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Contributions of articles for publication is **highly encouraged**.

Contents of *SPELEONICS* 24 - Volume VI #4

CREATING A SIMPLE REGULATED NI-CD CELL CHARGER

by Reno Lippold

Introduction Many inexpensive nickel-cadmium (Ni-Cd) cell chargers use a continuous constant current charging system. This means that when your cells are completely charged, full charging current will still be going through them, and they may be significantly "overcharged" if left in the charger. In this article, I first discuss the issue of overcharging and then present a simple way of converting a constant current Ni-Cd charger to a regulating type — one which will prevent overcharging but still keep cells fully charged.

Definitions First I need to define some terms for the purposes of this article.

C - numerically equal to the ampere-hour (Ah) rating of the cell
The following all refer to charging rates:
normal rate - C/10 to C/100 A
fast rate - C/10 A and higher
trickle rate - C/100 A and lower
(example: a C/10 rate would be 120 mA for a 1.2 Ah cell)

To Overcharge or Not to Overcharge

Some manufacturers of sealed Ni-Cd cells suggest that you can leave their cells on a normal rate constant current charger. The second edition of the Radio Shack Enercell Battery Handbook, referring to their standard capacity Ni-Cd batteries and normal rate chargers (definition a little different from mine), says ". . . overcharging is not harmful to the Ni-Cd battery. The batteries may be safely left on continuous charge." However, the book seems to contradict itself by later implying that a trickle charger should be used for "standby service" and that a normal rate charger, will ". . . hold [a cell] at full charge with little [but apparently some] cell degradation." The Black & Decker® Storm Light™ system charges its VersaPak™ battery with a normal rate constant current around C/10 A — and the system is specifically intended to be left plugged in and on constant charge. One might be tempted to take all of this as evidence that continuous charging is not a problem, but then you also need to consider what motivation these companies have concerning long term cell degradation. Advice against cell overcharging also exists. A cell charger I own has strong warnings about overcharging on the lid and on the back. One warning says "Overcharging may reduce the useful charging cycles." An information sheet from Real Goods Trading Corp (a supplier of Ni-Cd cells) states that "Unless you have a fancy charger that cuts back to a tiny trickle charge when done, leaving the batteries in the charger too long is the surest way to kill them. Ni-Cds can generally withstand being in the charger twice as long as necessary, but beyond that, the heat starts to damage them and shorten their life." So contradicting information exists on the matter of overcharging at the normal rate. My conclusion is that some overcharging at the normal rate will not have serious effects but is best avoided if you want to get "the most" out of your cells. It seems certain that the possibility and extent of cell damage would be greater due to fast rate overcharging. I'm not really sure if the damage caused by overcharging is in the form of loss of capacity (which leads to a sooner decision to retire the cell, i.e., less useable cycles), or an increased chance, sooner in time, of sudden and complete cell failure, or both. Regardless of the answer, the result would be undesirable.

I attempt to avoid overcharging my Ni-Cds and have been using normal rate continuous constant current chargers for years without serious problems. But with this system, I had to remember to take the cells out when I thought they were fully charged. Easily said, but I've left them in longer than I wanted on many occasions. Perhaps some damage occurred. Another drawback to this method is that the Ni-Cd cells start to rapidly self-discharge as soon as they leave the charger, and now you need to remember to charge them again before your cave trip — if there is time. Then you have to make a wild guess as to the amount of self-discharge that has occurred to estimate the charging time required. I suppose the "best" solution to this problem is to buy a regulating charger or modify the one you have with regulating electronics. But if you don't want to do that, I present here a simple solution that might work for you.

Problem Solution

The idea presented in this article is intended to be applied to continuous constant current normal, or fast rate, chargers. I propose that with a trickle charger you need not be concerned with overcharging. In my experi-

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ence, most of the commonly available home cell chargers are the continuous constant current type and use a normal charging rate (assuming normal capacity Ni-Cd cells). The basic idea I present is to use a home appliance timer to provide an initial charging period to bring the cells up to full charge and then to provide short periodic charging intervals to maintain the cells in a fully charged state, without overcharging.

The timer I recommend using is the mechanical type with rotating time dial and trip pins you set to switch a 120 VAC receptacle on and off. The Intermatic TIME-ALL® is one brand and model that is very common, but there are many look-a-likes on the market. You can pick up this kind of timer for around $12. These days, there are some fancy electronic timers around, but the mechanical type may be superior, as I will later explain, and will probably be of lower cost. Now, using an example, I'll describe how to use the mechanical timer in this application. I will first cover the maintenance of fully charged cells.

Let's say you have a constant current charger that delivers about 120 mA (0.12 A) to your 2.0 Ah high capacity C cells. First, you need to estimate how much charging time is needed each 24-hour period to keep the cells fully charged. A rule-of-thumb I use is that Ni-Cd cells loose about 2% of their charge per day at 20 C. The amount of charge lost, per day, from our example cell is then:

2.0 Ah x 0.02 = 0.04 Ah per day

So you have to replenish 0.04 Ah in each cell daily to maintain a full charge. Because charging is not a 100% efficient process, one must inject more than this amount -- I've seen rules-of-thumb suggesting that 125 to 140% of the cell Ah depletion is required. I'll use 135%. You may want to use a higher figure to be more certain of complete charging.

0.04 Ah x 1.35 = 0.054 Ah

The time required to deliver 0.054 Ah is then:

0.054 Ah / 0.12 A = 0.45 hour (27 minutes)

You need to set the trip pins on your timer so the 120 VAC power to your cell charger is turned on for at least 27 minutes each day. You will probably have to round this off to 30 minutes for the actual setting. You might want to make it a little longer anyway, just to be sure, and to provide a little extra boost in case your cells are not fully charged when you start. Be careful you don't place the trip pins in the wrong order, or you will get 30 minutes off and 23.5 hours on instead. (The voice-of-experience speaking!) Now let's look at initial charging.

You return home from a caving trip with fully depleted cells. You should already know that the charging time required for your drained C cells is approximately:

2.0 Ah / 0.12 A x 1.35 = 22.5 hours

To initiate charging, turn the dial of the timer so 23 hours will pass before the turn-off trip pin (the black pin for the TIME-ALL) hits the timer switch. Then manually close the timer switch. The charger will now run for 23 hours and after that will automatically go into the 30 minutes per day routine to maintain the charge. I doubt you can find an electronic timer that will do this so easily. If your cells were not fully discharged, then you could discharge them or just make a good guess at the initial charging time needed.

In recommending this idea, I am assuming that delivering 0.054 Ah per day (using the previous example) to a cell in a 30 minute period each day is roughly equivalent (in terms of the effect on the cell) as delivering the same amount of charge, but using a small, but continuous, trickle rate charging current.

Limitations

This method works well if you are charging cells of nearly the same capacity. If you have cells of different capacities in your charger, and if they receive the same charging current, then the daily charging necessary to maintain a full charge in a high capacity cell will overcharge a lesser capacity cell to some extent. Some chargers deliver differing current magnitudes to different cell sizes (D, C, or AA). This would help in the situation where you want to mix cell sizes. If you are using larger high capacity cells, you may not be able to fully charge them in the 24-hour period of the typical mechanical timer. For example it would take your 120 mA charger 45 hours to charge a fully depleted 4 Ah D cell.

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4 Ah / 0.12 A x 1.35 = 45 hours

If this is the case, you must remember to return to the timer sometime after the first 24-hour period and give your cells another extended charge.

I reluctantly bring up the subject of “memory”, a phenomenon often mentioned in association with Ni-Cd cells. The affect, as I understand it, may manifest itself when one repeatedly partially discharges a Ni-Cd cell to the same point, before recharge. The cell then may appear to be going dead if discharged past this partial discharge point. The system I have proposed, would repeatedly allow a very small, and nearly identical, partial discharge. I have never noted any problems or loss of performance with cells charged in the manner described in this article.

Conclusion

This method of creating a regulating charger has some drawbacks, but is inexpensive, simple to implement, and is an effective way of preventing overcharging while keeping your cells fully charged and ready to go.

Minutes of the 2003 Annual Meeting of the Communications & Electronics Section of the NSS

August 4, 2003, 12:30 PM Brian Pease, Secretary/Treasurer

Attendance:
33 people put their names on sign-in list either at the luncheon/business meeting or at the Program session. This compares with 37 last year. We now have a total of 58 "official" members. We had 13 known hams this year compared to 8 last year for a total of 15 hams. We had 2 people who did not list an email address each year for a total of 4. All of the officers were present.

Minutes from 2002:
The 2002 minutes were unanimously approved.

Treasurer’s Report:
Brian Pease (Sec/Treasurer) reported that we have $1525.07 in a People's Bank money market passbook account opened in the Section's name on 10/15/02. The initial balance was $1562.00. There were 2 withdrawals; $21 to reimburse for back issues not received; and $22 for our NSS web space.

Old Business:
The Section is now operating under its new Constitution and Bylaws, which are posted on our website. Brian said that he has not completed the project of contacting everyone who has in the past paid for paper copies of Speleonics not received. New issues of Speleonics will be posted on our website in PDF format and not mailed to the members. Any requests for paper copies will be handled on a case-by-case basis. Henry Schneiker said that he would continue to convert the back issues of Speleonics to PDF format for posting on our website. Paul Jorgenson solicited articles for Speleonics. He needs more articles. He does have my Diver Comms article.

New Business:
Bart Rowlett said that he could provide server space for the Speleonics PDF files, which are already causing us to exceed the basic cost of our NSS hosted website. Before we need to pay again, Gary Bush will simply change the links to the Speleonics issues on our website and remove the files from the NSS server. This will save a lot of money in the long run, especially once all of the back issues are available. Henry and Bart made a motion to move the files, which passed unanimously.
Brian suggested that the section should have some sort of project to spark interest in the section. Bart suggested that we have a workshop at the Michigan Convention in 2004, including field demonstrations in a nearby mine. He volunteered to look into this. He would like to advertise the workshop on the Speleonics email list.
Henry Schneiker made a motion to have me check into the possibility of putting the section's money into a larger NSS fund to earn more interest than the current money market account. The motion passed 5 to 4. During the convention, I talked with Roger McClure, who manages ~2.2 million in funds for the National Speleological Foundation, including NSS funds. He said that could be done, but that $1500 is much too small to bother with.

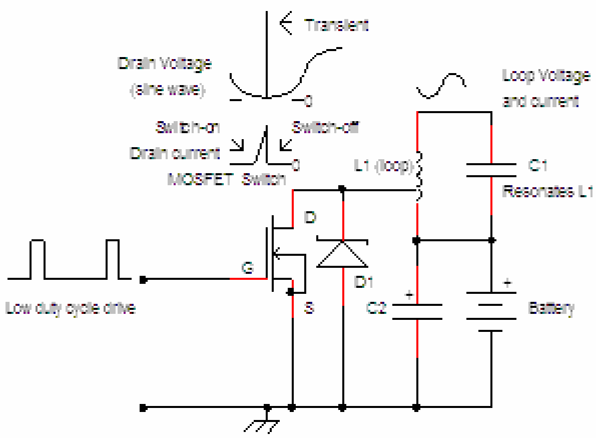
Elections:
John Lyles declined to run for Executive Chair again. Bart Rowlett volunteered for the job. The other officers agreed to serve again. Since there was no opposition for any office, I was directed to cast a ballot to approve the slate. The officers who will serve until the 2004 convention meeting are: Bart Rowlett, Executive Chair; Brian Pease, Secretary/Treasurer Chair; Paul Jorgenson, Publications Chair; Gary Bush, Communications Chair.

An Improved High-Power 3496Hz Radiolocation Beacon

Brian Pease

The Old Design

For many years, variations of the classic circuit shown in Fig 1 have been used to circulate current in the loop antennas of underground radiolocation beacons. This design is called a Class-E tuned power amplifier with one inductor and one capacitor [1][2]. Technically, it really should be called a DC-AC power converter because the output power is not related to the input amplitude. The power MOSFET, which acts as a switch with very low ON resistance, is driven with a low duty cycle rectangular wave (1/16 duty cycle in my units). When properly tuned, the MOSFET switches ON at the instant the drain-source voltage is zero. The MOSFET current then rises rapidly to 10 Amps or more. The MOSFET switches OFF 1/16 cycle later, interrupting this large current, creating a large positive transient voltage as the inductor tries to maintain the current flow. C1 and the inductance L1 of the loop antenna form a resonant circuit, with a typical Q of 30, which "rings" to fill in the remaining 15/16 of each cycle. The loop current is a nice sine wave. Moving the tap "up" the loop will increase output and battery current. Tune-up is easy, consisting of adjusting C1 for minimum DC supply current (a null), which (almost) coincides with maximum AC loop current. My actual beacon, with the same loop described in Figure 4 (except tapped at 2 turns from the bottom), draws 0.4 Amps at 12.5 VDC (5.0 Watts) and produces a Magnetic Moment of 50 Amp-Turns-M^2.



