Very High Power Radiobeacons
And Long Range Direction Finding

Brian Pease, 3/29/11

Abstract

This article describes the design and testing of 80 and 500 Watt high efficiency radiobeacons developed for direction-finding (homing) at 2-3km range on the Earth's surface using magnetic fields. Both are push-pull Class-E high-efficiency amplifier designs based directly on the author's existing single-ended class-E beacon. They could be employed underground for long range cave radiolocation and/or narrowband digital text communications use. Although intended for use with large high-Q tuned horizontal loops, this push-pull circuit can drive so-called Earth-current long wire antennas, with little additional filtering, exclusively for long range and/or deep digital communications use. There are no even harmonics. In a Spice simulation of the 80 Watt circuit with a resistive load (no series-tuned circuit) the 3rd and 5th harmonics are -16 and -25 dB down.

Why build a high-power beacon?

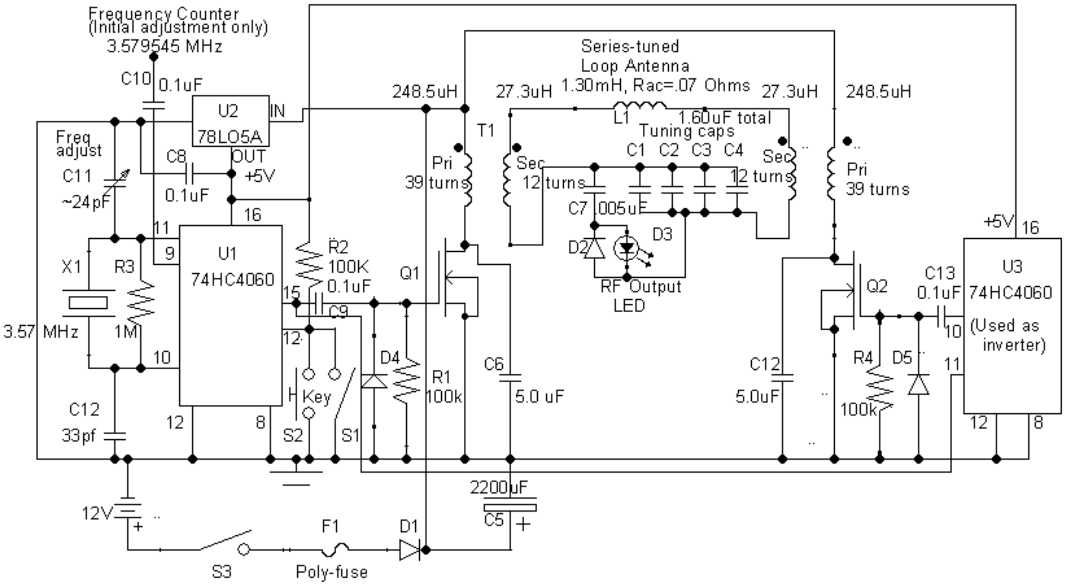
The author received an inquiry regarding the possibility of using a VLF magnetic field beacon on the Earth's surface to provide a homing signal that could be detected on the surface at 2-3 km range without generating a ground wave or skywave signal. A horizontal loop antenna, lying on the ground, for all practical purposes, generates only magnetic near fields. The primary magnetic field appears to be vertical everywhere (if the Earth is flat), and drops off approximately as 1/ distance cubed. This field sets up eddy currents in the somewhat electrically conducting Earth, which in turn produce a weaker secondary horizontal magnetic field that appears to come horizontally straight outward from the loop in all directions along the Earth's surface. This secondary magnetic field drops off approximately as 1/distance squared, which means that at longer ranges (km) it becomes stronger than the primary field. The secondary field can be used for direction-finding at km ranges.

This knowledge prompted me to do some simulations in the NEC-4 method of moments antenna simulation program. The results, although somewhat encouraging, turned out to be pessimistic (for once!). Real world conditions of uneven ground, varying conductivity, etc, improved the signal strength at long range when compared to theory on a flat Earth, at least on my hilly test range.

With the possibility of some paid work in the future, I decided to cobble together a beacon with as much power as I could with what I had on hand. I chose 3496 Hz because I could use an existing beacon loop antenna and my narrow band DQ receiver.

The first Design, 80 Watts push-pull at 3496 Hz

My current single-ended Class-E beacon design, for which I have made circuit boards, is documented on my website:
http://radiolocation.tripod.com/NewDQandBeaconFiles/2008DQboards/NotesOnThe2008_DQReceiverBoards.html
In Speleonics 25, pgs 11-12, http://www.caves.org/section/commelect/splncs/splncs25.pdf , I gave design equations for the single-ended circuit and described the use of the free LT Spice circuit analysis program for simulation. I knew that the single-ended design was capable of more power, perhaps 25-30 Watts, so I decided to combine two of these circuits, with one PC board (the Master) containing the 3496 Hz oscillator. The Master drove the second board (the Slave) 180 degrees out of phase, forming a push-pull circuit. The two outputs are added in series, with the output voltage looking like a slightly stepped sine wave.



80 WATT PUSH-PULL CLASS-E TRANSMITTER CIRCUIT DIAGRAM

NOTES: 1) Strictly speaking, the exact frequency 3495.65 Hz) is not important as long as it matches the receiver.
If you will use only this one beacon with your receiver, then C11 can be a 27pF fixed cap.
If you have two transmitters, however, or you will use other people's beacons you need to
standardise on the 3.579545 MHz crystal frequency, which is divided by 1024 to give 3495.65 Hz beacon freq.
C11 should be replaced with a fixed capacitor once the correct value is found.
2) F1 and D1 are optional for protection and reverse voltage protection.
3) S1 is a SPST switch to hold transmitter on for continuous measurements.
S2 is a momentary action pushbutton for morse code.
S1 & S2 can be replaced by a jumper wire (and R2 deleted). S3 will then turn the beacon on/off
Alternatively, because idle drain is so low, S3 can be deleted and the battery connected for the day's use.
4)The beacon can be keyed on/off by an external source such as a timer or pulser by connecting
5V CMOS logic to pin 12 (deleting S2 & R2).
5) D3 will light up only when a signal is actually being transmitted. Change C7 to adjust brightness.
6) U2 must be deleted and bypassed if the beacon is re-designed for operation on 5 or 6 VDC
7) See assembly instructions for info on winding T1 & L1 and tune-up.
The number of turns on the secondary of T1 will vary with the loop antenna chosen and
the power level desired. The secondary winding is typically 15-25 turns. See text.

