CONVERTING CB RADIOS FOR USE AS LOW-FREQUENCY CAVE RADIOS

Ian Drummond

Design Philosophy.

Julian Coward and I started building the 3 Alberta Speleological Society (ASS) Cave Radios in 1980, following hand-written circuits from **Pete Hart** in the UK. The radios [described in Speleonics 5] have proved useful, robust, and have generally provided the range necessary for use in the mountains of Western Canada. Unfortunately in the intervening 12 years no-one (including ourselves) has built any further units. Indeed the circuits are daunting, containing many hand-wound inductors requiring individual tuning, and by now several key components are obsolete, requiring redesign work.

There is a demand for Cave Radios; I have been contacted by people interested in using radios for improved communications in rescue work, in scientific studies, in administration of show caves, and in exploration of caves. Why then have no more been built? In talking to people, of the three resources needed (time, knowledge and money) it seems that time is the least available, followed by knowledge, while money is relatively the most abundant resource. (True! Speleonics has carried two adverts from people wishing to buy cave radio systems for cash, yet in talking to people knowledgeable enough to build them, most have preferred to spend their time with their families, caving, or doing something other than building radios in their basements.)

Thus the idea developed to create a cave radio system using where ever possible purchased sub-systems. Various sub-systems were considered, and finally a decision was made to build a system using a CB radio as the central building block. This would be followed by a "transverter" to provide frequency down-conversion on transmission, and up-conversion on reception. A loop antenna and battery would complete the system. A summary of the advantages and disadvantages of such a system was compiled.

I was greatly encouraged in this approach to a cave radio system by an article by **Pat Harrington** intitled "A Simple CB to Low Frequency Transverter" published in Northern Observer #13, October 1989, pp5-11. Pat's article described how he built a transmitter for the 160-190 kHz band, using similar concepts to the ones described here.

Advantages
- A big reduction in construction time.
- Repair services are widely available for CB radios.
- Many people are familiar with CB radio operation.
- The frequency of operation can be easily changed.
- The system can be upgraded and will not readily become obsolete.
- CB radios incorporate features such as squelch and noise-blanking.
- Optimized for 2-way speech communication.
- The known electrical performance of the CB radios provides more consistent performance of the communication system as a whole.
- Allows direct research on the effects of frequency and mode of transmission. [European CB is FM. Some countries also allow AM and SSB. See summary at the end of this article.]

Disadvantages
- The system is electrically inefficient (RF power from the CB is wasted).
- A non-optimum signal processing scheme is used.
- CB radios are not constructed to stand the cave environment.
- The system is awkward for transmission of tone signals.
- The automatic gain control's range and time-constant make null-finding more difficult in location work.
- There is a potential for interference between CB and cave radio frequencies. (Intense CB activity could interfere with a surface cave radio, or cave radio use could leak CB radio transmissions.)

Performance of completed units.

Two complete units have been made, the first by point-to-point wiring on a bread-board with a ground plane (Vector 8004). Building on that experience, a p-c board was etched for the second unit. The frequency and mode (114.28 kHz, upper sideband) was selected to match the ASS Cave Radios. tests in town between the second unit and the ASS radios over the surface gave a range for 2-way speech of 350m [~1150 ft], which exceeded the 300m [~1000 ft] achieved by the ASS radios only.

A similar test in the electrically quieter countryside had easily achieved a range of over 600m [~2000 ft] horizontally on the surface before heavy rain arrived to terminate the experiment.

There is no doubt that the communication was achieved at 114 kHz, not through 27 MHz CB frequency leakage, as the ASS radios are totally insensitive to CB frequencies.

CB leakage was tested by operating a 1.5w CB walkie-talkie (Radio Shack TRC-214) about 20m away. Unfortunately perfect 2-way speech was achieved, despite careful shielding and correct termination of the CB RF circuits. Further work is clearly needed to establish if this is a serious operational problem, both from aspect of CB noise interfering with cave communications, and from reduced security through transmission of cave communications in the the CB bands.

> In summary, these tests indicate that the CB cave radios will perform at least as well if not better than the ASS cave radios for voice communication.

Selection of a CB radio

The CB radio MUST be in a metal case to provide RF shielding. Early experiments using a plastic-case CB walkie-talkie (Radio Shack TRC-214) were terminated when it was found that the unit leaked so much RF radiation through the case when transmitting that it was impossible to make meaningful measurements on a circuit 2m away.