Classic Beacon Circuit
Figure 1

There are several drawbacks to this simple design. The transient voltage must be limited by a zener (D1), or by the natural zener action of the MOSFET. The transient power loss in the zener is significant, as much as 5-10%. Efficiency, defined as the ratio of power dissipated in the loop to DC input power, is ~84%. My beacons that use this design require a battery with low internal impedance to function properly, such as AGM lead-acid, even with a 1000 uF capacitor (C2) across the battery. These beacons will not function properly on either of two "lab" power supplies with 3 or 5 Amp current limits despite the fact that the DC current is only 0.4-0.5 Amps at 12VDC. Attempts to increase the beacon output result in reduced efficiency from losses in the MOSFET, the zener, and the loop feed-line due to the high peak currents. Higher Q designs, such as ferrite rod antennas, require even shorter duty cycles, such as 1/32, for proper Class-E operation, and produce huge switch-off transients. The one successful ferrite rod beacon I have built uses a 1/16 duty cycle and a special snubber to reduce the transient losses. My website http://Radiolocation.tripod.com has construction articles and antenna designs for this beacon.

The New Design

The simplified schematic shown in Fig 2 is my first successful High-Power beacon using the shunt-capacitor series-tuned class-E amplifier circuit with 2 inductors and 2 capacitors. Analysis has shown that the optimum MOSFET drive for tuned circuits of any Q is a square wave with 50% duty cycle, which simplifies the design and greatly reduces peak supply currents [3]. As before, the MOSFET switches ON at the instant the voltage across it is zero, but unlike the old design it switches OFF when the voltage across it (and the current through it) are zero. Optimum operation requires the slope of the MOSFET voltage waveform to be zero at the instant of turn-on, but this requirement turns out to not be critical, at least in this application. When properly tuned there are no switching transients. The drain voltage waveform looks exactly like positive ½ wave rectified AC, with a peak amplitude of about 3.5 times the DC supply voltage. As before, the loop current is a nice sine wave. This circuit uses a low-DC resistance RF Choke (L1) to act as a current source. I chose its inductance to be about 10x the impedance seen by the MOSFET drain when it is open circuit. Because of the RF choke, battery impedance is not critical. The series-tuned circuit consists of the loop antenna L2, polypropylene capacitor C2, and the AC loop resistance Rac, which dissipates most of the power produced by the amplifier. Capacitor C1 adjusts the impedance seen by the MOSFET. C1 is a part of the series tuned loop circuit during each half-cycle when the MOSFET is an open circuit and therefore causes slight

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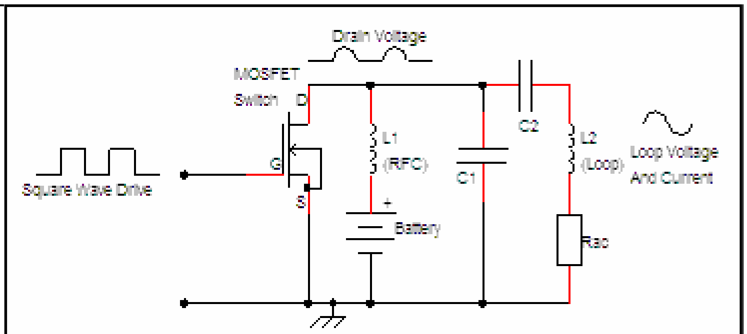
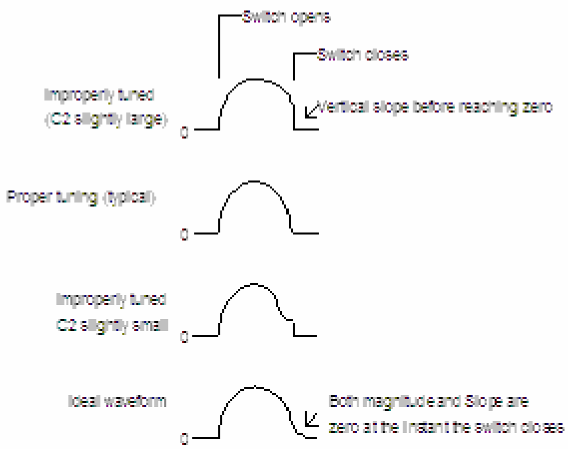
de-tuning (C1 is normally much larger than C2 and has much less effect on resonance). The C2/L2 combination is tuned slightly below the beacon frequency. Increasing C1 (while maintaining tuning by slightly decreasing C2) will increase output power (and DC current) or allow operation from a lower DC voltage. Loop current is directly proportional to the DC supply voltage, allowing amplitude modulation if desired.



Simplified High-Power Class-E Beacon circuit
Figure 2

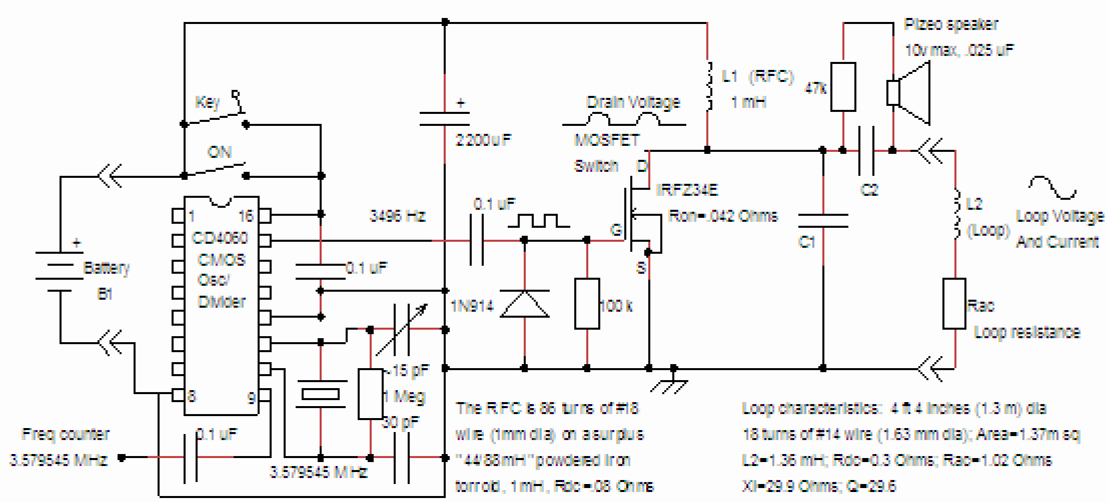


Class-E Drain voltage tuning waveforms
Figure 3

The piezo speaker connected across C2 acts as built-in test equipment. A 3496 Hz tone is heard only when AC current is actually flowing in the loop.

The one real drawback to this circuit is there is no simple indication of proper tuning. Mis-tuning the circuit by adjusting C2 varies the DC supply current up or down with no peak or null. Increasing DC current by mis-tuning results in increased AC loop current and only slightly lower efficiency, but will cause high peak currents in C1 (and the MOSFET) because the voltage across C1 will not be zero at the instant the MOSFET turns on. While tuning this circuit, I used an oscilloscope to monitor the drain voltage waveform. Figure 3 shows typical Drain voltage waveforms encountered during tuning.

Figure 4 is the schematic of the actual high-power Class-E beacon. Table 1 gives circuit performance for 2 values of C1 and 2 supply voltages. Efficiency is defined as the percentage of DC input power that is dissipated in the loop. Losses in this circuit appear to be divided evenly between C1 (lossy polyester for practical reasons); the MOSFET; and the RF choke. A commercial 1 mH RF choke with low Rdc can be substituted for my homebrew unit. The 2200 uF cap is probably not necessary, but I did not want to risk a problem when using the 15 V lithium batteries. Compare the Magnetic Moments with the 50 A-t-m^2 of the old design, remembering that doubling the Magnetic Moment requires 4x the output power. Optimum loop impedance along with the values of C1 and C2 can be calculated for a specific application [4]. However, since I used an existing loop, I started with the resonant value for C2 and an approximate value (guess) for C1. C1 can be a fixed



High-Power Class-E Beacon circuit
Figure 4

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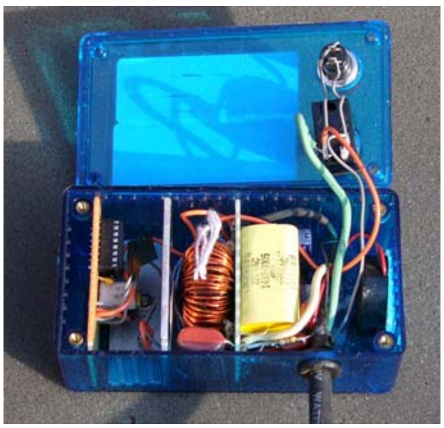
integer value such as 9 uF and changed in increments of 1 uF while C2 is quite critical and should initially be a capacitor decade box. Low inductance loops (fewer turns) reduce the AC voltage across C2. With the 15V supply the peak voltage is 192 Volts, which allowed the use of compact, low loss, 250 V metallized polypropylene caps for C2. The peak Drain voltage is ~3.5x the supply voltage, which allowed 50 V metallized polyester to be used for C1 (polypropylene would have been better, but was too large).

Supply V	Supply I	Pwr in	C1	C2	Loop V	Loop I	Efficiency	A-T-m^2
12.0 V	1.0 A	12.0 W	7 uF	1.93 uF	100 Vrms	3.32 A	91%	81.9
12.0	1.7	20.4	9	1.85	128	4.28	91	105
15.0	1.4	21.0	9	1.874	136	4.30	90	106

Table 1

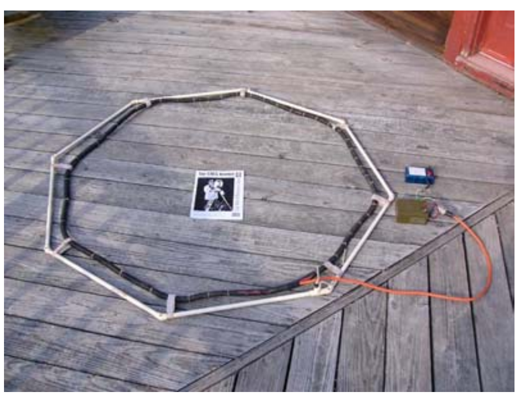
Testing



This high-power beacon (with a 15 V lithium battery) was used in Belize in March 2004. It was placed at a sump near the far end of Barton Creek Cave and used to locate the exact spot on the surface of this potential water source ~600 ft (180 m) underground. The location ended up inside a woman's home in a small village. None of our surface crew spoke Spanish, but that is another story!

It was also placed at the sumped end of another cave so that I could use the signal to chop straight through the jungle to a sinkhole known to be located directly overhead. This saved a lot of time. Initially, we had hired a licensed local guide who had been to the sinkhole the year before, but he failed to locate it. On the second try, after plotting the cave map (from a small copy) onto the topo sheet, we got fairly close with GPS (which is not as accurate, and difficult to use, in dense jungle). On the third try, when I Radiolocated ground-zero, it turned out that the sink was invisible from even 50 ft (15 m) away!

Conclusions



The new beacon circuit is better and simpler than the old design. It can easily be tailored for different loops, battery voltages, and power levels by changing the values of 2 capacitors, and is also more efficient. It works best with low impedance loops (few turns of heavy wire), which require only a 2-wire feed-line. It could easily be tailored for low power/low voltage operation with 4 AA cells.

My next goal is to incorporate an automatic leveling circuit to hold the AC loop current constant regardless of changes in battery voltage or mis-tuning due to changes in loop shape or temperature. A constant repeatable output will improve the accuracy of depth measurements, particularly the depth-by-signal-strength method. This refinement is not required for ground-zero locating.

References:

[1] N.O. Sokal, "Class E High-Efficiency Switching-Mode Tuned Power Amplifier with Only One Inductor and One Capacitor in Load Network-Approximate Analysis," *IEEE J. Solid State Circuits*, vol. SC-16, No. 4, pp. 380-384, August 1981.

[2] M. Kazimierczuk, "Exact Analysis of Class E Tuned Power Amplifier with Only One Inductor and One Capacitor in Load Network," *IEEE J. Solid State Circuits,* vol. SC-18, no. 2, pp 214-221, April 1983.

[3] F.H. Raab, "Idealized operation of the class E tuned power amplifier," *IEEE Trans. Circuits Syst*., vol. CAS-24, pp 725-735, Dec. 1977.