Figure 1
80 Watt beacon

The left half of Figure 1 is one of my single-ended Class-E beacon circuits, unmodified except for the number of turns on the secondary of T1 which sets the power level. T1 is the same CM270125 toroid core of MPP material (from CWS Bytemark) that I supply with my beacon boards. The right half of the schematic is a modified Class-E beacon board with only a few parts installed. The power MOSFET with its output circuit is unchanged except that it is driven from an inverter that is part of the 74HC4060. It is necessary that Q2 turn off when Q1 is turned on by the 3496 Hz square wave drive. The secondary output of T2 (connects to Q2) is 180 degrees out of phase with T1, giving the desired push-pull output. The TO-220 style MOSFETs are secured to copper pads on the boards without heat sinks.

The single-ended design equations found in Speleonics 25 can be used to derive the values of C6/C12 and the inductance (called L1/L2 here) of the primaries of T1/T2. The actual values of L1/L2 are not critical, but it is best to calculate them assuming that each half of the push-pull circuit provides ½ of the output power, 40 Watts in this case. The values of C6/C12 are calculated directly from the L1/L2 values and form a tuned "tank" circuit whose resonant frequency is offset from the beacon frequency by a specific amount. 5% capacitors are adequate for this low-Q circuit. The original single-ended equations are:

$$L1 = L2 = (.2085)\frac{V_{DC}^2}{Pf} \qquad C6 = C12 = \frac{1}{(1.2915\,\omega)^2 L1} \qquad Z_{LOAD} = \frac{1.2638 V_{DC}^2}{P}$$

$L1/L2$ are Henries
V_{DC} = battery, volts
P = desired output power, Watts. For a push-pull circuit, P is ½ of the desired output power.
$C6/C12$ are Farads
$\omega = 2*\pi*f$ where f = frequency in Hz
Z_{LOAD} = series-resonant load that, when placed directly across L1 or L2, will cause the single-ended circuit to draw the design power P. A secondary winding is used to translate the actual resonant load resistance to this value.

Notes:

1) Once C6/C12 is calculated, the nearest available value (5uF in this case) can be selected, then the equation used in "reverse" to calculate a new value of L1/L2 to match. The shift in values are no problem as long as both L and C are changed. 5% values are OK.
2) After constructing this circuit, I discovered that C6/C12 can be replaced by a single 5uF capacitor wired directly between the drains of Q1 and Q2. This works because one MOSFET is always conducting, which alternately grounds one end of the single capacitor.
3) Z_{LOAD} is not very accurate and should be used only as a guide. Start with extra secondary turns. Increasing secondary turns increases the power level. It is very inaccurate for the push-pull circuit. Experimentation is required.

My old 4 ft 4 inch (1.3 mtr) diameter folding loop was used for this first test. It consisted of 18 turns of #14 wire (~1.9mm dia). This circuit worked the first time! With a fresh battery pack of two 12V, 7AH, lead acid batteries in parallel, I series-resonated the loop to 3496 Hz by tuning for maximum DC current, which was approximately 9.25 Amps. Loop voltage was 320 VAC, which gave 11.2 Amps RMS. The magnetic moment was 276 A-T-M^2. With the loop disconnected, DC current was 0.18 Amps.

Using my "D-Q" receiver, with it's ~1Hz bandwidth, I was able to easily detect the magnetic field signal at 1km range with the beacon loop in any orientation; coaxial, coplanar, or flat on the ground. With the loop flat on the ground, I could direction-find on the beacon just as though it was underground even though the primary magnetic field was vertical, and useless for radiolocation. At this range, the secondary magnetic field, which is generated by eddy currents in the Earth, is almost as strong as the primary field. This secondary field appears to radiate horizontally directly from the beacon and is perfect for direction-finding. This field falls off with the square of distance, instead of the cubic falloff of the primary field, which causes it to actually dominate at long ranges.

The Second Design, 500 Watts at 15 kHz with a giant loop

The 80 Watt beacon proved the concept of direction finding on the surface. Simulations showed that there was a different optimum frequency for each combination of range (distance) and ground conductivity. 15kHz was picked as a better compromise than 3496Hz. I decided that 500 Watts was the highest power I dared try for. This of course raises legal issues because of the part 15 regulations for unlicensed operation above 9kHz. The short answer is that there is no problem. A horizontal loop lying on the ground creates only a horizontal electric field, which decays rapidly in a very short distance. Only "near" magnetic fields are created by the beacon, with no possibility of a radiating electromagnetic field. Any attempt to measure a vertical electric field at a significant distance would fail. The use of a vertical wire loop oriented to put the beacon in it's plane would result in a magnetic field null at any range.

I started the design by picking a beacon loop (Figure 2). Large size (when deployed) and weight were not a problem for this application, so I procured a heavy duty 100 ft (30 mtr) extension cord with three #10 wires which used special 20 Amp connectors that I had to procure mates for. I laid out the loop to form a circle ~32 ft (9.75 mtrs) in diameter, then measured its impedance at 15 kHz, getting L=403uH and Rseries=0.47 Ohms, which gives Q=81. Eventually, I had to replace the male plug on this cord as the original plug contained a neon bulb that self-destructed, causing a short circuit.