It is strongly recommended that the CB radio be capable of Single Side-Band (SSB) operation. While the cheaper, smaller AM units will certainly work for voice communication, they will be very electrically inefficient, and cannot receive CW (tone) signals for location work. A compromise might be to use a cheap AM unit underground and a SSB unit on the surface. Then the SSB unit can receive the tone needed for location work, and voice contact can be conducted via the AM mode.

The electrical quality of the CB radio certainly affects the performance of the system as a whole. The unit used in the tests mentioned above was a Radio Shack Realistic TRC-453 purchased during a clear-out sale in the USA for US$95.00. (A Uniden(tm) chassis is hiding inside the Realistic(tm) case.)

The most relevant specifications to determine selectivity and sensitivity of the receiver are as follows:

Receiver selectivity - adjacent-channel rejection 70 dB.
Sensitivity for 10 dB S/N, 0.5 microvolts AM, 0.25 uV SSB

Addendum

Since writing the original article, two more transceivers have been built using commercially-produced printed-circuit boards.

The units were matched with antennas tuned to 185 kHz, with the result that CB channel 11 gives the appropriate frequencies. The unit is essentially a 2-channel voice unit, as upper sideband operations covers frequencies from 185.3 kHz to approximately 188 kHz, and lower sideband operation covers 182 to 184.7 kHz. Interferences that are prominent in one sideband are unnoticeable in the other. Unfortunately, I have not been able to devise a simple method of matching the antenna to the transceiver units for a wider variation in frequency.

The PC boards were made by Alberta Printed Circuits who provide a prototype service for small numbers of boards (even numbers, 2 to 12). The cost of two prototype boards (11.4 x 9.5 cm [4.5" x 3.75"]) was approximately $80 Canadian.

One attractive feature of dealing with APC is that they have a bulletin board and it is possible to download "Easytrax" software. Easytrax is a previous generation of professional design software which is fully capable of designing the 2-sided board, with ground information and drill tables that APC need.

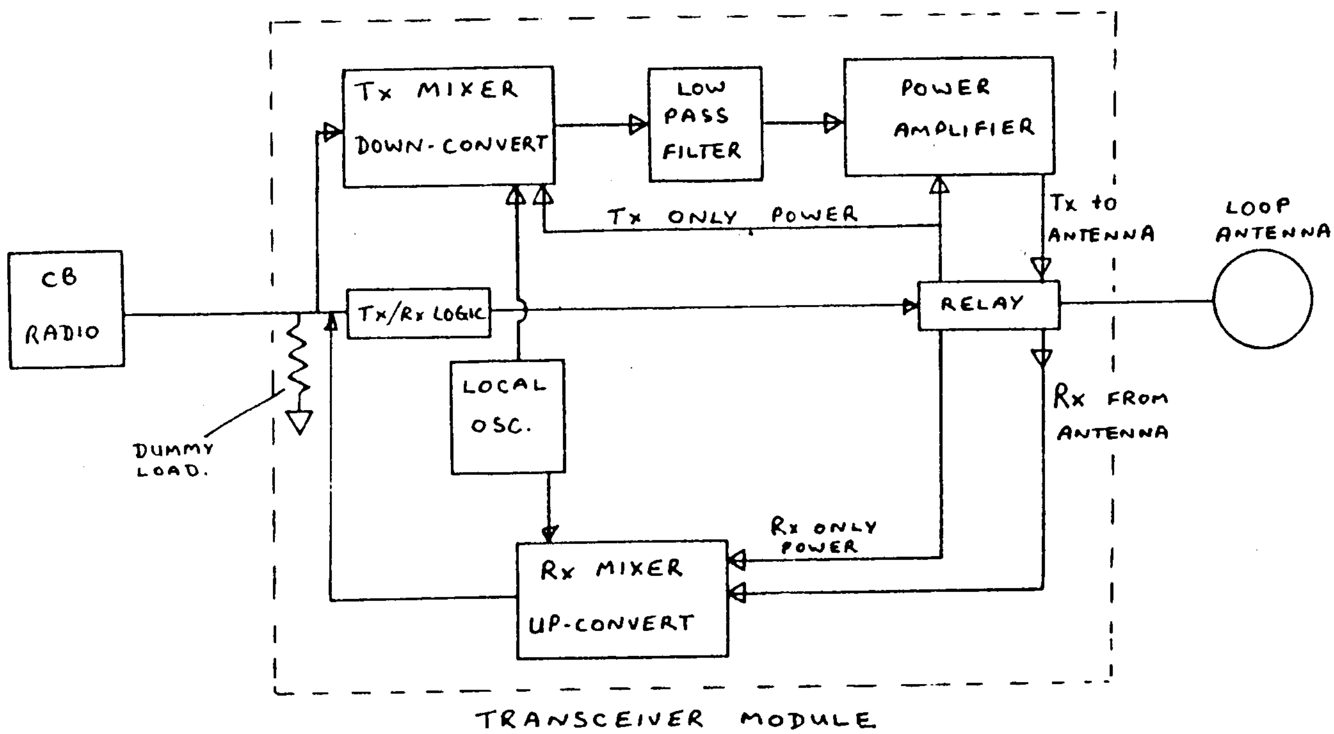
The whole production can be done by modem from a home computer (and not a very fancy unit either; I am running a Tandy 1000 SX with a 20-Meg hard drive and monochrome CGA graphics, but I do have a mouse which is nearly essential for the application). It is possible to download the software, design the board, upload the data files, and have APC make the boards, put them in the mail, and bill your credit card, all by modem over the phone lines.

