatch repeater provided outside communications. We successfully conducted simplex local-area communications on the repeater-output frequency. Another channel would have been required if traffic volume had caused interference.

Special thanks to **Russ Ryle** (N9DHX), who brought ham equipment to the Indiana State Police post in Bloomington (according to emergency pre-plan) and relayed long-distance traffic through their facilities.

A program on cave-rescue communications was presented at the Bloomington (IN) Amateur Radio Club in October.

* **Dwight Hazen** (WB9TLH) provided long-distance communication to the cave and to rescuers enroute to a major vertical rescue at Birthday Plunge (Indiana) in November. Dwight used a large beam antenna and high power to reach 2-meter repeaters about 80 miles [130 km] away. Multiple repeaters sharing the same frequency were sometimes a problem.

Ammar Mirza (N9ISY) and **Amanda Clark** (N9ESF) used a piezoelectric sound-powered telephone (see Speleonics 18 and 19) during the Birthday Plunge rescue. Ammar's two TA-312 battery-powered phones were placed at the entrance and at the bottom of the 70' [21 m] entrance pit. The piezo phone's relatively weak signals were inaudible at the entrance, again because of the firefighters' ubiquitous generator, so the operator of the other underground phone had to relay messages. An amplified handset later deployed at the entrance failed because of broken wires, but at that time the piezo phone was no longer needed. Noise made even the battery-powered phones unusable when a helicopter arrived to collect the patient.

Piezoelectric "bubble-gum" phones (so called because of their containers) have created much interest at cave-rescue seminars. Experience in real and practice rescues suggests that, since they lack full capabilities, piezo phones should not be considered a primary rescue-communications system. Their small size and low cost (hence their availability underground in large numbers) has nevertheless made them extremely valuable in several situations.

* Experience shows that human factors cause far more problems in cave-rescue communication than does equipment failure. Direct interconnection of underground and surface communications systems has proven invaluable for preserving message integrity and saving time. (Refs: Speleonics 3, 7, 16.)

Management difficulties sometimes arise when cavers interact with established emergency-services during rescues. Said "agencies," lacking the required equipment, usually must depend upon cavers to establish underground communications. Once the link is operational, however, they may try to commandeer it. A telephone with two handsets (Speleonics 19) provides a diplomatic opportunity for cavers to maintain control of communications.

The "phantom circuit" is an old method for providing two independent voice-channels on a single pair of wires. The auxiliary circuit places a common-mode signal on the pair via the center tap of a transformer, and uses earth return. Several caving and rescue applications have been suggested, but the circuit is seldom used because of its relative complexity. My interest in the phantom circuit was renewed during a recent incident where it would have been useful to bypass an individual who was obstructing communications. Experiments will be reported in a future issue of Speleonics.

* NCRC National Coordinator **Steve Hudson** reports that he used the "passive-repeater" or "guidewire" effect to provide a much-needed independent channel during a rescue. The telephone wire was used to conduct signals from VHF-FM radios into the cave, by holding their antennas near the wire. (See Speleonics 14.)

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RESOURCES [continued from p. 7]

BRITISH CAVE-RESEARCH ASSOCIATION CAVE-RADIO AND ELECTRONICS GROUP (BCRA-CREG)

[The editors of Speleonics highly recommend our "sister" organization and its publications, from the United Kingdom. See RESOURCES, Speleonics 19, page 2.

New yearly subscription rates: £ = British Pounds.

* Membership, includes Newssheet: £2.50 (or £1.60 for BCRA members)
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Great Britain

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FLASHGUN SLAVE KITS AND READY-BUILT UNITS AVAILABLE

(see page 6)

A technical description of David Gibson's flashgun slave (circuit, but no pcb layout, and only general construction tips) is given in the issue 10 of the journal of the BCRA's Cave Radio & Electronics Group. This costs £3.00 airmail (see above). A printed-circuit board for the flashgun slave costs £3 and, at the time of writing, a kit of parts is available for £11 and ready-built pcbs for £25. (You still need to solder your own choice of connector, and provide a box.)

You should pay with a check drawn on a UK bank in UK currency. At your own risk you can send US paper dollars (add 20% to exchange rate). Mail to **David Gibson** (address above).

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CAVERS' FORUM ON ELECTRONIC MAIL

The cavers' electronic-mailing list includes hundreds of cavers worldwide, and you can read the latest uncensored/unedited caving news several time each week (albeit with a considerable signal:noise ratio). If you have a computer and a modem and can reach internet, give it a try! To join, send a message to:

cavers-request@vlsi.bu.edu

Include a paragraph about yourself and your caving interests. Thereafter, to post a message to all participants, send to:

cavers@vlsi.bu.edu

COLOR-CODE MNEMONICS

(Compiled from Usenet newsgroup sci.electronics.)

Various mnemonics have been devised to help students of electronics remember the resistor color-code (Black = 0, Brown = 1, Red = 2, Orange = 3, Yellow = 4, Green = 5, Blue = 6, Violet = 7, Gray = 8, White= 9, or BBROYGBVGW). The classic example (World War II or earlier vintage) is:

Bad Boys Rape Our Young Girls But Violet Gives Willingly.

Cleaner versions have evolved in our enlightened modern age:

> Bad Boys Ruin Our Young Grass But Violets Grow Wild.
>
> Better Be Right Or Your Great Big Venture Goes West.
>
> Bad Bourbon Rots Our Young Guts But Vodka Goes Well.
>
> Blue Barbituates Really Order Your Geometry But Vernon Gibbers Wildly.

The Society of Women Engineers at the University of Minnesota, c. 1980, preferred:

> By Becoming Revolutionary Orators, Young Girls Become Very Great Women.

(Hopefully they also become engineers, albeit the process of doing so has been compared to rape.)
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INTERESTING REFERENCES

"The Fluxgate Magnetometer: A Very Sensitive ELF Magnetic Detector" by Peter Vizmuller, RF Design magazine, January 1994, page 24. Article describes how to build an inexpensive and sensitive (10V/gauss) fluxgate magnetometer which has been used to measure diurnal variation of the earth's magnetic field. The article includes an excellent and concise description of how fluxgates work.
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Newsgroup sci.geology, 25 Jan. 1994:
From: dmturne@ptsfa.PacBell.COM (Dave Turner)

Radio-Electronics had a two-part article on a seismograph in 1966:

Seismic Amplifier	Seismometer-Recorder
Earl T. Hansen	Earl Hansen and Merle Monia
Sept. 1966, pp 54-57	Oct. 1966, pp 50-53

See also:

> The Laser Cookbook
> Gordon McComb
> TAB 3090
> Chap. 16 Experiments in Laser Seismology
> pp 237-245

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