Figure 2

100 foot (30 mtr)circumference loop

The 15kHz Test Receiver(s) and Antenna:

Before doing a quick reality check with this transmit loop, I had to assemble a test receiver. I had a Rycom 3121B Selective Level Meter (Figure 3) with a 250 Hz bandwidth and a direct readout of signal strength, with no AGC, but it was not very sensitive. I needed a preamp and decided to use one stage of the venerable LM833 dual bipolar op-amp, which is designed specifically for low noise audio frequency use. I decided to use a non-inverting circuit with its infinite input impedance that would not load the parallel-tuned receiving loop antenna. The preamp schematic is shown in Figure 4, with the parts list in the Appendix. I constructed it as a dual preamp to also allow testing of dual x-y rod antennas with a sound card receiver that had I/Q inputs. Theoretical gain is 40dB, with enough sensitivity to detect the thermal noise from the antennas, which in turn was overridden by atmospheric noise during my tests.

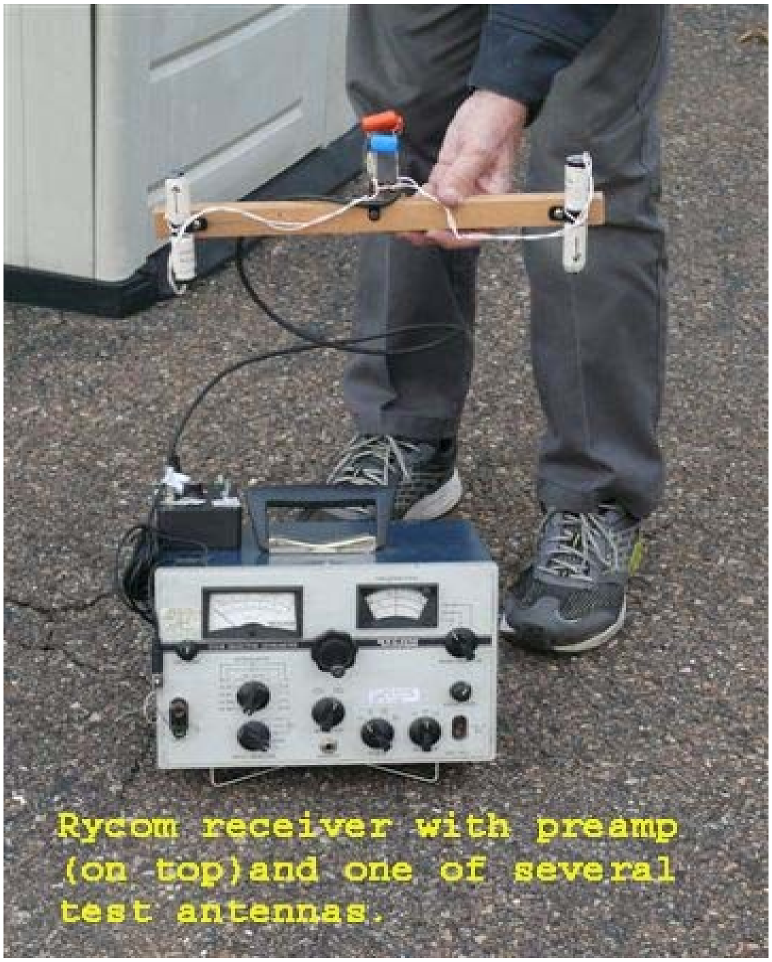


Figure 3

The optimum antenna impedance for the LM833 for best sensitivity is 6857 Ohms but anything from ½ to twice this value will work well. Atmospheric noise levels actually peak near 15kHz, which allowed me to use a tiny 4” (10.2 cm) long ½” (1.27 cm) dia ferrite rod of type 61 (Ui=125) material. For one test antenna I used 140 turns of 220/46 Litz wire (220 strands of #46 wire) wound in 2 layers over most of the length of the rod. This gave L=1.04mH with Q=165 and resonated impedance of 16.1k Ohms which is a bit high but I went with it. The noise level of this tuned loop is 2.0 nA/mtr, well below atmospheric noise.

As a backup (and experiment), I downloaded a software defined sound card VLF receiver, which I installed on my netbook. This was “SD Radio” by Alberto, I2PHD, http://www.sdradio.eu/sdradio a very simple and robust program that provides both a spectrum analyzer display and audio output up to 20kHz. In the SSB mode, the bandwidth can be narrowed to ~100Hz. My preamp was able to drive the mike input of the netbook's sound card directly. S/N ratio is directly displayed. The program actually had both I and Q inputs, which created an omnidirectional pattern from a pair of “crossed” loop antennas. The only drawbacks I found were: 1) the netbook had to be placed at least 10 feet from the receive antenna to avoid introducing computer noise and 2) The program had very effective AGC that made direction-finding using the audio difficult. Never the less, it effectively received signals anywhere that the Rycom could.

A second program I tested was the Sound Card Oscilloscope by Christian Zeitnitz, http://www.zeitnitz.de/Christian/scope_en?mid=1022&PHPSESSID=iarotj9ooavm86l58165ku0ll0 . This program provides a 2-channel 20kHz oscilloscope that can also be used in x-y mode, with a brick wall filter allowing bandwidths down to 2HZ. Signals in the 2 channels can be added, subtracted, or multiplied. It includes cursors to measure amplitude, time, and frequency. It also has a signal generator for sine, square, triangle, and sawtooth waveforms which has two outputs with adjustable phase relationship. This program has great potential but I found 2 drawbacks: 1) there is no way to get a heterodyned audio output like the SD Radio and 2) the square wave had too much distortion and duty cycle error at 15kHz to be useful as a driver for the 500 Watt amplifier.