This software is by far the best deal I was able to locate anywhere in North America. The process is to log-on and download a file called "newuser.exe" which gives all the details needed. Alternatively, they will send the software on a diskette for a $10 handling charge.

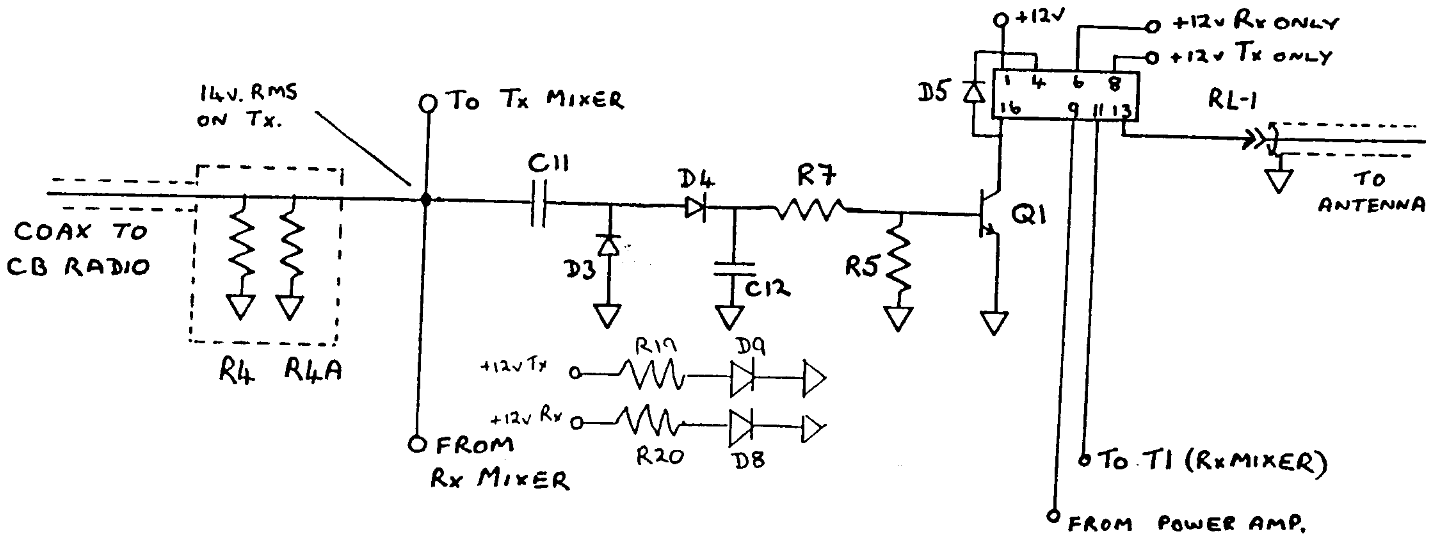
Alberta Printed Circuits, Bay 14, 3650-19 St. NE,
CALGARY, Alta
Computer (403 291-9342; voice (403) 250-3406

If you are interested in the PC boards used in this project, send Ian Drummond a letter (address in the front of Speleonics).