[4] CH. P. Avratoglou and N. C. Voulgaris, "A New Method for the Analysis and Design of the Class E Power Amplifier Taking into Account the Q_L Factor," *IEEE Trans. Circuits Syst*., vol. CAS-34, no. 6, June 1987.

185kHz Radiolocation and 7 MHz Communication Experiments in Bigfoot Cave 6~8 September 2002

---by Bonnie Crystal, KQ6XA

We just returned from a Cave Radiolocation and Communication Experiment in the Bigfoot Cave System of Northern California USA. This is an alpine, cold, wet, multi-entrance cave area in cracked-up marble karst with very thin or nonexistent soil and vegetation overburden. New caves and passages are being discovered, explored and mapped continuously in this area. Tape-and-compass survey is intensive due to the large number of survey stations and short distance between them. A high potential exists for radiolocation to benefit the survey and exploration of the system. The project is part of the Klamath Mountains Conservation Task Force of the NSS, operating under an MOU with the Klamath National Forest.

Equipment Utilized:
2 TRX 185kHz LSB, audible beacon 7Watts
1 Loop Ant @184kHz, 3ft dia, 9 turn #18wire
1 Loop Ant @184kHz, 5ft dia, 9 turn #18wire
2 TRX 7MHz LSB, 3Watts, 3ft whip ant

Initial surface-to-surface range testing of our 185kHz LSB loop-to-loop transceiver system indicated voice communications possible in excess of 1000ft, and beacon range in excess of 1500ft. Daytime static noise was found to be extremely low in this remote mountain wilderness area, approximately 20 miles from the nearest AC mains power lines.

We had not tried 185kHz or 7MHz in this cave system previously, so this was to be a learning experience! Still, we set ourselves an aggressive target. In preparation for future radiolocation surveys in the Bigfoot Cave system, our objective for this experiment was to test communication and radiolocation in an area of nearly maximum estimated depth below the surface that we might encounter. We selected two underground locations estimated to be more than -300ft and less than -500ft below surface.

Arriving at the main entrance, our schedule called for contacts every 30 minutes on 7MHz, and a 185kHz radiolocation beacon start time of 2 hours after initial descent. After a brief two-way voice radio-check on both 185kHz and 7MHz, and a beacon transmit check on 185kHz, the underground team proceeded down the 165ft entrance rope drop.

The surface team went up the hill from the entrance and set up the surface radios near the estimated ground zero beacon point. Two dipoles of insulated wire were laid out on the surface, one resonant at 7MHz, and the other non-resonant for 185kHz (about 250ft long). The transceivers were connected to these dipoles and placed in the receive mode with audio volume high while we waited in suspense for "first contact".

"SURFACE THIS IS CAVE"! We were all pleasantly surprised when the first try on the 7MHz radios yielded very, very strong and clear voice signals both directions. We immediately switched to the telescopic whip antenna on the surface 7MHz transceiver, and continued to talk with the underground team as they made their way toward the first beacon point. The 7MHz radios worked perfectly the whole time with continuous communications during the whole cave trip anywhere within a 1000ft radius of ground zero. We estimated by signal strength that it could have been easily possible to communicate at least 2000ft away (or more) on the surface from ground zero. The underground team moved fast through the cave, arriving earlier than their scheduled 2 hour time for the first 185kHz beacon site, so we coordinated the start of beacon survey by radio communication.

We first established voice communication on 185kHz LSB, and then fired up the 185kHz audible beacon. We found ground zero (the null point directly above the underground transmitter) using the loop antenna within a few minutes, but it took a little longer to survey the 45degree null angles from two radials 90degrees apart from ground zero. Signal nulls were sharp and deep. The radiolocation depth ended up being -354ft below surface, which was the result of an average between the two radial measurements. Then we made a compass and tape surface traverse from ground zero to a previously known survey reference point.

Moving to another beacon location in the cave, which was more toward the uphill rise, a second beacon measurement ended up being -444ft below surface. The biggest problem encountered was moving around on the surface between trees and over big cracks and sinkholes in the karst. Very rough ground, with a lot of potential to trip and

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fall while walking around swinging a big loop antenna!

During the -444ft radiolocation, we found that we could easily get good voice communication out at least 600ft surface distance or more from ground zero, which was as far as we wanted go while spending time walking around as the underground team was waiting and shivering in the wet 34degree F cave!

The pleasant surprise was how well the 7MHz SSB worked with simple telescopic whips. This makes it possible to have instant compact cave communications in the Bigfoot System between underground teams and the surface over a wide area for exploration (and rescue if ever needed).

The success we encountered with 7MHz indicates that HF and MF frequencies should not be overlooked for cave communications. The availability and low cost of commercial miniature SSB radios and ease of deploying small ruggedized whip antennas in the cave environment makes it a good choice for certain types of rock.

All the participants were quite excited about the success of the radio communications and radiolocation results. There are quite a few cave passages that have the possibility of connections to other caves, and some possible new entrances that could be tried that would make it easier to push the system further with quicker access.

Participants:
Steve Knutson, Underground Beacon and Comms
Midori Sundquist, Underground Comms
Bill Kenney, Surface Comms
Bill Broeckel, Sherpa
Bonnie Crystal, Surface Radiolocation

Beacon Controller; Cave Radio; Remote; DTMF Programming

Bonnie Crystal

WHY USE A BEACON CONTROLLER?
The method we now use for 185kHz SSB cave radio beacon control was found to be very convenient and alleviates the need for clock-scheduled transmissions between cave and surface. It also provides efficient and maximum effective use of transmitter and thus conserves battery power. The method integrates voice communication with beacon transmission for non-technical operators.

PROGRAMMABLE TX/RX SEQUENCE
An amateur radio programmable "foxhunt" controller is used as the basis for beacon control. This controller device has both a PTT control output and an audio output. Audio is applied to the SSB transmitter's internal microphone circuit. The "beeps" are programmed for a repetition rate of 1 second; a half-second of sweep tones---300Hz to 3kHz--- and a half-second of silence. The sequence is continuous for 50 seconds, a 4 second Morse identification signal is transmitted, then the transceiver automatically switches to RECEIVE for 6 seconds. During the 6 second receive interval, the surface may call the cave beacon transmitter operator for 2-way voice communications. The sequence continues automatically until the pre-programmed time to stop is reached or the beacon operator manually stops it. Various programmable delay times may control the beacon start time, stop time, or other intervals.

SWEEP AUDIO TONE TRANSMISSION
The sweep tones have been found to be better than a single frequency tone, because the loop antenna resonance and system bandpass frequency is not precisely controlled in the cave environment. With many frequencies being transmitted, the modulation has a better chance of being transmitted at full amplitude.

PICCON CONTROLLER
The controller used in our cave radios is called "PicCon". We have been using these controllers for several years for amateur radio transmitter hunting (aka Foxhunting, Foxtailing, ARDF, etc). It may be easily programmed remotely over the radio link or hardwired by DTMF tones using an HT keypad.

Information about PicCon: PicCon by Byon Garrabrant, N6BG.

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Byon Garrabrant
8378 Granite Mountain Lane
Las Vegas, NV 89129 USA

From the Byonics website: http://byonics.com/piccon/
"PicCon is a PIC microcontroller based radio controller designed for hidden transmitter hunting. When combined with a radio transmitter, it will produce tone sequences and Morse code messages at user-programmed times. It is completely field programmable via DTMF tones, utilizes EEPROM for all programmed options so they are remembered when power is removed, and is quite compact."

Bonnie Crystal KQ6XA

Can You Patent an LED Flashlight?

By Henry Schneiker
January 2003

If you do a quick patent search, you will discover that at least 6 patents have been issued for LED flashlights in the past few years. And, of course, the holders of those patents probably have expectations of licensing those patents. The question is, are those patents valid? Is it really possible to patent an LED flashlight? Not really.

For a patent to be valid, an idea must be both new and not obvious to someone skilled in the art. Any patent can be invalidated by showing prior art or that the idea is obvious to someone skilled in the art.

Flashlights have been around for a long time and come in a vast array of styles and configurations. A flashlight is basically a battery, a switch and a light source packaged together in a portable form – either as a single unit or with the light and battery separated by a cord. Mounting the light on your head allows for hands-free use and is referred to as a headlamp.

The manufacturer of a flashlight does not care what technology is used to generate light. Any light generating technology is a candidate including incandescent bulbs, arc lights, plasma lights, film emission devices or solid state LEDs. What device will be used is ultimately decided by practical considerations such as cost, weight, space, heat, amount of light, beam pattern, efficiency, ruggedness, reliability and safety. Using a newly available technology is obvious to someone skilled in the art – especially when the creator of that new technology advertises the new light source for that very purpose. Or, if you wish, the advertisement constitutes prior art. HP (Hewlett-Packard) was giving away LED flashlights to engineers back in the early 1990's when they came to market with the first true high brightness amber LEDs.

An LED flashlight has all the standard flashlight parts: a battery, a switch and a light source. Since the basic idea of a flashlight is not new, that leaves the LED light source. LEDs have been around since they were first demonstrated in 1947. Once they became practical in the '60s, it became obvious to people familiar with them that if you could make them efficient enough and wire enough of them together you could make a light bright enough to be useful. It was also obvious that once other colors became available, you could mix them together to get white or any other color you wanted.

I can remember the articles in Popular Science about the flat screen TV sets built with large arrays of red, blue and green LEDs – that was over 25 years ago and blue LEDs were not even possible back then. I remember sitting around one evening with friends doing a design for LED stage lighting – that was in 1975. And the thought of an unbreakable flashlight built from LEDs was also considered – cavers are always looking for indestructible lighting. The problem was that these designs were done before practical LEDs were available – so they had to wait. The ideas were obvious to someone skilled in the art. Those early designs constitute prior art.

LEDs are made from solid-state materials and have a very steep voltage-current curve. They have always required some form of power regulation. The simplest power regulator is a series resistor. The HP-35 calculator from the early '70s used a simple PWM scheme to regulate power to the LEDs – clearly visible by moving the display rapidly from side to side. They also used PWM to get better efficiency out of the early red LEDs - something no longer

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required with modern LEDs. Motorola used PWM solely to regulate LED brightness in their cell phones in the late 1980's.

There are zillions of power regulation circuits to choose from. They come in vacuum tube, transistor and integrated circuit form. The basic principles were discovered back in the days of vacuum tubes and have been updated to work with the latest technology. The simplest regulation circuit is a series resistor. At the other end of the spectrum are complex regulation circuits that include PWM, buck, boost, charge pumps of various configurations, just to name a few. Regulation being some combination of voltage, current or power regulation. At one time you built regulated power supply circuits with discrete parts. Now you buy single chips that do the same thing. Or even use microprocessors with specialized software. All of these methods are obvious to someone skilled in the art. And the schoolbooks, technical journals and company marketing literature are full of prior art.

The use of LEDs in the caving community dates back to the later 1980s when a caver was selling red LED flashlights. While they made excellent survey beacons, they were not pleasant to cave with - red was certainly not an optimum cave color. Later in the early 1990s when HP came out with their truly bright amber LED, several members of the caving community, including myself, immediately set about designing and building flashlights for them – regulation circuits and all. The HP amber LEDs produced a more pleasing light when compared to the red. Finally, when Nichia came out with their white LEDs in 1997, it was clear LEDs had come of age. Again, the use of LEDs and the regulation circuits needed to control them were obvious to those skilled in the art. Which circuit to use was a practical engineering design trade-off.

The bottom line is that the issued patents that I have looked at are invalid. There is plenty of prior art. The ideas are not new. And the ideas were obvious to those skilled in the art at the time the patents were applied for.

A short list of prior art includes the following:

- Wayne Yamaguchi, from private lab notebook, page 26, showing a boost converter built around a Max778 (January 1994) and associated photographs of the implementation (later 1994)
- Peter Ludwig, thoughts about a perfect cave headlamp using regulated LEDs, State of the Art Main Caving Lamps, Cave Radio and Electronics Group (Creg Journal), 1997.
- Don Lancaster, publication of technical column in national publication providing full technical details about the upcoming Action Light (Muse124, May 1998).
- HDS Systems, Inc., technical paper presentation (January 1998), circuit board design, assembly and demonstration of working production prototypes of regulated LED light (October through December 1998), additional technical paper presentation (January 1999) manufacture and sales of Action Light products (March 1999).

Need I say more? These references cover single and multi-LED configurations, single and multibattery configurations, regulation by resistor, PWM and fancy buck and boost converters. Other references, such as NiteRider can be used to cover microcontrollers and intelligent functions.