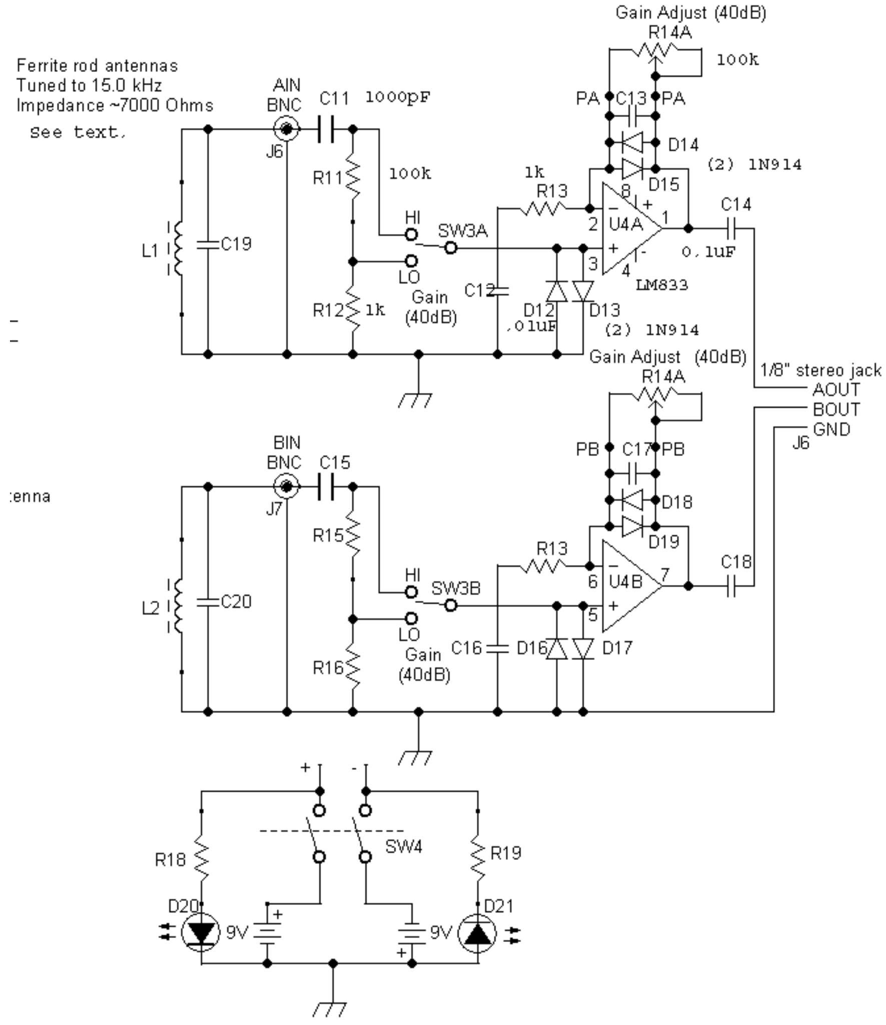


Figure 4
Preamp Schematic

The 15kHz Reality Check:

I series-resonated the 100 ft (30 mtr) circumference beacon loop with 0.2754uF, using high-voltage polypropylene caps. I then used a CWS Bytemark CM270125 toroid of MPP material to convert the 0.47 Ohm loop impedance to 4 Ohms, using 12Turns/37Turns. I used a 50 Watt car stereo amplifier in 4 Ohm bridged mode, driven with a 15.000kHz sine wave source, to generate 8 Amps of signal current in the loop, which is a magnetic moment of 1775 Amp-Turns-Mtrs squared.

At 1km range, using the Rycom receiver, the signal was just above the atmospheric noise level, which was very good considering that the 250 Hz bandwidth has 24dB more atmospheric noise than the 1 Hz bandwidth used for the original 3496 Hz test. I could direction-find (by ear) at this range. I decided to build a 500 Watt beacon amplifier.

The 500 Watt 15kHz Push-Pull Class-E Amplifier:

The basic design is the same as the 3496 Hz push-pull amplifier, with additional circuitry to protect the MOSFETs (Q1 and Q2) from destruction. The schematic is shown in Figure 5, with the parts list in the Appendix. To save space and cost, C2 serves as the “tank” tuning capacitor for both MOSFETs. This is possible because Q1 is ON (grounding C2) when Q2 is OFF, and vice versa.

The MOSFET driver U3 performs several functions. It has a high impedance input with Schmidt trigger action for very fast switching and inverting/non-inverting low impedance outputs with 4 Amp drive to rapidly switch the push-pull MOSFET inputs. The Enable inputs are used to prevent any MOSFET gate input unless sufficient DC supply voltage is available to switch it full ON.

The “RF” input is a 5V p-p square wave dc referenced to ground. If the source is capacitor-coupled, add a 1N914 diode across R10, with anode to ground. It is critically important that the duty cycle be exactly 50% to prevent large current transients in the MOSFETs that will destroy them in minutes.

The best simple signal source is a 74HC4060 oscillator/binary divider with a common 7.68MHz clock crystal running on 5VDC. 9 binary stages gives 15.000kHz with a precise 50% duty cycle. Simple “free-running” generators could be used by dividing a 30kHz output frequency in half with a flip-flop. For my actual testing, I acquired a Protek Direct Digital Synthesis (DDS) waveform generator which I set to produce a 15.000kHz square wave with a precise 50% duty cycle that was keyed on for ~5 sec/off for ~5 sec. The on/off timing is synchronized with the square wave, eliminating any possibility of transients.