BLOCK DIAGRAM



Tx/Rx LOGIC CIRCUITS



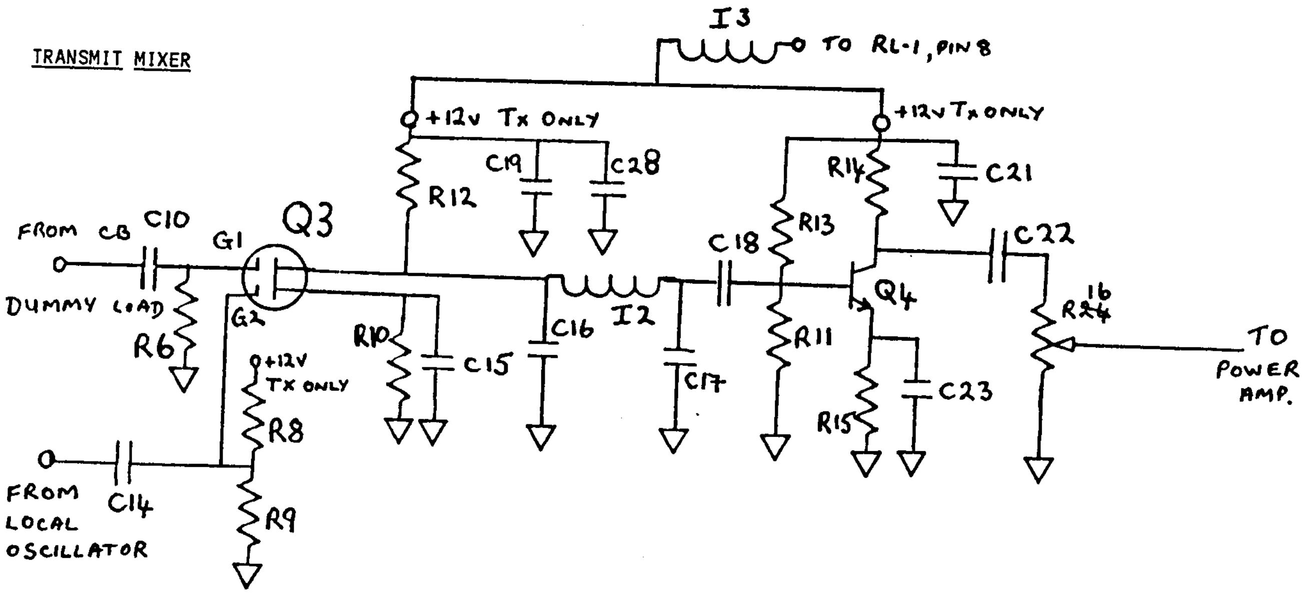
Notes - 1. Adjust C12 to change the 'hang' of the switch after releasing the CB radio transmit switch.

2. Adjust C11 to change the 'attack' of the switch on keying the CB radio.

3. R4 and R4A must present a matched load to the CB radio. Use an SWR meter to check and adjust R4 as necessary.

4. The values given are for a 4w CB transmitter.

TRANSMIT MIXER



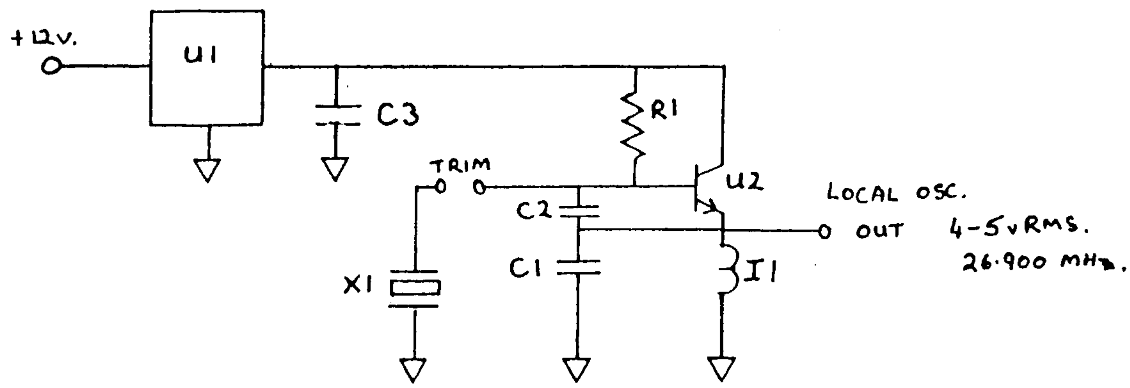
Notes - 1. Values are for a 4w CB transmitter. Adjust R6 for other powers.