Attendees at the 2003 NSS Convention - Communications & Electronics Section Session

Thru-The-Earth 2-Way Voice Communication With Cave Divers

Equipment and Test Results

Brian Pease

4/5/03

Last fall, Wes Skiles asked if it was possible to modify some commercial diver-to-surface acoustic communication units to allow him to talk through the limestone to divers in Florida springs while we were tracking them from the surface with my 3496 Hz Radiolocation gear (the subject of another article). I said "probably yes" and borrowed two units for testing. I was able to design antennas for surface and diver use. Two months later I successfully tested the system at Wakulla Springs, Florida to a depth of 100 ft (30m) through the limestone and later to 200 ft (60m) at Alachua Sink. The most recent use was at Florida's Hart Springs Park where divers were tracked and directed to features visible from the surface and the tunnels were mapped by surveying the surface track.

Description of the Commercial Acoustic Equipment

The units were manufactured by *Ocean Technology Systems* and operate on Single Sideband voice. The basic operating frequency is 32.768 kHz upper sideband. Other manufacturers also use this frequency. The center of the sideband energy is near 34.5 kHz. The units can also be operated on lower sideband and optionally on other frequencies.

Right: The Surface Unit, an STX-100 Buddy Phone

The surface unit is an STX-100 Buddy Phone built into a special Pelican box. It operates on 12V from either internal alkaline C-cells or external power and has a standard PTT microphone, and built-in loudspeaker. The acoustic transducer supplied with the STX-100 has a connector and enough cable to allow the sensor to dangle in the water below a boat. The unit turns on when the transducer is connected to the unit.

Left: The Underwater Unit, an SSB-2010 with microphone, 2 earphones, and PTT Switch. The inboard end of the antenna with its matching network is visible.

The underwater unit is an SSB-2010. This DSP unit is voice-menu controlled via the PTT switch on the full-face mask, which also has a ceramic microphone and two 8-ohm dynamic earphones. The acoustic transducer attaches directly to the unit with a built-in connector. The 12V battery pack uses 8 alkaline AA cells. Transmitter power for both units is about 2 watts.

Antenna Design

This gear operates in the near field range using the magnetic fields generated by the antennas. There is very little true electromagnetic radiation.

From past experience I knew that the diver-to-surface uplink was the most difficult path because the surface receiver must contend with atmospheric (and manmade) noise while the diver's unit is shielded from most of the noise by the attenuation of the noise as it passes through the rock overhead. The voice signals are attenuated equally in both directions. The equation for plane wave attenuation is:

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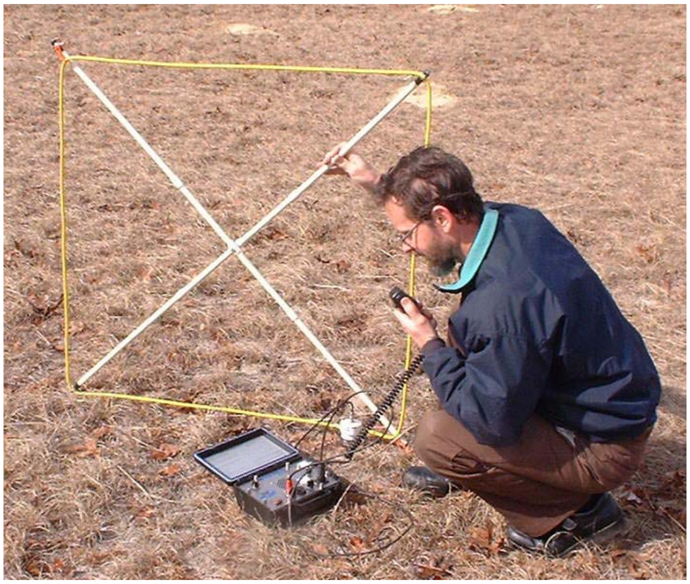
$$\text{Plane wave loss} = .01726 \sqrt{(\text{Freq, kHz})(\text{s, S/m})} \quad \text{dB/mtr}$$

For 34.5 kHz, and typical water-saturated Florida limestone with s = .02 S/m, plane wave loss is 0.453 dB/mtr. For 100 ft (30m) depth the loss is 13.6 dB. If the diver's receiver was atmospherically noise limited at this depth (it is not quite, at least during daylight), then the signal to noise ratio of the downlink would be 13.6 dB greater than the uplink if both units had the same transmitted signal strength. For a symmetrical link, the diver's unit should transmit a much stronger signal than the surface unit. For this reason, I decided to use a long wire antenna underwater, which transmits a stronger signal than a small loop. The loop is an ideal antenna for a mobile surface operator.



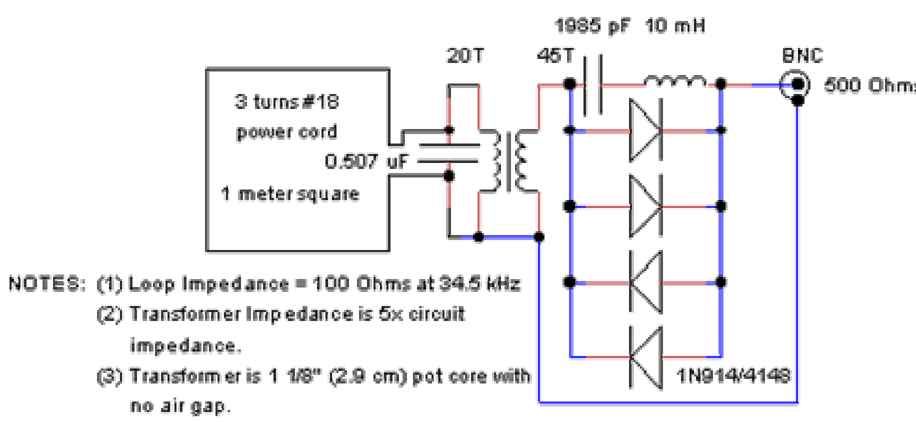
Left: Surface unit with 1-meter square antenna

I calculated the impedance of one of the acoustic transducers, using Ohm's Law, by inducing a known current through a resistance and measuring transducer voltage. The impedance was 440 ohms at 34.5 kHz.

The input/output of the STX-100 is transformer coupled. In transmit, I loaded the output with resistance until the open circuit voltage was reduced 50%. Based on these measurements, I assumed that the output impedance was ~500 ohms. Using a similar technique, I found that the input impedance during receive was >1000 ohms.

Surface Antenna: I estimated that a square loop 1 meter on each side with 3 turns of #18 wire would have a bandwidth wide enough to pass voice. I constructed the loop with a folding, shock-corded frame, and waterproof matching network case, exactly like the antennas used with my 185 kHz transverters.

The loop resonates with 0.485 uF of low-loss polypropylene capacitance. The bandwidth is 5.2 kHz with a resonant impedance of 100 ohms at 34.5 kHz. I built a 100/500 ohm matching transformer using a 1" (2.5 cm) pot core with no air gap, 20/35 turns ratio, and winding reactance of 5x the circuit impedance. I also added a simple series-resonant filter to improve the front-end selectivity of the receiver, which was not designed for RF.



Surface Loop for STX-100

NOTES: The diagram shows .507uF - .485uF was actually used.
The diagram shows a 20:45 turns ratio (which might be better) - 20:35 turns was actually used.

Underwater Antenna: I realized that a loop antenna similar to the surface design was impractical underwater. A compact ferrite rod antenna with voice bandwidth would not have sufficient range. I settled on a "trailing wire" antenna similar to the ones used by nuclear submarines to receive ELF and VLF broadcasts. I chose 25 feet (7.6m) as the longest practical length (longer is better). The antenna has two grounding electrodes; one at the tip, and the

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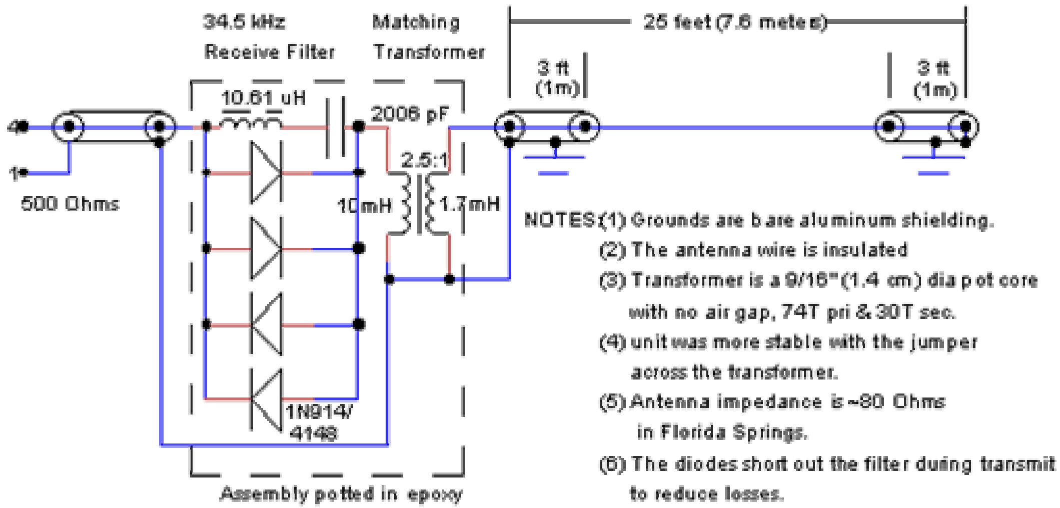
other near the unit. The transmit current flows through the water between the electrodes, creating the electromagnetic fields. The magnetic field pattern is essentially the same as that of a vertical loop oriented parallel to the wire. The antenna efficiency is determined by its impedance (the lower the better), which is mostly just the resistance between the electrodes through the water, calculated from Dave Gibson's equation below with R = resistance between two electrodes in Ohms; ln = natural log; L = electrode length in meters; d = electrode diameter in meters; pi = Pi s = conductivity of earth (or water) in Siemens/mtr.



Diver's Trailing Wire Antenna for the SSB-2010

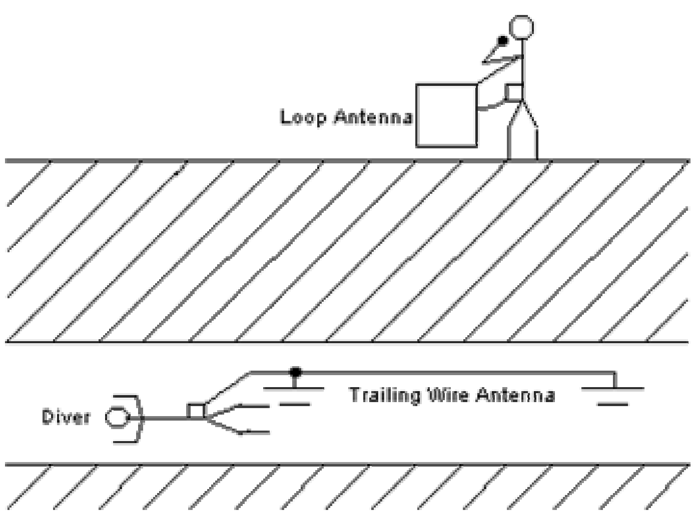
$$R = \frac{\ln(4L/d)}{pi \cdot s \cdot L} \text{ Ohms}$$

With my trailing wire electrodes, the antenna impedance in typical Florida spring water (conductivity=.028 S/m) is 80 Ohms calculated. This has been checked by actual measurement. The 2.5:1 turns ratio of the transformer matches the 500-ohm output of the SSB-2010. Unlike the surface loop, the trailing wire antenna is broadband and non-resonant. For this reason I included a simple 34.5 kHz bandpass filter to provide some selectivity.

Important Note: *This underwater antenna is optimized for Florida springs water. It should work in most water filled limestone caves, and also sumps in dry caves. For waters of drastically different conductivity, the transformer turns ratio must be changed.*

The wire antenna could be used in dry caves if the grounds can be submerged in a cave stream or in pools. A longer wire and large grounds could be used.

For fresh water lakes and streams, and non-karst springs and caves where the conductivity is very low, the antenna impedance will become quite high. The transformer can be eliminated, or changed to step the antenna impedance down to 500 Ohms. There is a possible shock hazard to divers from the high transmit voltage developed between the electrodes. I suppose that divers in open water could use the 1-meter loop. The optimum frequency will be much higher, probably in the low MHz range, where a tuned (loaded) insulated antenna can be used.



Optimum Orientation and Position of the Antennas

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In seawater, the range will be very limited despite the low impedance between the electrodes, even with a proper impedance match. The optimum frequency is much lower. I don't recommend use in seawater. Let me know of any successful results!