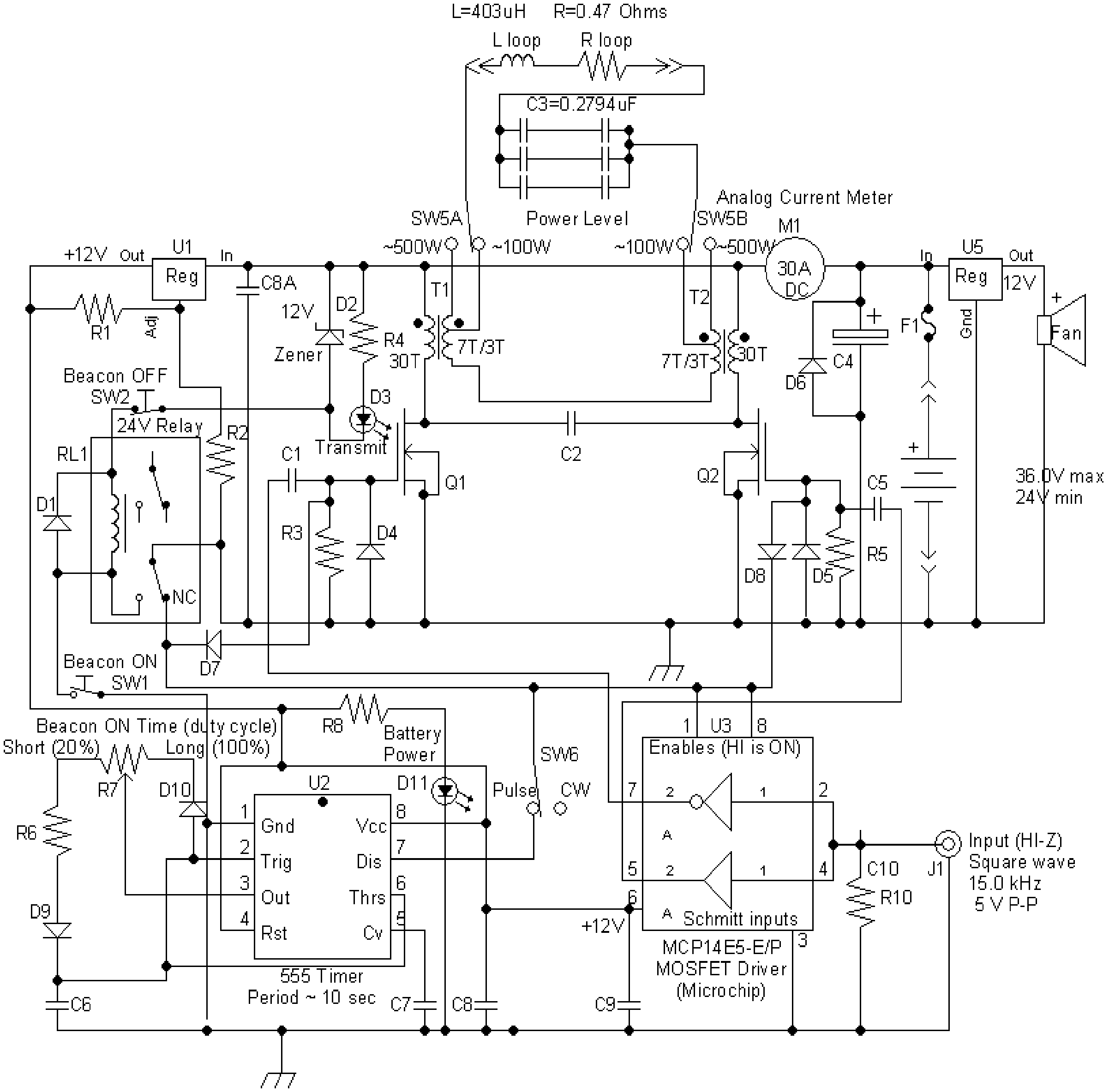
The 36 Volt supply was chosen to allow operation from three 12V deep cycle batteries in series, but for actual testing I opted to use a 28.5VDC power supply that could deliver up to 100 Amps from 240 VAC. The power input level with this supply is about 370 Watts.

At this power level, even a brief (milliseconds) excursion into the linear region during power-up can destroy the MOSFETs. I added a latching relay circuit that disables the driver U3 and shorts the gates of Q1 and Q2 to ground when the power supply is first connected. Pressing SW1 latches the amplifier ON. If the battery voltage becomes too low for proper gate drive, or there is a momentary power failure with an AC supply, the relay drops out to save the transistors.

I included a timer circuit U2 to cycle the beacon on-off every ~10 sec with a 20-100% duty cycle when used with a continuous square wave input. There is a slight risk using this timer because it is not synchronized with the 15kHz square wave which will alter the duty cycle of the first and last pulses of each ON period. I experienced no failures from this.

After an embarrassing failure due to overheating, I added a cooling fan. Even though efficiency is high, >90%, there is still 40-50 Watts of heat to dissipate, much of which appears to be due to the undersize wires used in the toroid transformers, plus some core loss. Only a few Watts are lost in the MOSFETs. Although not tested, with the fan it will likely operate continuously without overheating.

500 WATT 15 kHz BEACON



NOTES:

1) Loop antenna is 3 turns of #10 wire, 100 ft circumference.
2) Drive is an accurate 50% duty cycle square wave 5 V P-P centered on gnd or referenced to gnd.
3) External duty cycle control, syncronized to the carrier is preferred, with SW5 in CW position
4) Long periods of high duty cycle in 500W mode may cause overheating. 33% duty cycle is OK.
5) 100W mode can be continuous.
6) With internal duty cycle control, minimum ON time (duty cycle) can be shortened to nearly zero by reducing R6.
7) To operate, connect and deploy antenna in a circle, then connect battery and operating square wave source.
8) Press ON button to activate beacon and red LED. Meter should swing up during each transmission pulse.
9) Tune the loop by distorting shape slightly until DC current peaks.
10) Output power is the current squared times 0.47 Ohms. Power is proportional to battery voltage squared.
11) The fan will not work above 36.0 VDC. A resistor in series with U5 input will fix it.

Figure 5
500 Watt 15kHz Beacon

The simulated raw output voltage waveform (between the 500 Watt poles of SW5) is shown in Figure 6, with the amplifier running 370 Watts input from a 28.5V supply. The stepped sine wave has no second harmonic and the third harmonic is -14dB. The actual resonant loop current of ~27Amps RMS has a third harmonic of -48dB. Loop (and total C3 voltage) is ~1000 volts RMS. The magnetic moment is ~6000 Amp-Turns-mtr squared!