2. Design is based on 1982 Radio Amateur's Handbook (ARRL), page 8-17.

3. I3 provides power supply isolation from the power amplifier.

4. R12, C16 and 17, I2 and R11 form a low-pass filter with cutoff approx. 500 kHz.

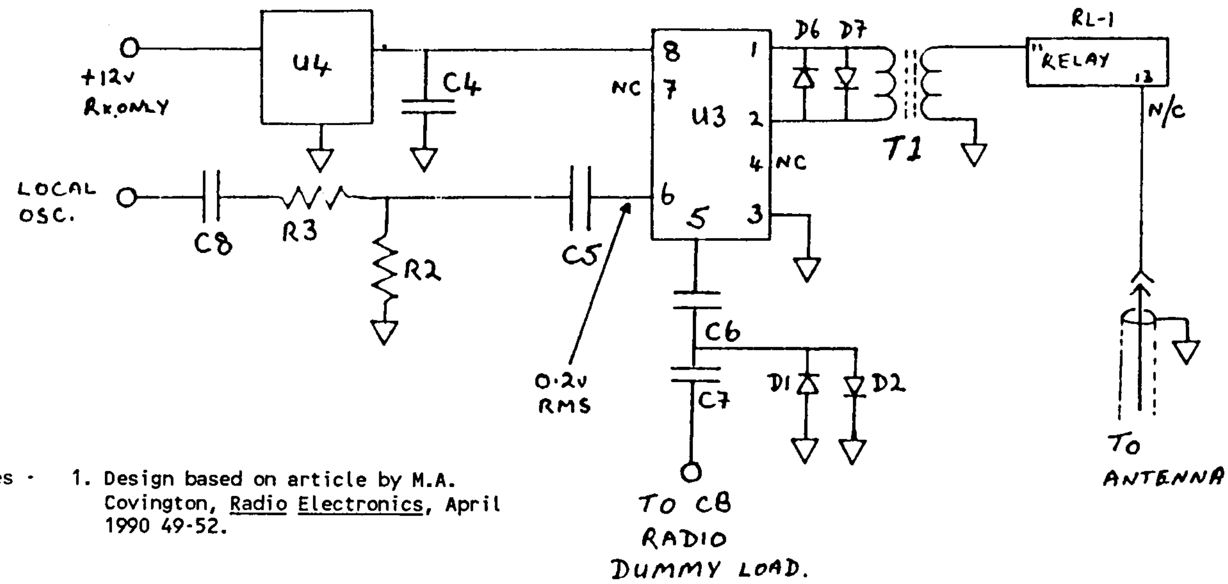
LOCAL OSCILLATOR



Notes -

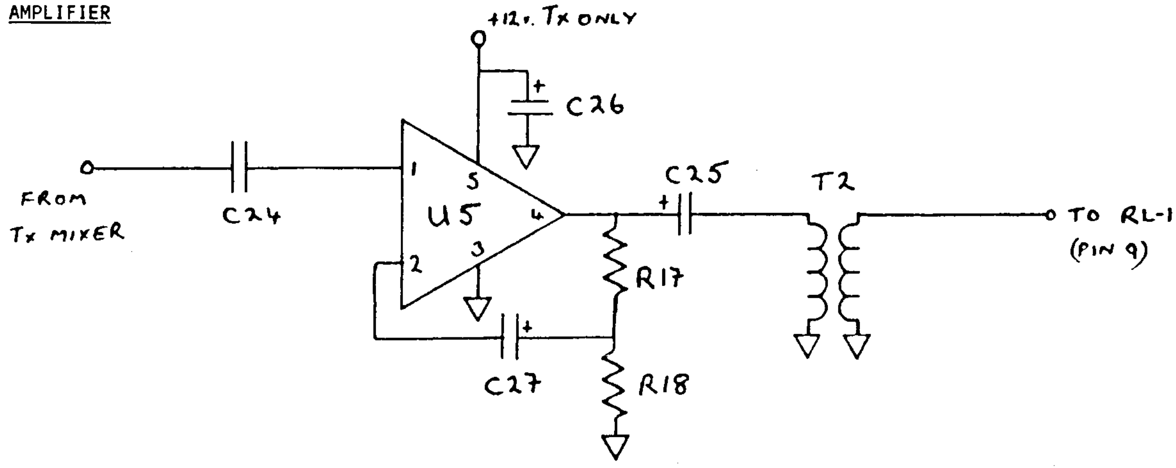
1. I1/C1 values are critical. Feedback is <1 at fundamental and >1 at 3rd overtone, so X1 resonates at 3rd overtone.
2. U2 must be a high frequency, high gain transistor. Substitutions can significantly change both output voltage and frequency of oscillation.
3. Do not increase the operating voltage, as power dissipation in the crystal could become excessive.
4. Trim = capacitor or inductor to trim frequency up or down (or short).
5. Design details from Crystal Oscillator Circuits by R.J. Matthys, Wiley & Sons, 1983. ISBN 0-471-87401-9.