I have not yet found a good wire for this trailing antenna. I think that the antenna should be very flexible and float on its own, or be neutrally buoyant with a float close to the diver to hold it up away from his fins. The original antenna was constructed with very flexible "test lead" wire with thick rubber insulation. I attached about 30 small Styrofoam balls (available at craft stores) with tie wraps to make it neutrally buoyant, which was ok for testing but might snag on projections. The present antenna, using the core of 75-Ohm RG-6 foam coax, is slightly buoyant but fairly stiff due to the solid center conductor. It works well only when a support diver holds the trailing end to keep it stretched out. I may try a "sinking" wire.

Test Results

The first test was conducted at the entrance to Wakulla Springs in north Florida. The antenna with Styrofoam balls was used, with no one holding the wire straight-out underwater. The diver swam deeper while I stayed on the "beach". We still had 2-way voice communications at the 100-ft (30m) limit of the dive. Atmospheric noise was low, but EMI from digital and video still cameras was severe at a range of less than 10 feet (3m). Visit http://www.floridasprings.org/expedition/dispatch2 to see photos, video, and audio clips from this test.

The second test was conducted further south at Alachua Sink, where successful comms were maintained at ~200 ft (60m) depth (160 ft of rock plus 40 ft of overburden). The diver used the improved trailing antenna built from RG-8 foam coax. A support diver kept the antenna stretched out. I tracked the divers with 3500 Hz Radiolocation gear while a second person followed me with the voice unit. The optimum orientation for the vertical surface voice loop is parallel to the diver's direction of travel, with the strongest signal directly overhead. The tunnel passed under a busy 4-lane highway. The surface voice operator was forced to orient his loop to null out interference from the high tension power lines that ran along both sides of the road, but was able to maintain comms even in the median.

The final trial involved some real work at Florida's Hart Springs Park. I tracked the divers carefully at modest depths ~65 ft (20m), while a second person on the surface used the voice unit to direct the divers to swim under certain surface features to inspect blockages from underneath. My path was marked with flags, while the divers reported depths. They could also have reported passage cross sections and other details instead of writing them down. We later surveyed the path with compass, clino, and tape; in effect surveying the tunnels from the surface.

Conclusions

Thru-the-earth voice communications with divers is both possible and useful. The system described here is easy to assemble, because only the antennas need to be constructed. Other brands of underwater acoustic gear could probably be modified in a similar way.

The range of my system is adequate for its intended use, but is not enough for 250-300 ft (90m) depths, or when used by itself without separate diver tracking. Due to the shape of the trailing wire's magnetic field, it is not possible to track the diver closely, in real time. All one could do is to run around on the surface hunting for the best signal. The best solution to increase range may be to increase transmit power. Orcatron.com has several acoustic SSB units that operate on 32.768 kHz USB, and also long range 8 and 16 kHz units with 50 watts output.

A longer trailing wire and/or larger grounds (with proper impedance matching) will improve the link in both directions, as the diver's receiver is typically not atmospheric noise limited.

A better surface loop will improve the downlink s/n, but not the uplink, which is usually atmospherically noise limited. Changing the loop to #16 wire should narrow its bandwidth to about 3kHZ, the highest practical Q. The transformer ratio would have to be changed to reflect the higher impedance. The largest mobile surface loop is probably 1.5 meters square and might be worth trying.

A long grounded wire can be deployed along the surface over known passage. This should provide comms throughout the dive. The surface operator can then remain at the entrance. Since good grounding is very difficult in dry earth, it would be far better to run the wire between two water-filled sinkhole entrances. It can be matched like the diver's antenna, using the impedance equation. Most likely a multi-pole bandpass filter will be necessary to reduce interference from out of band signals.

This voice system could be used in dry caves if the trailing wire grounds were submerged in a cave stream or pools. It would not be mobile unless the operator was wading in a cave stream. The SSB-2010 diver unit is about as "caver-proof" as electronics can get. An SSB-2010 could be used, with a headset/mike, on the surface in place of the STX-100 for improved waterproofness and portability.

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References

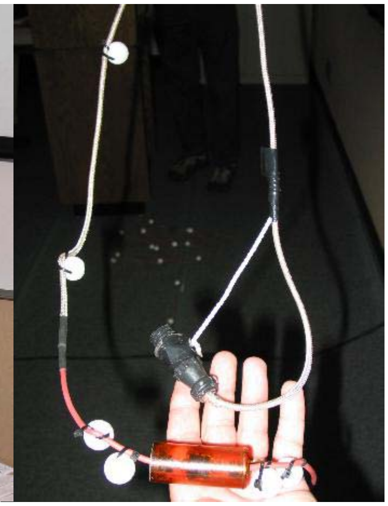
Gibson, David, *The Resistance of Ground-Electrode Arrays*, CREGJ 29, pp 26-27, Sept 1997

Ocean Technology Systems (SSB-2010 & STX-100):
http://www.oceantechnologysystems.com

Orcatron Communications Ltd (High Power gear):
http://www.orcatron.com

Florida Springs website (Voice and Tracking demo at Wakulla Springs):
http://www.floridasprings.org/expedition/dispatch2

Thru-the-Earth Radiolocation & Voice construction and use (author's Website):
http://Radiolocation.tripod.com



ABOVE: The Author presenting at the 2003 Convention and close up of the diver antenna.

LED Flashlight White Paper

By Henry Schneiker
www.HdsSystems.com
March 10, 2004
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A flashlight (headlamp, torch) designed around an LED can offer significant advantages over the same flashlight designed around an incandescent light bulb or other light emitting device. In this paper, I will cover the luminous, electrical, thermal, optical , mechanical and interface aspects of flashlight design as they pertain to LED's as well as how the human visual system adapts to different lighting conditions. Although certain aspects of this paper are somewhat technical, even the non-technical person will be able to gain a better understanding of the issues and trade-offs involved in designing an LED flashlight.

By necessity, this paper talks about specific devices. However, I do not mention any manufacturers or part numbers because that information is not important to the points being discussed. As with any project, you should fit your design to the actual parts being used - taking advantage of their capabilities and being careful of their limitations.

The LED

LED stands for Light Emitting Diode. A diode is a device that passes current in the forward direction while blocking it in the reverse direction. When you pass current through an LED in the forward direction, the LED emits light. The color of the emitted light depends on the material and construction of the diode. The amount of light varies roughly linearly with the amount of current passing through the LED, which provides us a convenient way to efficiently change the light output.

LED's are solid state devices and therefore quite reliable. Mean time to failure is often listed at over 100,000 hours of operation under specified conditions. LED's are far more reliable than the ubiquitous incandescent light that you normally find in a flashlight. LED's can also tolerate much higher shock and vibration loads than other common light sources including incandescent lights, florescent lights and other arc lights.

But as good as LED's are, they not perfect.

The most significant issue from a production point of view is the variability of LED's. When LED's are manufactured, considerable effort is made to get all the LED's to come out the same. However, even on the same wafer, there is tremendous variation from LED to LED. The variations are so significant that the manufacture must test all the LED's and sort them into bins. Common bin categories include color, light output (flux) and forward voltage.

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So to get consistent production results all you have to do is specify the bin you want when you order the LED's, right? Wrong. To illustrate why this is so, let's take a closer look at what the bin ranks actually mean.

If you take a color bin for a white LED and convert the CIE xy coordinates of the bin corners to CIE L*a*b* values - where each whole number is approximately one distinguishable shade of color or brightness - even a small bin can have 13 shades of distinguishable colors diagonally across the bin. A larger bin can easily have 30 or more shades of distinguishable colors diagonally across the bin. This means that if you take two LED's from opposite diagonal corners of the same bin and view them side by side, you will see that the white light being emitted from each LED is of a different shade of white. Further, people often find some shades of white more pleasing than other shades, with shades closest to the black-body temperature curve being the most pleasing.

A similar situation results when you look at the light output at a specific current (the flux) and the forward voltage. A typical bin can cover a flux range of n to 1.3n and a forward voltage range of v to 1.1v. When combined in the worst case scenario, this can produce a 40% difference in overall efficiency within the same bin. This difference can be seen easily if you compare the two lights side by side.

If a customer compares two lights and sees an easily distinguishable difference between them, the customer will generally assume that one of the two lights is defective. Educating the customer to the realities of production variations only goes so far. Significant variations will often result in customer dissatisfaction and returns.

There is, of course, a statistical side of this. The actual distribution within the bin is statistical in nature and the probability of any two lights exhibiting a sufficient difference that the customer will notice or be concerned about the difference is also statistical.

The unit-to-unit variation is much higher in LED's than in most other light sources. Some of these differences can be reduced through a calibration process. However, it might be easier if you have multiple product lines and carefully sort the LED's for each model - thus reducing the intra-model variations.

LED's have another problem that is worth noting. LED's become less efficient as you increase power and temperature. And since LED's have a negative temperature coefficient, the hotter they get, the more power they want to draw. This makes them unstable and prone to thermal run-away unless careful attention is paid to how they are driven. Further, high temperatures will increase the rate of permanent lumen (light output) loss beyond the typical 3% per 1000 hours.

When I talk about high power LED's, I am referring to LED's that are designed to handle one or more watts of continuous power per LED. However, the same principles can often be applied to the low power LED's or arrays of low power LED's. The high power LED's typically provide a fairly low thermal impedance which can be coupled to an effective heat sink to minimize the LED's junction temperature. Every effort should be made to keep the LED cool for maximum efficiency. If the LED's will be driven at high power levels under conditions where effective heat dissipation is not possible, the LED's must be thermally protected to ensure reliable operation.

And finally, when you dim an LED by reducing the current, the LED can and often does undergo a significant color shift. The severity of the color shift is dependent on the individual LED. This effect is most noticeable to a human observer with white LED's. What happens is that as the current drops, the dominant frequency also drops. The amount of frequency shift is quite variable from one LED to the next and a manufacturer seldom tests for it. With white LED's, the dominant frequency (blue) is used to excite a phosphor that re-emits at the lower end of the spectrum to provide yellow, orange and red. As the frequency shifts down, the blue dominant frequency shifts toward green making less of the required blue frequency available for down-conversion to yellow, orange and red and so the color shifts toward green. The only way to reliably prevent this is to always drive the LED at recommended power levels while dimming.

The Power Supply

The purpose of the power supply is to supply and regulate power to the LED and ensure a stable operating environment. The power supply can vary in sophistication from a voltage source in series with a resistor - such as a battery with or without an additional resistor - to a fully regulated constant power system with thermal regulation. The characteristics of the power supply directly affects cost and the stability of the light output.

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LED's have a steep Vf/If curve. This means that a slight change in forward voltage (Vf) will have a relatively large affect on the forward current (If). Further, this curve is different for each LED. To drive this point home, if you assume you have LED's that all come from the same bin and the bin provides a Vf tolerance of 10%, the power consumed by LED's in that bin can vary from n to 2n if powered with a constant voltage.

As I mentioned earlier, LED's have a negative thermal coefficient. This means that Vf decreases with increasing temperature. With a constant voltage power supply, increasing the temperature slightly decreases the Vf and increases the current by a relatively large amount - causing a net increase in power and a further increase in temperature. For any given thermal path, there is a power level at which the heat transfer can no long keep up the increasing power and falling Vf. Thermal runaway is the result and it will destroy the LED if nothing limits the power to safe levels.

Regulating the current or power through an LED effectively prevents thermal runaway. Regulating power through an LED has the added benefit that it tends to provide better brightness regulation over a wide temperature range. A good regulating circuit will keep the flashlight brightness the same throughout the life of the battery. Both systems can include thermal regulation to prevent dangerous heat build-up if the thermal path is inadequate at a high power setting.

A direct drive flashlight - i.e., batteries in series with an LED, with or without an additional resistor - cannot provide a constant output brightness. The brightness/time graph of this class of flashlight produces a smoothly descending curve. This is because the battery voltage sags quickly and thus the power through the LED drops rapidly. Suffice it to say that in the first quarter of the battery life, the brightness drops significantly. Battery life in this case is being defined as the amount of time it takes for the brightness to drop to 25% of the original value with fresh batteries. Another problem with direct drive flashlights is that power through the LED can be at dangerously high levels until the internal resistance of the battery increases sufficiently to limit the power to safer levels. As a result, direct drive flashlights are usually less reliable as a result of a higher LED failure rate.

The efficiency of a system is controlled by the efficiency of all the parts. In a typical LED flashlight, you have a battery, a power supply (or regulator) and the LED. The efficiency of the battery drops as the power increases. Most power supplies and LED's have an optimum point where they are most efficient and are less efficient at higher or lower power settings. This optimum point is often around 10 to 20% of rated power. In general, the increase in battery efficiency at low power settings more than offsets any decrease in power supply and LED efficiency at low power settings. The net result is that there is little or no net decrease in total efficiency at typical low power settings.