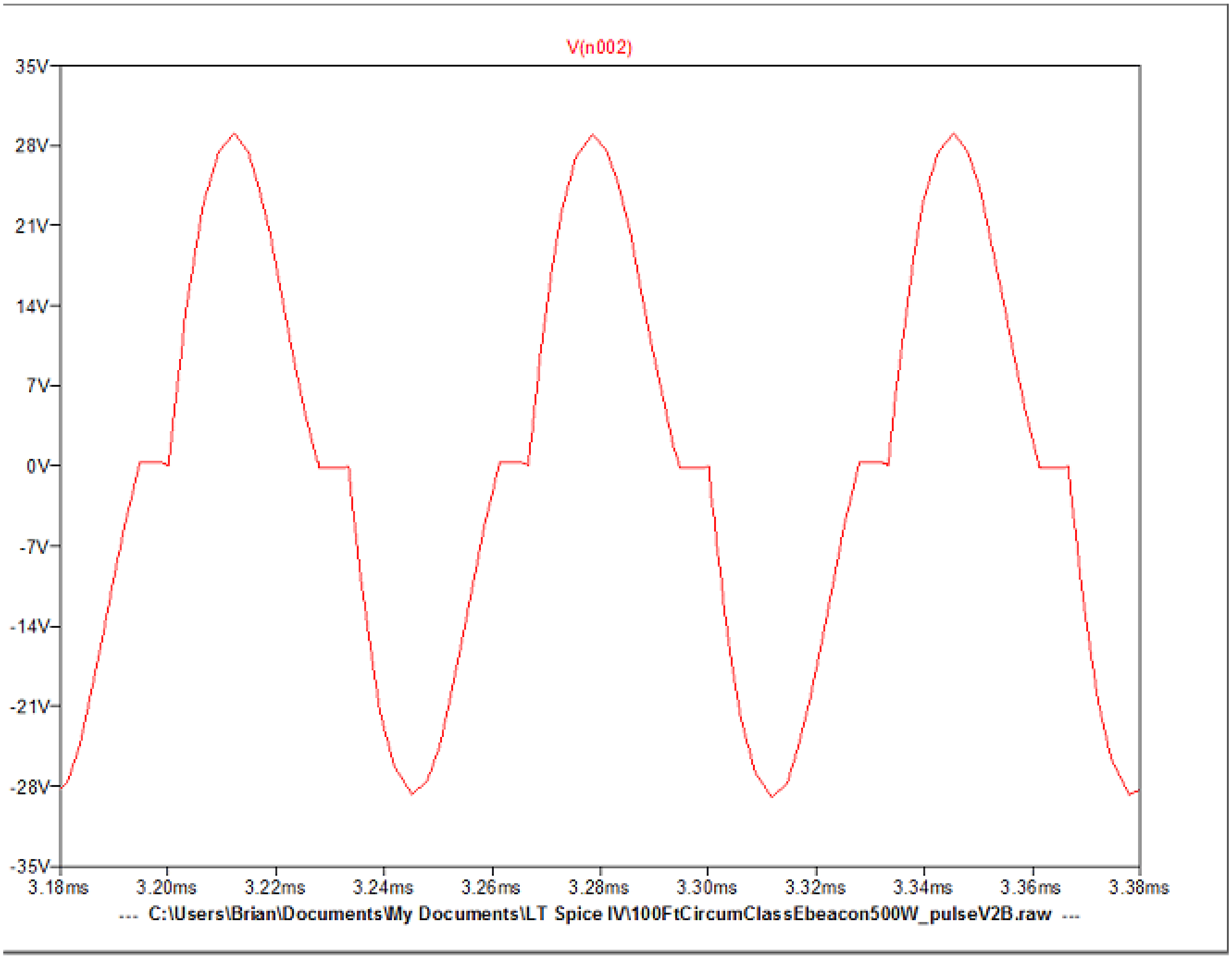


Figure 6
Raw output voltage waveform of the 500 Watt Amplifier

Figure 7 is the prototype 500 Watt beacon amplifier. The lid is raised on spacers to provide an outlet for the cooling air. Note that no expense was spared on the labels!