RECEIVER MIXER (up converter)



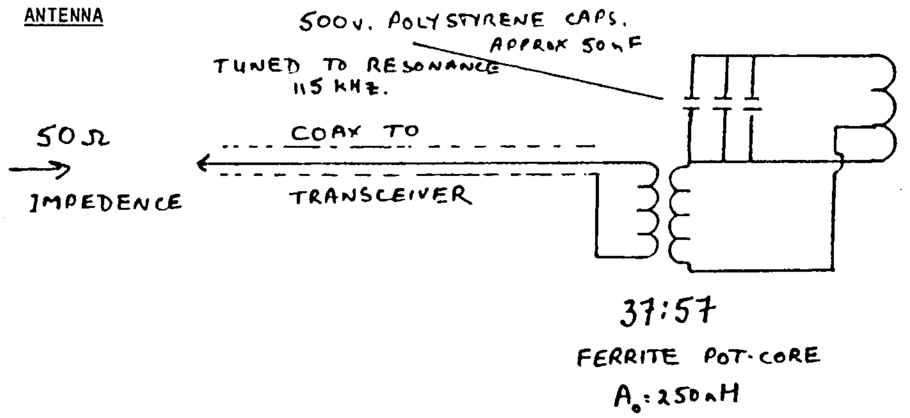
Notes - 1. Design based on article by M.A. Covington, Radio Electronics, April 1990 49-52.

POWER AMPLIFIER



Notes -
1. Heat sink for 5w needed. Pin 3 is ground and case, so no need to isolate chip from sink electrically.
2. TDA2002A provides useful gain to 300 kHz.
3. Power delivered to 50 ohm load is approx. 2.5w.
4. Output at pin 4 cannot exceed 9.5v peak-to-peak.
5. Gain is adjusted by R18. Balance gain in preamp and power amp. to avoid oscillation problems. System is sometimes ok with dummy load but oscillates with antenna connected. Put electronics in metal box to cure!

ANTENNA



Notes -
1. Square frame, 1.42m across diagonal. Coil is 1 turn of 16/3 outdoor cable connected in series to give 3 electrical turns, tapped at 1 turn.

PARTS LIST (PC Board version 92-11-27)

All resistors 1/4 w unless otherwise noted.

R1	120k	
R2	1k	
R3	10k	
R4, R4A	100	2w metal oxide
R5	220k	
R6	5	
R7	10k	
R8	100k	
R9	33k	
R10	680	
R11, R12	3.9k	
R13	18k	
R14	2.2k	
R15	470	
R16	20k	potentiometer
R17	1k	
R18	220	
R19, R20	1k	

C1	36pf	silver mica
C2	1pf	silver mica
C3	1nf	0.1" monolithic ceramic
C4	10nf	0.2" monolithic ceramic
C5	100pf	0.1" monolithic ceramic
C6, C7	5pf	disk ceramic
C8	10pf	0.2" monolithic ceramic
C9		not used on this board
C10	1pf	disk ceramic
C11	24pf	disk ceramic
C12	22uf	35v electrolytic
C13		not used on this board
C14	10pf	0.2" monolithic ceramic
C15	10nf	0.2" monolithic ceramic
C16, C17	220pf	silver mica
C18, C19	10nf	0.2" monolithic ceramic
C20, C21		not used on this board
C22	10nf	0.2" monolithic ceramic
C23, C24	100nf	0.2" monolithic ceramic
C25	470uf	35v electrolytic
C26, C28	220uf	35v electrolytic
C27	100nf	0.2" monolithic ceramic

Trim = Wire jumper (short), a silver mica cap. (0 - 10pf) or inductor (0 - 3uH) to trim the crystal oscillator frequency to desired value.

X1 CB channel 35 Rx crystal (26.900 MHz, 3rd overtone)
R1 Omron G6A-274P-ST-US (DPDT telecommunications relay)
Fuse, 3A picofuse
T1 Mouser 42TL004 transformer (200:8 Ohms)
T2 12:60 turns 26AWG wound on 18mm pot-core (A_1=250 nH) [26AWG = 0.455mm diameter.]
I1 2.2uH inductor
I2 1000uH inductor
I3 470uh inductor
U1 78L05 (5v 0.1A voltage regulator)
U2 MPS6531 transistor (high frequency oscillator)
U3 NE602 (double balanced mixer)
U4 78L06 (6v 0.1A voltage regulator)
U5 TDA 2002A audio amplifier
Q1 2N2222A general-purpose NPN transistor
Q2 not used on this board
Q3 3N211 or NTE 454 dual-gate FET mixer
Q4 2N2222A general-purpose NPN transistor
D1 - D4 1N4148TA (175v 0.1A signal diodes)
D5 1N4004TR (1A diode)
D6, D7 1N4148TA (175v 0.1A signal diodes)
D8 Red LED
D9 Green LED