At the higher power settings, a compounding affect can be observed that decreases total efficiency in a non-linear fashion - often faster than N squared. The primary cause of this rapid drop in efficiency is the I squared R (current squared times the resistance) losses found throughout the circuit - especially where high currents are found. The next biggest loss in a switching power supply is usually coil saturation. And finally, as the LED junction temperature goes up, the LED efficiency drops.

Batteries have a large affect on a flashlight's design because they supply the power. Alkaline batteries develop a high internal resistance as they are used up. Therefore, alkaline batteries are not well suited to high current applications because large amounts of their power will be lost due to the internal resistance - dissipated as heat. Further, alkaline batteries stop producing useful amounts of power by the time the temperature drops below freezing, making them inappropriate for cold environments. Lithium batteries (in many different chemistries) have a fairly low internal resistance throughout their life and work at temperatures well below freezing. The economics of lithium batteries has changed to the point that they are now similar in cost to alkaline batteries, making them the first choice in battery power for most flashlight applications.

You must be careful when using rechargeable batteries not to over-discharging them. Over-discharging rechargeable batteries can damage or destroy them. When a regulating switching power supply is used, the battery can be over-discharged before the light output drops by a noticeable amount. A flashlight should detect rechargeable batteries and prevent them from being over-discharged. Further, lithium rechargeable batteries often contain a special protection circuit that turns off the battery to prevent accidental over-discharge - causing instant darkness. Once the protection circuit turns off the battery, only recharging it will turn the battery back on. A flashlight should detect a lithium rechargeable battery and prevent the battery from turning off and suddenly leaving you in the dark.

As your batteries nears the end of their life, a flashlight should signal you and reduce the brightness gracefully. You

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should be notified that the batteries are nearing the end of their life so you can find a safe place to change them. If you cannot change the batteries, the light should continue to provide light for as long as possible - long enough for you to return to safety - and fresh batteries. Even if that takes you a day or two. Once you know the batteries are at the end of their life, you should be able to manually reduce the brightness further to make the remaining battery power last even longer.

The Optics

The LED chip emits light in all directions. An optical system is used to gather the light and shape it into a beam. The LED itself has a built-in lens. This lens is limited in its ability to gather and shape the light into an acceptable beam and the LED manufactures only offer a limited number of lens options. An optical system consisting of just the built-in lens in the LED may produce acceptable results for inexpensive flashlights, but for higher quality results, a more advanced optical system is required.

A parabolic reflector can theoretically generate a beam of perfectly parallel light rays the same size as the exit aperture (the large open end of the parabola) given a point source of light at the focal point. Some percentage of the light from the point source will not be incorporated into the beam because it never contacts the reflector surface. The solid angle that intersects the parabola relative to total spherical solid angle is used to define the reflector capture efficiency - the smaller the exit aperture solid angle, the higher the capture efficiency and the brighter the beam - all other things being equal.

In a real reflector you have imperfections that tend to scatter the light beam. First, your light source is never a point source - it is always a complex 3-dimensional surface. Second, the reflector's surface is never perfectly smooth or exactly the correct shape. This leads to angular errors that tend to spread the beam. By designing in and controlling the angular errors you can shape the light distribution (beam pattern) to suit your purposes. Reflectors tend to provide the highest quality beams and the highest overall efficiency.

A transmissive lens, such as a common magnifying glass, uses refraction to achieve a similar result. Instead of light being reflected off a surface, light is bent at the air/lens interface. Transmissive lenses have three main problems. First, they have a relatively low capture efficiency - any light that falls outside of the aperture is lost. Second, as the angle between the lens surface and the light source deviates from perpendicular, an increasing amount of light is reflected off the surface and lost instead of being bent into the lens. Third, the lens projects an image of the emitting surface - as a result, the focal point is normally chosen to be different from the emitting surface so the image is blurred.

There are also compound reflector-refractor optics that combine properties of both systems. These optics often use the high reflectivity of the air/optic interface to form the reflector surface. These optics tend to be more efficient and have better beam quality than a pure transmissive lens but are not as good as pure reflectors. However, these optics have the advantage that they tend to be more compact than reflectors.

An interesting property of lenses is that they are all about angles. Since the same angular error will produce the same result regardless of size, the only limits to small size are the emitter size and surface tolerances. As a result, a smaller emitting surface can use a smaller optical system and produce the same beam pattern. Or, you can increase the size of the optical system to reduce the angular errors and improve the beam pattern definition. The variations are endless.

The Human Visual System

If you look at typical flashlight marketing literature, you might think that brighter is always better. But allow me show you why that may not be the case.

Your eyes can adapt to a wide range of light intensities. At noon on a summer day the sun can illuminate a surface to 120,000 lux while an overhead full moon might illuminate the same surface to only 0.1 lux. Your eyes use three main methods when adapting to changing light levels. Under bright conditions, your eyes exclude excess light by closing the pupils. As the light level falls below the point where the pupils are fully open, the eyes undergo a chemical change to increase the cone (color) cell sensitivity. Finally, as the light level falls below the capability of the cone cells, the rods (no color) cells take over and become maximally sensitive. It takes 20 minutes after you leave a brightly illuminated area to become fully dark adapted.

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So how much light do you actually need to perform a task? 1000 to 2000 lux is recommended for fine detail work where maximum visual acuity and color recognition is required. 100 to 200 lux is appropriate for most office work. By 10 lux, colors are less vibrant while visual acuity is good. By 1 lux, unsaturated colors cannot be distinguished and visual acuity is only acceptable. By 0.1 lux, no colors are visible and visual acuity is poor. By 0.01 lux, visual acuity is lousy and you can see objects better if you don't look directly at them.

The forgoing illustrates that providing 50 to 200 lux of illumination is plenty for most tasks that require good color recognition and good visual acuity. Much less light is needed for tasks that only require object shape identification.

It takes one lumen - that's one candela per steradian - to illuminate one square meter (about 10 square feet) with 1 lux. Note that luminous flux - in lumens - is mapped against the color sensitivity curve of the human eye. However lux can also be defined in terms of radiometric flux at a single frequency and is equivalent to 1.46mW of radiant electromagnetic power per square meter at 555nm (the color to which you are most sensitive - a shade of green).

The amount of light illuminating an object depends on how bright the light is and the distance the light is to the object. If you know the amount of light illuminating an object at one distance, you can calculate what the amount of light illuminating an object will be at another distance using the inverse square law. For example, if you move the light twice the distance from an object, the illumination drops to one quarter (2 squared is 4 and the inverse of 4 is 0.25 or one quarter). As another example, if you have a light that generates 500 lux at 1 meter (just over 3 feet), it will generate 100 lux at 2.2 meters (about 7 feet) or 10 lux at 7.1 meters (about 23 feet) or 1 lux at 22.4 meters (about 73 feet). The drop in illumination corresponds to an increase in the illuminated surface area. Put another way, you need 4 times the light to see twice as far with the same illumination level.

The eye responds to light in a logarithmic manner. That is, for the eye to indicate a significant increase in brightness - i.e., an easily recognizable increase in brightness - the amount of light must double. For dealing with the large variations of light in your environment, this is a wonderful thing. For flashlights trying to get ever brighter, this is a terrible thing because it takes over twice as much power to generate twice as much light while the battery life drops to less than half - due to the escalating inefficiencies discussed earlier - for a single incremental increase in brightness. However, if you want to maximize battery life by using lower brightness settings this is a great thing. Why? For every incremental decrease in brightness, you more than double the battery life and after a few minutes, your eyes adapt to the new brightness level so the apparent drop in brightness actually decreases. By reducing the amount of light to match your task, you can dramatically improve the battery life.

The eye's logarithmic response to light suggests that brightness levels should be spaced in a logarithmic way. That is, the steps between brightness settings should be a constant factor - such as 2x - instead of using a more linear approach. This provides the appearance of the steps being equally spaced. This same method is used in the audio industry for volume controls. Because of the eye's adaptive characteristics, a continuous control in inappropriate for a flashlight. The reason is that you are quick to turn up the light but slow to turn it back down. In fact, if you are asked to turn up the light for a minute and then turn it back down to where it started, the resulting brightness will usually be brighter than before starting the exercise. Human factors should never be forgotten when designing controls.

Putting all the light in a narrow beam is great for looking at an object at a great distance. However, the contrast from the bright beam center to the dark area just outside the beam is so great that you will have difficulty seeing objects just outside the beam - to the extent that trying to walk using such a beam can be difficult or dangerous. A general purpose light should provide enough light outside the main beam so your eyes can move comfortably between the beam center and the outer areas and take in a large viewing area. Better still is to provide a smooth transition between the two areas. The broader the transition zone, the lower the contrast and the safer you will be when using the light to navigate rough terrain. You will find that you can use less total light with a smooth broad beam. If fact, you might want to carry two lights - one with a broad beam for walking and general use and another with a narrow beam for spotting distant objects.

User Interface

As you may have gathered from the previous discussion, there is a lot to be gained by providing a flashlight with more than an on/off switch. Adding a brightness control extends the utility. Having the flashlight automatically detect and compensate for different battery systems allows operational flexibility. And there are always a few extra

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features that would be nice to have, such as automatic emergency signaling, a way to find the flashlight in the dark or a way to prevent accidental turn-on.

As soon as you start adding features to the flashlight, you increase the complexity of the user interface - not to mention the design and cost. Let's take adding a brightness control as an example. Will there be a single button (click codes), two buttons (brighter/dimmer), n buttons (one for each brightness), linear slider or a rotary switch (volume control)? Is the brightness control integrated with the on/off switch or is it separate. Do you have to worry about making the controls water proof or making them work after being abused? How many brightness levels will there be? Will the user have access to all brightness levels all the time? Will the brightness control be continuous or a step function? How will brightness levels be spaced. Are there other features that will need controls and how will they interact with the brightness control?

And how will the flashlight's electronics detect the user's input? On/off switch? Change in resistance? Change in capacitance? Change in inductance? Mechanical coupling? Optical coupling? Magnetic coupling? Digital or analog? The possibilities seem endless.

While you are thinking about all this, you should never forget that the main purpose of a flashlight is to turn on and generate light. So this function should remain as simple to use as any other flashlight. Features that are used the most often should be the simplest to use - a user should never have to scroll through a list of brightness settings to get to his favorite brightness setting.

A microcomputer can be used to help implement the user interface, whether it involves a single control or multiple controls. The microcomputer is also handy in implementing automatic functions and performing other tasks. Having the intelligence in software instead of in hardware provides us with the opportunity to tailor various characteristics and provide automatic controls that are not easily done in hardware. Further, it allows us to add new features with relative ease.

Summary

Designing a flashlight around an LED allows us to design a very rugged and sophisticated light. A typical laundry list of desired features includes small size, high maximum brightness, multiple brightness settings, constant brightness regulation, thermal regulation, a smoothly tapered beam pattern, support for multiple battery chemistries and rechargeable batteries, long battery life, battery end-of-life warning, simple controls, automatic emergency signal, switch lock-out and an in-the-dark locator. These features can now be found in a single compact flashlight.

Automatic Dark Detector Emergency Light

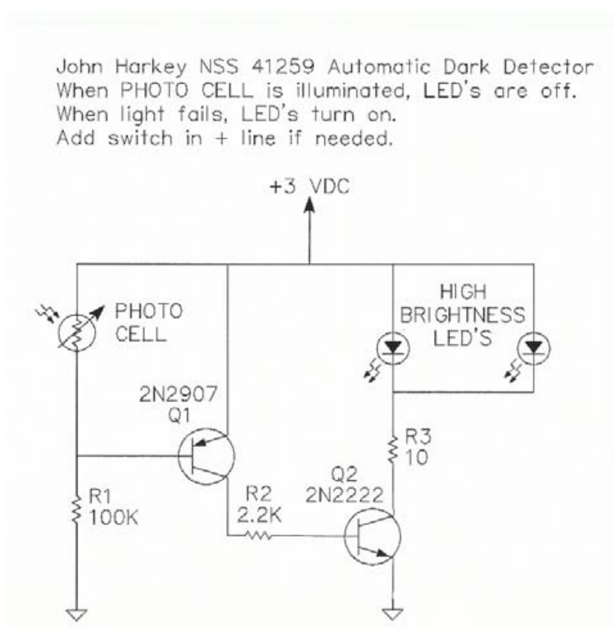
by Paul R. Jorgenson KE7HR NSS 39382

I was caving with a fellow that had a big LED attached to his headlamp. On closer inspection I discovered that he had designed and built an automatic dark detecting emergency light. It uses a photocell and transistors to switch current to the LED's.