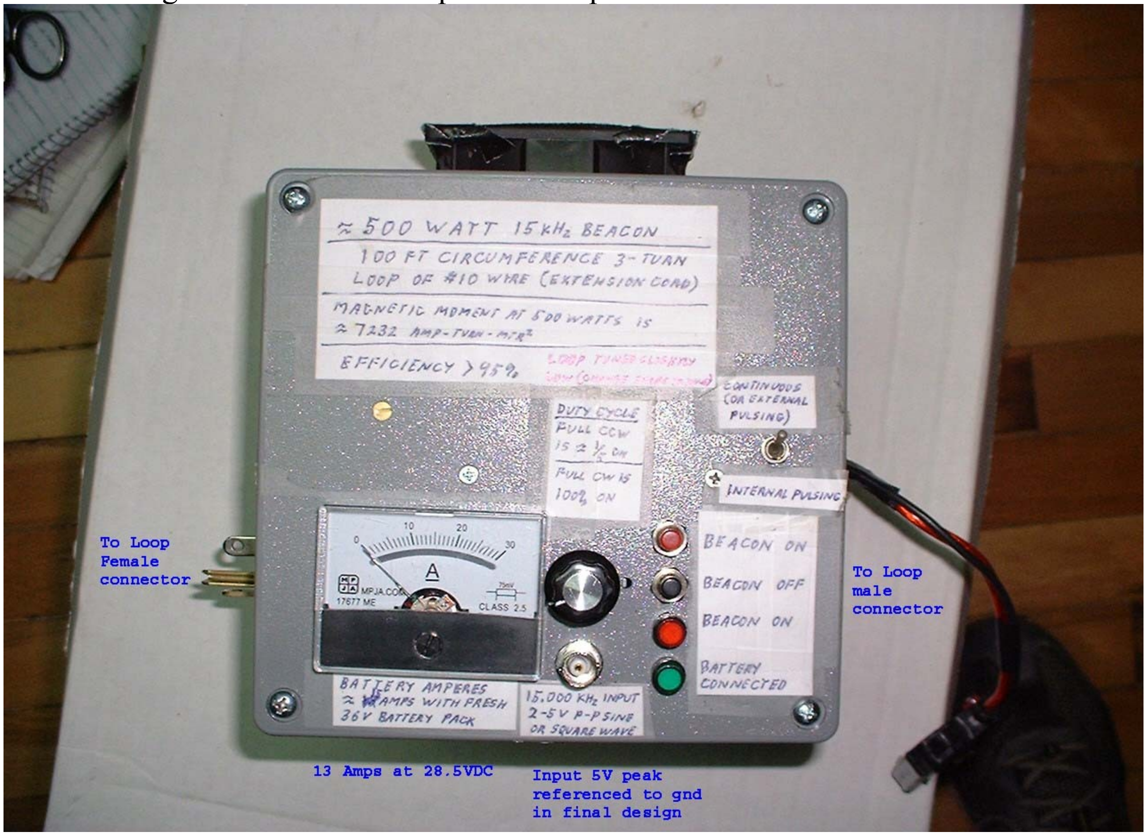


Figure 7
Prototype 500 Watt Beacon Amplifier

The Field Test:

I set up the loop on a gravel driveway next to my garage where a 220 volt outlet was available. I operated my Protek signal source from a true RMS inverter in my motorhome, since a momentary interruption of AC power would change the Protek settings and possibly damage the amplifier. There was no problem detecting and direction-finding on the secondary magnetic field at 2.0km range in an area far from pipes and wires, using the little 4” (10.2 cm) rod antenna/preamp and the Rycom's 250Hz bandwidth. With a narrowband receiver, range should be 3km or more.

Conclusions:

- It is relatively easy to construct a very high power radiobeacon. For portable use, a low on/off duty cycle mode should be used to save the battery.
- This non-linear amplifier design is compatible with FM voice or any one-tone-at-a-time digital text mode such as CW, RTTY, FSK31, JASON, MFSK, etc. There is no legal issue when operating below 9kHz (in the USA), and should be no issues at higher frequencies when used with a horizontal tuned loop since it should be able to pass the Part 15 tests for unlicensed operation. Just don't cause interference to licensed operators (or anyone else!).
- These tests show how the secondary magnetic field allows cave radiolocation to work so well at ranges on the surface many times the depth of the beacon.

APPENDIX

Parts List for 500 Watt 15 kHz Class-E Beacon and Dual low noise antenna preamp

10/5/10

Part	Description	Part #, “ND” is DigiKey	Each	Total
R1	240 Ohm Carbon film, ¼ Watt, 5%	240QBK-ND		
R2	2K “	2.0KQBK-ND		
R9 R10,R11 R15	100K “	100KQBK-ND		
R4,R8 R12,R13, R16,R17	1K “	1.0KQBK-ND		
R6	240K “	240KQBK-ND		
R7	1Meg linear pot	Mouser 31VC601-F		
R14A,B	100k dual linear pot	Mouser 31VW501-F		
R3,R5 R18,R19	3.3k	3.3KQBK-ND		
C1, C5 C8, C8A,C10, C14,C18	0.1uF 50V ceramic, 0.1” spacing	BC1084CT-ND		
C2A	0.47uF 450V hi-Amp polypro, 10mm sp 8.7mm W, 13mm L	P14202-ND		/4
C3	0.15uF 3000VDC hi-Amp axial polypro 1.2mm dia lead, 46mm L, 27mm dia	338-1188-ND		/2
C3	0.10uF 3000VDC 1.2mm dia lead, 46mm L, 22.5mm dia	338-1187-ND		/2
C3	.01uF 3000VDC 1.0mm dia lead, 34mm L, 11.5mm dia	338-1183-ND		/2
C3	.015uF 3000VDC 1.0mm dia lead, 34mm L, 13.5mm dia	338-1184-ND		/4
C4	100uF 50V, ELEC,8 dia, 12H, 3.5mm sp	565-2005-ND		
C6	10uF 63V, 9mmW, 18mmL, 0.6” spacing	Mouser 5989-100V10.0-F		
C7,C12, C16	.01uF 50V ceramic, 0.1” spacing	BC1078CT-ND		
C9	1uF 59V ceramic, 0.2” spacing	BC1168CT-ND		

C11,C15	1000pF 50V COG ceramic	BC1025CT-ND		/10
C13,C17	50pF 50V COG ceramic			/2
C19,C20	0.11uF 63V polypro tuning cap	BC2055-ND		/10
C19,C20	.047uF 63V polypro tuning cap	BC2068-ND		/10
C19,C20	1000pF 63V polyester tuning cap	399-5419-ND		/10
C19,C20	.01uF 63V polyester tuning cap	399-5437-ND		/10
C19,C20	4700pF 63V polyester tuning cap	399-5417-ND		/10
D1,D4,D5 D7,D8,D9 D10, D12-19	1N914/4148 diode	1N4148TACT-ND		/15
D2	12V 1W zener diode	1N5242BFSCT-ND		
D3	12V panel mount Red LED	MPJ 17303-LE		
D6	6 Amp 100V rectifier	MPJ 5219-DI		
D11	12V panel mount Green LED	MPJ 17303-LE		
D20,D21	3mm diffused Green LED	P564-ND		/2
F1	30 Amp auto fuse	MPJ 3619-FU		
Holder	Heavy duty inline fuseholder	MPJ 8879-FH		/2
J1,J6,J7	BNC female panel jack.	MPJ 0507-RC		/3
J2	Male 120VAC plug	local		
J3	Female 120VAC socket	local		
J4,J5	30 Amp Power Pole conn, 4 pieces	On hand		/4
J8	1/8” stereo phone jack	Mouser 161-3402-E		
Loop	100 foot extension cord, 3 cond #10 wire	Local		
M1	30 Amp DC analog meter with ext shunt	MPJ 17679-ME		
Q1,Q2	IRFI4321PBF MOSFET (150V) Original Choice	IRFI4321PBF-ND		/2
Q1,Q2	IRFB260NPBF (200V, higher Ron) Current Choice	IRFB260NPBF-ND		/2
RL1	Omron G5V-2 style 24VDC, 1600 Ohms	Z772-ND		
SW1A	Momentary ON red push button (norm OFF)	MPJ 5019-SW		
SW1B	Momentary ON blk push button (norm OFF)	MPJ 5020-SW		
SW2A,B SW3	DPDT mini toggle switch	MPJ 5011-SW		/2
U1	LM317L voltage regulator	LM317LZ-ND		
U2	555 timer	MPJ 2350-IC		/2