RF connector to CB radio (male PL-259 and 50 Ohm coax)
CB power cord with in-line fuse (Radio Shack 21-550)
Switch (front panel, subminiature)
BNC female bulkhead connector
Molex 2-pin polarised battery connector
Cable header (PC board connections)
Box (Hammond 1411LO)
Sheet tin for shielding

2-sided printed circuit board (ground plane), produced as a prototype by Alberta Printed Circuits, Calgary.

Antenna Parts List
4m 16/3 outdoor wiring
Plastic Box (Radio Shack 270-222)
BNC male connector
2m 50-Ohm coax
Pot-core, Amidon 1811-77 (A_1 = 2250nH) (wind to match impedance of antenna to 50 Ohm output of transverter).
Capacitors, 630v polystyrene (At least 4 in parallel to tune the antenna to resonance at the operating frequency.)
Self-fusing rubber tape and heat-shrink tubing to splice loop.
Silicone conformal coating.
Wood, to form hub and struts. (Finish with several coats of urethane to water proof.)
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CB Radio Worldwide - a brief summary

"CB" (Citizens' Band) radio is so named because it is intended to be 2-way radio which anyone can use. Many countries (including the former USSR) now allow 27M-Hz CB as a minimally-regulated set of channels for short-range communications. There are also UHF citizens' bands.

USA: A license is no longer required to operate CB radio in the USA. Legal CB transmitters use AM (4 watts maximum power) or single sideband (12w max) on the following channel-numbered frequencies:

Ch.	MHz						
1	26.965	11	27.085	21	27.215	31	27.315
2	26.975	12	27.105	22	27.225	32	27.325
3	26.985	13	27.115	23	27.255*	33	27.335
4	27.005	14	27.125	24	27.235*	34	27.345
5	27.015	15	27.135	25	27.245*	35	27.355
6	27.025	16	27.155	26	27.265	36	27.365
7	27.035	17	27.165	27	27.275	37	27.375
8	27.055	18	27.175	28	27.285	38	27.385
9	27.065	19	27.185	29	27.295	39	27.395
10	27.075	20	27.205	30	27.305	40	27.405

* Channels 23-25 are not in ascending order for historical reasons. CB originally had only 23 channels. Later, 24 and 25 filled a gap between 22 and 23, and 26-40 were added in ascending order.

Canada: Frequencies, modulation, power same as USA.
United Kingdom: A license is required in the UK. AM and SSB are not allowed.
26.965 - 27.405 FM 40 ch. same as USA. 4w max.
27.6 - 27.99 FM 40 ch. 10kHz spacing. 4w max.
Australia: License is required; there is no examination. Frequencies, modulation and power are the same as in USA. Made-for-USA CB radios are legal in Australia.
France: License required, no examination. France uses the same frequencies as USA but allows FM in addition to AM and SSB. Max power: 1w AM, 4w SSB, 4w FM.
Germany: License required. AM and FM are the only legal modes of modulation; SSB is not allowed. 40 channels, same as USA. Max power: 1w AM, 4w FM. FM is allowed on all 40 channels. AM is allowed only on channels 4-15.
The European CEPT conference: These countries have implemented the Conference of European Postal and Telecommunications administrations (CEPT) recommendations T/R 20-02 and T/R 20-07 for CB radios:

Austria, Belgium, Cyprus (pending), Denmark, Finland, France, Germany, Luxembourg, Netherlands, Portugal, Norway, Sweden, United Kingdom, and Vatican City.

26.965 - 27.405 FM 40 ch, same as USA. 4w max.

With certain exceptions, CEPT-approved radios from any of the countries listed above can be used in any other on the list. If you travel to another CEPT-conforming country, you may use CB under the terms of your license from your own country. **Only FM is CEPT-approved;** AM and SSB may not be legal to use upon crossing borders.