When the photo cell has light striking it (from your main headlamp, for example) it keeps the LED's switched off. When the light is removed from the photo cell, the transistors switch the LED's on.

I put together a copy of this circuit with two high brightness LED's and had to play with the resistors a bit to get mine to work. The resistance of my photocell or it's response to light was probably different than the original one. A photo transistor could possibly be used in place of the photo cell.

This makes a fine emergency light source if the main headlamp fails. A switch in the + line of the battery source will keep from draining the battery during transport to the cave.



Salvaging Throw Away Flash Cameras

Paul R. Jorgenson KE7HR NSS 39382

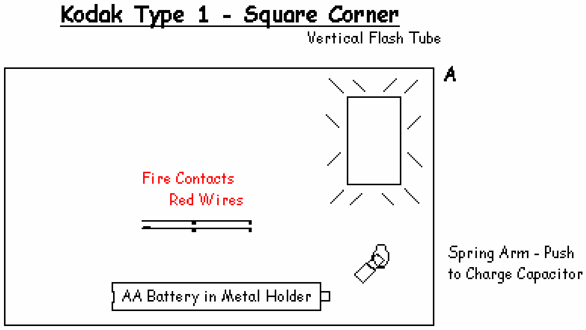
While bring in film for processing at a local mini-lab, I noticed that there was a bucket of 'one time use' camera bodies. I asked the clerk about them to see if they were being recycled. The answer was that the recycling procedure was complex and time consuming to the point that the used cameras were just thrown away in the trash. I saw several cameras that had flashes in the trash and asked if I could have them. They were happy to give them away. These little boxes are loaded with fun stuff, but need to be taken seriously.

CAUTION: HIGH VOLTAGE ON THE CAPACITOR AND FROM THE INVERTER INSIDE THESE CAMERAS. THIS HIGH VOLTAGE MAY CAUSE SERIOUS INJURY OR DEATH. ONLY TAKE THESE CAMERAS APART AT YOUR OWN RISK.

I found that over time I was getting four types of cameras from my trips to the mini-lab (they would put aside the flash cameras for me to pick up a couple of times a week). The first was Kodak Type 1 (Fun Saver 35, Fun Time 35), Kodak Type 2 (Fun Saver Pocket Camera), Fuji Type 1 (Quick Snap Plus), and Fuji Type 2 (Quick Snap Super Flash). The different types are shown graphically below with instructions on how to remove each board with the flash attached. I have seen some Chinese screw together types lately, but have not taken the time to take them apart. I am sure that there are even more different types than these, but the basic procedures should work for most of them.

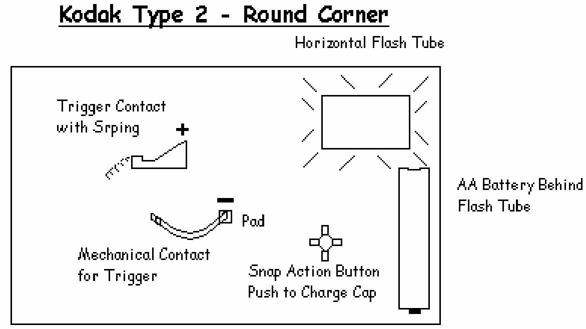
Inside the cameras, besides the flash unit, is a AA size battery that is still fairly fresh. The capacitors can be added in parallel to increase the output of the flash tube. It shortens the life of the flash tube, but there are always more in the salvage pile. Slaves can be added so that these units can be used for fill flash. Have fun, but be careful!

Kodak Type 1 - Square Corner



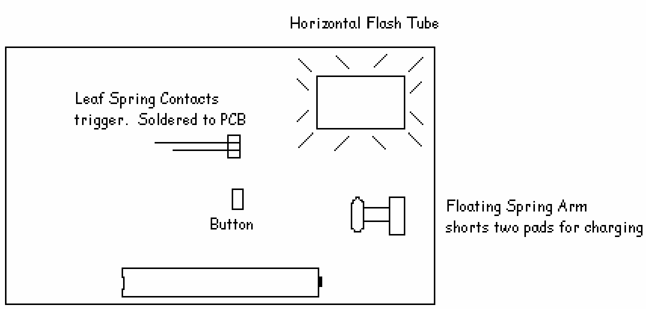
1. Remove Paper Cover
2. Pop off front
3. Remove Battery
4. Short Contacts (discharge cap)
5. Bend corner 'A'
6. Remove Flash

Kodak Type 2 - Round Corner



!. Use Screwdriver to remove battery and open camera
2. Wind Blue sprocket in film chamber to cock shutter
3. Fire camera with shutter to discharge cap
2a 3a. OR short + to - to discharge cap
4. Remove Spring
5. Remove Flash

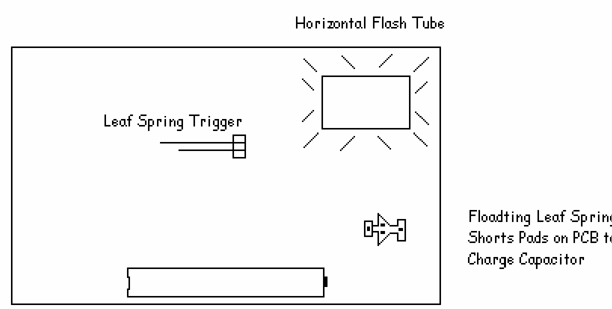
Fuji Type 1 - Square Corners



AA Battery in Bottom Compartment

!. Remove Paper
2. Remove Battery
3. Remove Front - from left side
4. Short Contacts
5. Push button to left & remove flash

Fuji Type 2 - Round Corners Small Tube



AA Battery in Bottom Compartment

1. Remove Paper
2. Remove Battery
3. Pull off Top
4. Lift out Flash

COMPUTER MODELING
THRU-THE-EARTH COMMUNICATIONS ANTENNAS

Brian Pease

For many years the only cave radio computer modeling that I did was to use Steve Shope's DOS-based FATE-VMD program (which stands for Fields Above The Earth from a Vertical Magnetic Dipole) as an aid in understanding the effects of electrical conductivity on the magnetic fields of a buried transmitter with a horizontal loop antenna. This program assumes that the earth is primarily a conductor. This proved to be an invaluable aid during the design of my 3496 Hz radiolocation system.

When I became interested in wire antennas for voice communications at higher frequencies a couple of years ago, I looked for some suitable modeling software. I was aware of NEC, which stands for Numerical Electromagnetics Code-Method of Moments, but had never used it. It has been developed by the Lawrence Livermore National Laboratory for the military. It is used to model thin wire antennas and 3-D models constructed of thin wires. You can derive the input impedance of an antenna, add a matching network if desired, then calculate the near or far Electric and magnetic fields in any direction or at any distance from the antenna. The program breaks the wires of the model into short segments and calculates the current (and phase) in each. It then uses integral equations to compute the fields at any distant point.

NEC has been improved over the years. NEC-2 is widely available, even for free, and can model wire structures in free space, especially at HF and VHF. NEC-3 does the same but can also model wires buried in the ground or penetrating from the air into the ground. Both versions suffer loss of precision when modeling electrically small structures such as low frequency cave radio antennas. NEC-4 uses revised algorithms which will (with some limitations) model electrically small structures in, on, and above real earth with finite conductivity and permittivity. It also can model insulation around the wire, which is very useful for modeling antennas in water. NEC-4 is not (in theory) available to the public, but having worked in a Navy Lab for 30 years that did antenna work among other things, and still having a security clearance, I was able to borrow a double-precision copy of the basic code, but without a Graphical User Interface.

As I understand it, NEC-4 is a Fortran program (remember the IBM 1620 circa 1960?) adapted to run on a PC. One creates a text file with Windows Notepad in which each line represents a single IBM punch card. Each "card" starts with a 2-letter command for geometry input or program control, followed by several items of data separated by commas or spaces (your choice). The initial output is an annotated text file giving impedance, efficiency, currents along the antenna, and whatever fields were requested. There is a plotting program, but so far I have found it easier and faster to just request fields at a single distance in the primary directions. This reduces the calculating time to a few seconds.

One can include wire resistance, lossy loading coils, and impedance matching components anywhere in the structure. This is really useful with electrically small ungrounded antennas such as mobile whips where most of the loss is in the matching network. The loading coil can be modeled as a radiating element if it is large.

So far I have run into a few limitations in modeling electrically small antennas. Although in theory NEC-4 can model small loops down to .002 wavelength in circumference, I have not succeeded yet. There is a card that creates a helix, which is a multi turn inductor at our frequencies, but it does not behave properly. The inductive reactance should double when frequency is doubled, and should correspond to a value of inductance that can be easily calculated, but neither is true.

NEC-4 calculates values of resistance for ground stakes that agree exactly with Dave Gibson's simple equation, but only when the antenna wire connecting the stakes is above ground. This means that it is possible to accurately model the input impedance of grounded or ungrounded antennas on or above the earth's surface and predict the fields above or below ground at any distance. When antenna is entirely underground, and radiating portion of the antenna is insulated, the resistance is way off. This appears to be due to a modeling problem with the air or plastic insulation that surrounds the antenna wire. Underground or underwater modeling of grounded antennas is still possible, but first one has to model the antenna on the surface in order to get the actual input impedance to be able calculate the maximum input current from your transmitter. Knowing that the underground antenna will have nearly the same impedance, one can adjust the applied voltage (or power) until the correct input current is obtained. The field strengths should then be close to correct.

The Near Electric fields can be calculated anywhere including the surface of the Earth, but due to the use of a lookup table, the Near Magnetic fields can only be calculated for distances greater than .001 wavelength (in the medium) above or below the surface. At 185 kHz this is only 1.6 meters, which is not a serious limitation, but at 3.5 kHz the minimum distance is 86 meters above or below the surface which really limits what you can do.

Ungrounded Insulated wire antennas can be modeled in water. For predicting the fields from underwater anten-

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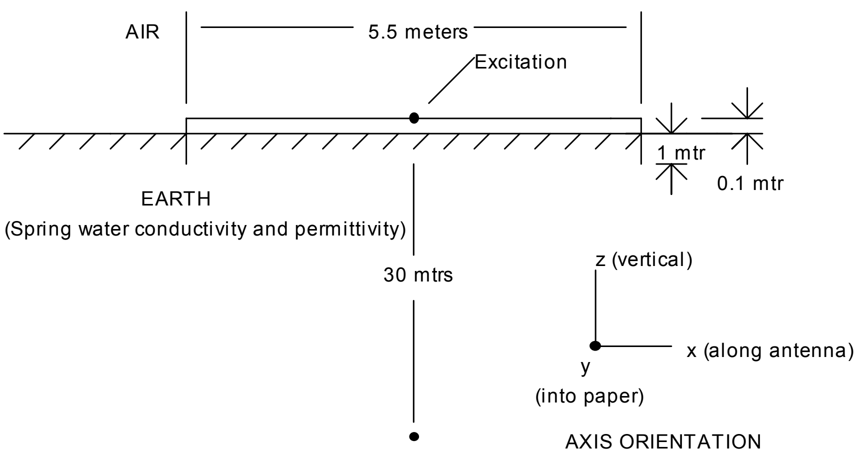
nas, one can assume that the antenna is immersed in water that has the conductivity and permittivity of the surrounding rock. For grounded antennas the impedance will not be correct, but the correct antenna current can be induced which will give approximately the correct field strengths.

It is also possible to model a wire at the center of an air or water filled cave passage, but I have not worked out all of the bugs yet. See Examples 1 & 2. The maximum diameter of the passage depends on the wavelength in the rock. For typical limestone with conductivity of .005 S/m and 185 kHz, the passage could be up to 5 meters in dia. The diameter becomes impractically small at HF.

The uplink signal is usually the weak link in 2-way voice comms as it has to overcome the full atmospheric noise. Generally the in-cave unit requires a better antenna than the surface unit, and/or greater transmit power. If the average rock conductivity and passage depth is known for a particular cave, one can then play "what if" games with NEC to calculate the expected uplink signal strength on the surface at different locations. This strength can be compared with the expected atmospheric noise level for the operating frequency location, season of year, and time of day that comms are desired. The noise information is published in the CCIR noise tables. 10 dB s/n ratio is a reasonable minimum for SSB voice comms. Comms may be great on a winter morning and impossible on a summer evening at the same location.

The following simple examples barely scratch the surface of what can be done with this software. They may contain errors, especially overlooked limitations of the program itself.