U3	MCP14E5-E/P dual mosfet driver, DIP	MCP14E5-E/P-ND		/2
U4A,B	LM833 dual op amp, DIP	497-1598-5-ND		/2
DIP sockets	8-pin	ED90032-ND		/3
Dip socket	16-pin	ED3316-ND		/1
Heat sink	TO-220 10W vertical screw mount Aavid 1.65W x 1.0TK x 1.5” H	HS276-ND		/2
Case	Gray plastic Elec box, 6x6x4” high	Lowes local		
Case	4x3x1.6” plastic box	MPJ 15523-BX		
Cable	5 ft BNC male-BNC male (for preamps/ants)	290-1013-ND		/2
Cable	12 ft shielded stereo 1/8” phone cable	MPJ 11292-CB		/1
Batteries	(2) 9V	local		
Holder	(2) 9V battery holders	1295K-ND		/2
Wire	#14 magnet wire	MPJ 7258-WI		
Wire	#16 magnet wire	MPJ 7257-WI		
	MPJ is Marlin P Jones, mpja.com			

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and Dual low noise antenna preamp
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R4,R8 R12,R13, R16,R17	1K "	1.0KQBK-ND		
R6	240K "	240KQBK-ND		
R7	1Meg linear pot	Mouser 31VC601-F		
R14A,B	100k dual linear pot	Mouser 31VW501-F		
R3,R5 R18,R19	3.3k	3.3KQBK-ND		
C1, C5 C8, C8A,C10, C14,C18	0.1uF 50V ceramic, 0.1" spacing	BC1084CT-ND		
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C4	100uF 50V, ELEC,8 dia, 12H, 3.5mm sp	565-2005-ND		
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C7,C12, C16	.01uF 50V ceramic, 0.1" spacing	BC1078CT-ND		
C9	1uF 59V ceramic, 0.2" spacing	BC1168CT-ND		
C11,C15	1000pF 50V COG ceramic	BC1025CT-ND		/10

C13,C17	50pF 50V COG ceramic			/2
C19,C20	0.11uF 63V polypro tuning cap	BC2055-ND		/10
C19,C20	.047uF 63V polypro tuning cap	BC2068-ND		/10
C19,C20	1000pF 63V polyester tuning cap	399-5419-ND		/10
C19,C20	.01uF 63V polyester tuning cap	399-5437-ND		/10
C19,C20	4700pF 63V polyester tuning cap	399-5417-ND		/10
D1,D4,D5 D7,D8,D9 D10, D12-19	1N914/4148 diode	1N4148TACT-ND		/15
D2	12V 1W zener diode	1N5242BFSCT-ND		
D3	12V panel mount Red LED	MPJ 17303-LE		
D6	6 Amp 100V rectifier	MPJ 5219-DI		
D11	12V panel mount Green LED	MPJ 17303-LE		
D20,D21	3mm diffused Green LED	P564-ND		/2
F1	30 Amp auto fuse	MPJ 3619-FU		
Holder	Heavy duty inline fuseholder	MPJ 8879-FH		/2
J1,J6,J7	BNC female panel jack.	MPJ 0507-RC		/3
J2	Male 120VAC plug	local		
J3	Female 120VAC socket	local		
J4,J5	30 Amp Power Pole conn, 4 pieces	On hand		/4
J8	1/8” stereo phone jack	Mouser 161-3402-E		
Loop	100 foot extension cord, 3 cond #10 wire	Local		
M1	30 Amp DC analog meter with ext shunt	MPJ 17679-ME		
Q1,Q2	IRFI4321PBF MOSFET (150V) Original Choice	IRFI4321PBF-ND		/2
Q1,Q2	IRFB260NPBF (200V, higher Ron) Current Choice	IRFB260NPBF-ND		/2
RL1	Omron G5V-2 style 24VDC, 1600 Ohms	Z772-ND		
SW1A	Momentary ON red push button (norm OFF)	MPJ 5019-SW		
SW1B	Momentary ON blk push button (norm OFF)	MPJ 5020-SW		
SW2A,B SW3	DPDT mini toggle switch	MPJ 5011-SW		/2
U1	LM317L voltage regulator	LM317LZ-ND		
U2	555 timer	MPJ 2350-IC		/2
U3	MCP14E5-E/P dual mosfet driver, DIP	MCP14E5-E/P-ND		/2

U4A,B	LM833 dual op amp, DIP	497-1598-5-ND		/2
DIP sockets	8-pin	ED90032-ND		/3
Dip socket	16-pin	ED3316-ND		/1
Heat sink	TO-220 10W vertical screw mount Aavid 1.65W x 1.0TK x 1.5” H	HS276-ND		/2
Case	Gray plastic Elec box, 6x6x4” high	Lowes local		
Case	4x3x1.6” plastic box	MPJ 15523-BX		
Cable	5 ft BNC male-BNC male (for preamps/ants)	290-1013-ND		/2
Cable	12 ft shielded stereo 1/8” phone cable	MPJ 11292-CB		/1
Batteries	(2) 9V	local		
Holder	(2) 9V battery holders	1295K-ND		/2
Wire	#14 magnet wire	MPJ 7258-WI		
Wire	#16 magnet wire	MPJ 7257-WI		
	MPJ is Marlin P Jones, mpja.com			