CEPT-approved CB radios are NOT legal in the USA and made-for-USA CB radios are not legal anywhere in Europe.
Japan: No license required. 26.968 - 27.144 AM (no SSB), maximum power 0.5w. Some channels are assigned to fishing vessels (1w max). As in Europe, made-for-USA CB radios are illegal in Japan. Such radios have caused interference with maritime emergency traffic.
Other countries have variations on the CB theme. See references:

1. Popular Communications magazine, Sept. 1992, p59.
2. File PART2 available via anonymous ftp from pit-manager.mit.edu /pub/usenet/news.answers/cb-radio-faq

FURTHER DEVELOPMENTS WITH THE CB TRANSVERTERS

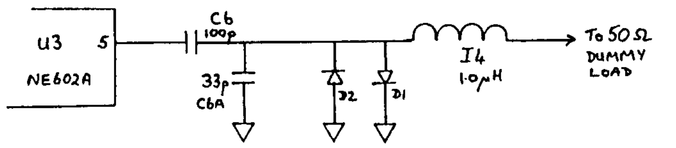
Ian Drummond

A significant improvement to the up-conversion circuit.

During tests at Rats Nest Cave in Alberta, I was surprised to find that while underground in a very quiet electrical environment, connecting and disconnecting the antenna (1 m square, 3 turns) made no difference to the noise which was heard from the CB radio. This meant that the electrical noise from the radio circuits was much stronger than the atmospheric electrical noise. In turn this suggested that a larger antenna would improve the signal to noise ratio at the receiver.

I was surprised by this observation as the CB radio claims that an input of only 0.25 microvolts is needed (SSB mode) to give a S/N ratio of 10 dB. I had thought (without any serious calculation) that there would be more chance of overloading the CB radio receiver than of presenting too weak a signal. Consequently I had deliberately mismatched the output of the NE602A mixer to the dummy load. The mismatch was intended to prevent high voltages burning out the NE602A when the CB radio was transmitting.

Given that the range of the cave radio during the Rats Nest test was being limited by the magnitude of the received signal (and not by atmospheric noise), I revisited the design of this piece of circuit and made the changes shown below. I4 and C6A constitute an L-network matching the 1500-Ohm output impedance of the NE602A to the 25-Ohm impedance of the dummy load in parallel with the CB radio input. (C6A could be made a variable capacitor, so the circuit could be "tweaked" for maximum response). When the CB radio is transmitting, the diodes D1 and D2 conduct, shorting C6A and creating a mismatch to prevent the burnout of the NE602A.



Testing the transverter after this modification indicated that a signal injected into the transverter was only 1/8 of the voltage for the same S-meter reading on the CB radio; a gain of 18 dB! Tests in the cave were even more impressive with the range being nearly doubled. We were able to use 2-way speech (SSB) to 280 m using the 1m antennas, and to 170 m using the 28 x 43 cm (11 x 17") antenna wound into the lid of the carrying case.

I should mention that in town the higher electrical noise means that the signal strength from the 1 m antenna gives an S-meter reading of S-9. Clearly this is close to the largest antenna that could be used in these conditions.

A "Pulser" for transmitting tone signals.

To use a CB transverter system for location work, it is necessary that the underground unit operate in the AM mode and transmit pure carrier, and the surface unit be operated in SSB mode so that the carrier can be detected. The underground unit should also be pulsed, or turned on and off at about once per second, for several reasons. The pulsed tone is easier to detect on the surface, pulsing reduces energy consumption to as little as 10% of continuous operation, and a CB radio is not designed to stand transmission of continuous carrier.

It is possible to pulse the CB radio in the AM mode automatically by an electronic microphone "key" which plugs in between the microphone and the CB chassis. When the unit is "Off/Normal" the CB radio behaves as if the pulser were not present and can be used for 2-way speech in any mode. On turning the pulser "ON", the CB radio switches from receive to transmit for 0.1 seconds every 1 second. If the transverter has been constructed with values as shown (Speleonics 19), the Tx/Rx switch "hangs" for more than a second to accommodate pauses in speech when operating in the SSB mode. Consequently when the pulser is in use, the transverter will stay in the Tx state all the time. This is not an electronic problem, but it does mean that no one can contact the underground unit while they are transmitting tone. If you would like "break-in" operation whereby the underground radio can receive between pulses, the value of C12 in the transverter should be reduced to 10 or even 4.7 uF.

The circuit shown here was designed to work with a Radio Shack SSB CB radio. Other makes will have different microphone plugs, and perhaps even different functional pin connections.

It is worth mentioning here that the transverter system can be used effectively for location work. There have been suggestions that systems which have automatic gain control cannot be used to find nulls in the magnetic field. In my experience the nulls are deep enough that the signal strength falls below the range of the AGC ability to compensate. My feeling is that in the cases where nulls could not be found, the problem is likely to have been the secondary magnetic fields from currents induced in the earth. (see Speleonics 17, Magnetic Moments #5, The Phase Problem).