5.5 meter grounded dipole just above ground
Figure 1

EXAMPLE 1

I modeled a grounded horizontal dipole just above the earth's surface to obtain the input impedance for matching purposes at 185 kHz. The intended use of the antenna is underwater in limestone springs, but, as noted earlier, the grounds will not model correctly with the entire antenna underwater. The antenna is sketched in Figure 1. All dimensions are in meters because the program itself works in meters (If one wants, there is a card for converting units). The following paragraph is an annotated NEC-4 input text file which calculates the input impedance, wire currents, and the magnetic fields 30 mtrs (100ft) directly below the antenna in the earth. Consider each line to be a "card". The **CM** cards are just comments to document output. The notes following the "!" on the other cards are just reminder notes. The **GW** cards describe the antenna geometry. For example, the third **GW** card is the horizontal wire, which runs 5.5 mtrs along the x axis at 0.1 mtrs above the ground and is tagged #3; has 50 segments; starts at x=0, y=0, z=0.1m; ends at x=5.5m, y=0, z=0.1m; radius=.000635m. Card **NH** tells the program to calculate the near magnetic fields at a single point 30 mtrs directly below the antenna. "0" specifies rectangular coordinates; 1,1,1 specifies one point in x,y,z directions; the point is located at x=2.75 m, y=0, z=-30 m; "0,0,0" sets the distance increments to zero because we are only doing one point.

Input "cards" for Example 1

```
CM 5.5 MTR (18 ft) HORIZONTAL GROUNDED WIRE DIPOLE 0.1 MTR OVER GND
CM 1 MTR GROUND RODS, .011 MTR DIA, 185 kHz
CM EARTH COND=.025 S/m, RELATIVE PERMITTIVITY=80 (SPRING WATER)
GW,1,5,0,0,-1,0,0,0,.0055 !1 mtr vertical ground rod, .0055 m radius, at x=0, y=0.
GW,2,2,0,0,0,0,0,.1,.0055 !0.1 mtr vertical "stub" on ground rod.
```

(Continued on page 25)

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```
GW,3,50,0,0,.1,5.5,0,.1,.0055 !5.5 mtr horiz wire along x axis.
GW,4,2,5.5,0,.1,5.5,0,0,.0055 !0.1 mtr "stub" on ground rod.
GW,5,5,5.5,0,0,5.5,0,-1,.0055 !1 mtr vertical gnd rod at x=5.5, y=0.
GE,-1 !End of geometry input. Ground plane is present.
LD,4,3,25,25,0,-6.84 !6.84 ohms cap reactance in series with Zin.
EX,0,3,25,1,1,0 !Excitation of 1 volt at center of wire.
GN,2,0,0,0,80,.025 !Earth characteristics (spring water).
FR,0,1,0,0,.185,0 !Excitation frequency 185 kHz.
NH,0,1,1,1,2.75,0,-30,0,0,0 !Calculate Near mag field 30 m below ant.
NE,0,1,1,1,2.75,0,-30,0,0,0 !Calculate Near elec field 30 m below ant.
XQ !Execute program
EN !End of run
```

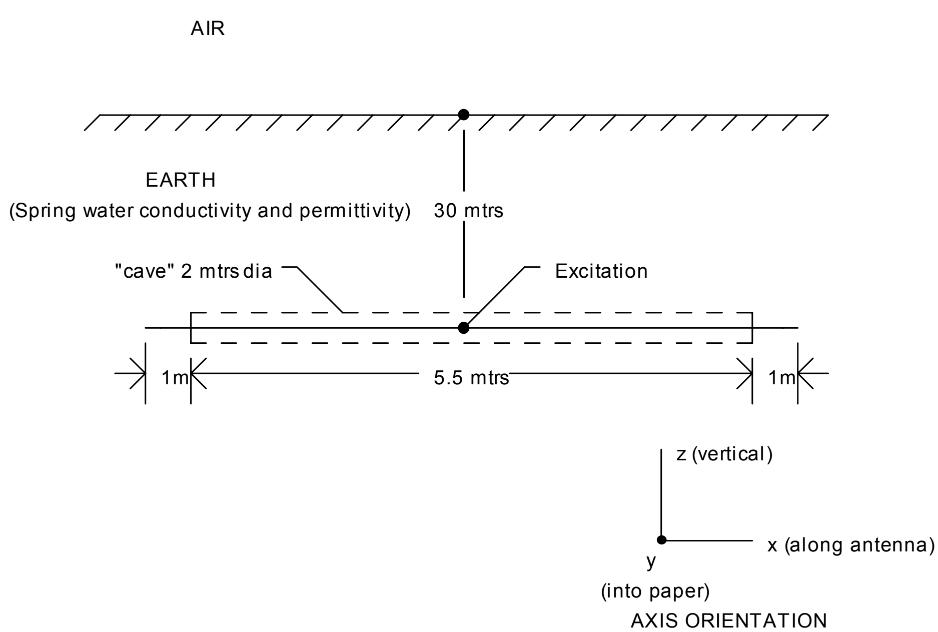
Table 1

The entire output file is far too large to reproduce here. After running the program once to find the input impedance (68.5+j6.84 ohms), the reactance was cancelled with the **LD** card. On the second run, the antenna current (now all in-phase) for 1 volt input was found. The only significant near magnetic field 30 meters directly below the antenna is Hy=1.42E-6 A/m (perpendicular to the wire).

The significant electric fields are Ex=1.11E-5 V/m (parallel to the dipole) and Ez=1.41E-11 V/m (vertical). It is obvious that a horizontal dipole will be better than a vertical whip for receiving this signal.

EXAMPLE 2

I modeled the same 185 kHz horizontal grounded dipole as Example 1, except located 30 meters underground, in the center of a 2 meter diameter air-filled cave passage. I wanted to compare the uplink field strength with that from example 1. The antenna is sketched in Figure 2. I know from experience that the input impedance will not be computed correctly, but the field strengths should be close to correct for whatever current is applied. I have the correct input impedance from Example 1, which will allow me to compute the real input power.



5.5 Meter Grounded Dipole Centered in 2 mtr diameter "cave"
Figure 2

Input “cards” for Example 2

```
CM 5.5 MTR GROUNDED WIRE DIPOLE BURIED 30 MTR IN 2 MTR DIA "CAVE"
CM 1 MTR GROUNDS, .011 MTR DIA, 185 kHz
CM EARTH COND=.025 S/m, RELATIVE PERMITTIVITY=80 (SPRING WATER)
GW 1 15 -3.75 0 -30 3.75 0 -30 .0055 !5.5 mtr wire with 1 mtr gnds
GE -1 !End of geometry input
LD 4 1 7 7 0 3029 !3029 ohms inductive reactance in series with Zin
IS 0 1 3 13 1 0 1 !2 mtr dia air filled "cave" around wire
```

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```
EX 0 1 8 1 37.41 0 !1V at center of dipole
GN 2 0 0 0 80 .025 !Earth constants cond=.025 S/m, rel per=80
FR 0 1 0 0 .185 0 !185 kHz excitation
NH 0 1 1 1 0 0 2 0 0 0 !Mag field 2 mtrs up (min height for accuracy)
NE 0 1 1 1 0 0 2 0 0 0 !Elec field 2 mtrs up.
XQ
EN
```

Table 2

After running the program once to find the input impedance (2526-j3029 ohms), the reactance was cancelled with the **LD** card. On the second run, the antenna current (now all in-phase) for 1 volt input was found, and the voltage raised to 37.41V to give the same current as Example 1. Despite the bogus high ground rod impedance, the antenna current is nearly constant along its insulated length, as shown in table 3 below.

The only significant near magnetic field is, Hy=1.92E-7 A/m. It appears that the program is underestimating the magnetic field on the surface by nearly an order of magnitude. This might be another effect of the **IS** card.

The significant near electric fields are Ex=1.06E5 V/m (parallel to the dipole) and Ez=1.16E-8 V/m (vertical).

SEG. NO..	- - - CURRENT (AMPS) - - - MAG.	PHASE
1	3.7177E-03	-2.996
2	1.0439E-02	-2.699
3	1.4188E-02	-2.229
4	1.4324E-02	-1.743
5	1.4461E-02	-1.265
6	1.4599E-02	-.796
7	1.4703E-02	-.336
8	1.4600E-02	.011
9	1.4463E-02	-.327
10	1.4327E-02	-.787
11	1.4419E-02	-1.256
12	1.4058E-02	-1.734
13	1.3924E-02	-2.220
14	1.0246E-02	-2.691
15	3.6490E-03	-2.988

NOTE: Segments 1 & 2, 14 & 15 are the grounds

Currents on Each Segment

Table 3

EXAMPLE 3

I recently modeled some ungrounded 160 meter Amateur band horizontal dipoles for Bonnie Crystal, KQ6XA for use over or in marble caves at the upper end of the band. The rock has such low conductivity (estimated to be ~0.2E-6 S/m) that the displacement currents cannot be ignored. Relative permittivity is ~ 6.2. The antenna wire is insulated. Axis orientation is the same as in Figure 1.

Dipole 1 is 68 meters (223 ft) long. The dipole is resonant at 2 MHz in air at 1 mtr elevation over the marble surface, with Zin=101 ohms. This antenna would be suspended over the ground or passage floor on stakes.

Dipole 2 is 58 meters (190 ft) long. The dipole is resonant at 2 MHZ in air at .03 mtr elevation over the marble surface, with Zin=87 ohms. This antenna would be more or less lying directly on the rock.

Dipole 3 is 30 meters (100 ft) long. The dipole has Zin=20.2 – j919 ohms. I added 38.5 uH inductors in series with each leg of the dipole to resonate it at 2 MHz, with Zin=28 ohms, at .03 mtrs elevation I actually wound an inductor to estimate its loss, and included antenna wire loss in the model.

Dipole 4 is 2 meters (6.6 ft) long with flat tape elements 1.3 cm (0.5 inches) wide. The program calculated Zin=.0827 – j9040 ohms. This is equivalent to 8 pF! I assumed Q=500 for the two series inductors with L=319 uH, which resonated the dipole at 2 MHz, with Zin=18.2 ohms, at 1 mtr elevation. Antenna efficiency is about 0.5%. Bandwidth is only 4 kHz.

I calculated the fields at 3 points, all 100 mtrs underground in the marble with 5 Watts applied to each antenna: a) directly under the antenna; b) 500 mtrs along the x-axis (off the end of the antenna); and c) 500 mtrs along the y-axis (perpendicular to the antenna). The results are shown in Table 4.

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On-Surface Dipole length (along x-axis)	a)100m depth directly Below Dipole	b)100m depth,500m along x-axis	c)100m depth,500m along y-axis perp to ant
1) 68 mtrs 1 mtr elevation	Hy=1.53E-3 A/m Ex=.225 V/m	Hy=3.31E-5 A/m Ex=2.58E- 3 V/m Ez=3.67E- 3 V/m	Hy=2.60E-5 A/m Hz=8.49E-5 A/m Ex=1.35E- 2 V/m
2) 58 mtrs .03 mtrs elevation	Hy=1.46E-3 A/m Ex=.215 V/m	Hy=4.46E-5 A/m Ex=2.90E-3 V/m Ez=5.38E-3 V/m	Hy=2.61E-5 A/m Hz=8.62E-5 A/m Ex=1.38E-2 V/m
3) 30 mtrs .03 mtrs elevation	Hy=1.18E-3 A/m Ex=.175 V/m	Hy=6.40E-5 A/m Ex=3.30E-3 V/m Ez=8.39E-3 V/m	Hy=2.08E-5 A/m Hz=6.84E-5 A/m Ex=1.09E-2 V/m
4) 2 mtrs 1 mtr elevation	Hy=1.10E-4 A/m Ex=1.63E-2 V/m	Hy=6.63E-6 A/m Ex=3.32E-4 V/m Ez=8.78E-4 V/m	Hy=1.80E-5 A/m Hz=5.86E-6 A/m Ex=9.36E-4 V/m

Fields for Example 3

Table 4

The signal 100 m directly under the antenna decreases for the smaller dipoles as one would expect. The 2 meter long dipole has an efficiency of 0.5% which should put its signal about –23 dB compared to the 68 meter dipole, which is the case.

Some of the other results in the above table seem strange. The 100 mtr deep E and H fields at 500 mtrs along the x-axis are stronger for the 30 mtr dipole than for the 58 mtr antenna. Both dipoles are at .03 mtrs elevation.

The 100 mtr deep Hy field at 500 mtrs along the y-axis perpendicular to the dipoles does not decrease as much as one would expect for the shorter dipoles. Hy for the 2 mtr dipole is only 3 dB below the 68 mtr dipole.

Conclusions

I have a lot to learn before I can be confident in using NEC-4 to predict antenna performance. I must find a better way to model grounded insulated antennas underground, and must find my errors in modeling electrically small loops.

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