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AMRAD Low Frequency Upconverter

Use your HF transceiver to eavesdrop on activity below 500 kHz with this easy construction project.

The AMRAD LF (low frequency) upconverter project was established to provide radio amateurs with a high-performance receiving converter that can be constructed with simple hand tools and a readily available set of PC boards. This LF converter can be used to convert the whole VLF/LF band up to a band in the range of 2 to 14 MHz so that these signals can be heard on common HF radios. (These same radios may have either low or no performance at the LF frequencies.) We think these objectives have been met.

Background

We considered two potential approaches. The first approach considered is the use of a double balanced mixer best represented by the excellent design by Doug DeMaw, W1FB and Jay Rusgrove, W1VD.[1] They implemented the DBM with discrete components. Tim Brannon, KF5CQ, using a commercial DBM module, refined this design.[2]

The other approach we considered uses a high-speed CMOS switch, such as the excellent design by Johan, SM6LKM (**home4.swipnet.se/~w-41522/lfconv/lfconv.html**). Johan found that by paralleling the CMOS switch sections on an inexpensive and readily available IC, the overall loss could be reduced. While both exhibited virtually equal good performance, we chose the CMOS switch approach for the AMRAD project.

There is a third approach that we did not breadboard. It uses a 1496 mixer chip. This approach was used by Sheets and Graf[3] and in the Palomar Engineers VLF converter.

In addition, we came up with a construction concept that provides the radio amateur considerable flexibility in the construction details, and we have created two modular blocks that can be used beyond application as a receiving converter. For example, by reconnecting the two blocks, the same blocks can be made into the heart of a *transmitting* converter. And by adding a DDS frequency synthesizer under computer control and an IF strip the blocks can be part of a sophisticated computerized LF receiver. By swapping a logarithmic amplifier in place of the IF strip you have the essential elements for an LF spectrum analyzer under computer control. With the addition of synchronous and asynchronous noise-blanker blocks to generate noise-blanking pulses, the receiving converter can be used as an LF noise blanker. In a simpler application, the LF lowpass filter module can be used to clean up the spurious response performance of an HF receiver/transceiver that tunes to the LF frequencies.

Low Pass Filter Design

We broke the LF upconverter into two functional blocks, a low pass filter and the upconverter itself. By splitting these two blocks apart we keep with the con-

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[1]Notes appear on page 39.

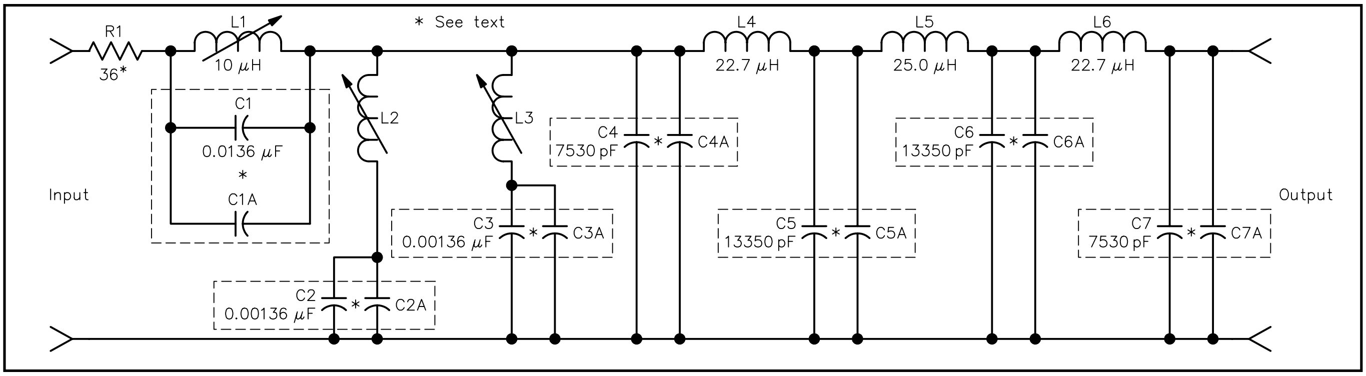


Figure 1—Low pass filter schematic diagram. DigiKey (tel 800-344-4539; www.digikey.com) part numbers shown in parentheses unless otherwise noted. See text on page 37 for an explanation of capacitance values.

C1, 1A, 4, 7—0.0068 µF, 2%, 50 V (P3682).
C2, 2A, 3, 3A, 4A, 7A—0.00068 µF, 50 V (P4580).
C5, C6—0.012 µF, 2%, 50 V (P4583).
C5A, C6A—0.0015 µF, 50 V (P4553).
L1—10 µH adjustable coil, Toko series 10EZ (TK1207).
L2, 3—100 µH adjustable coil, Toko series 10EZ (TK1219).
L4, 6—22.7 µH, 33 turns on Amidon T50-3 (gray) core. #30 wirewrap wire or #24-30 magnet wire (see text).
L5—25 µH, 35 turns wire on Amidon T50-3 (gray) core. #30 wirewrap wire or #24-30 magnet wire (see text).
R1—36 Ω, 1/4 W. Optional when used with AMRAD active antenna.

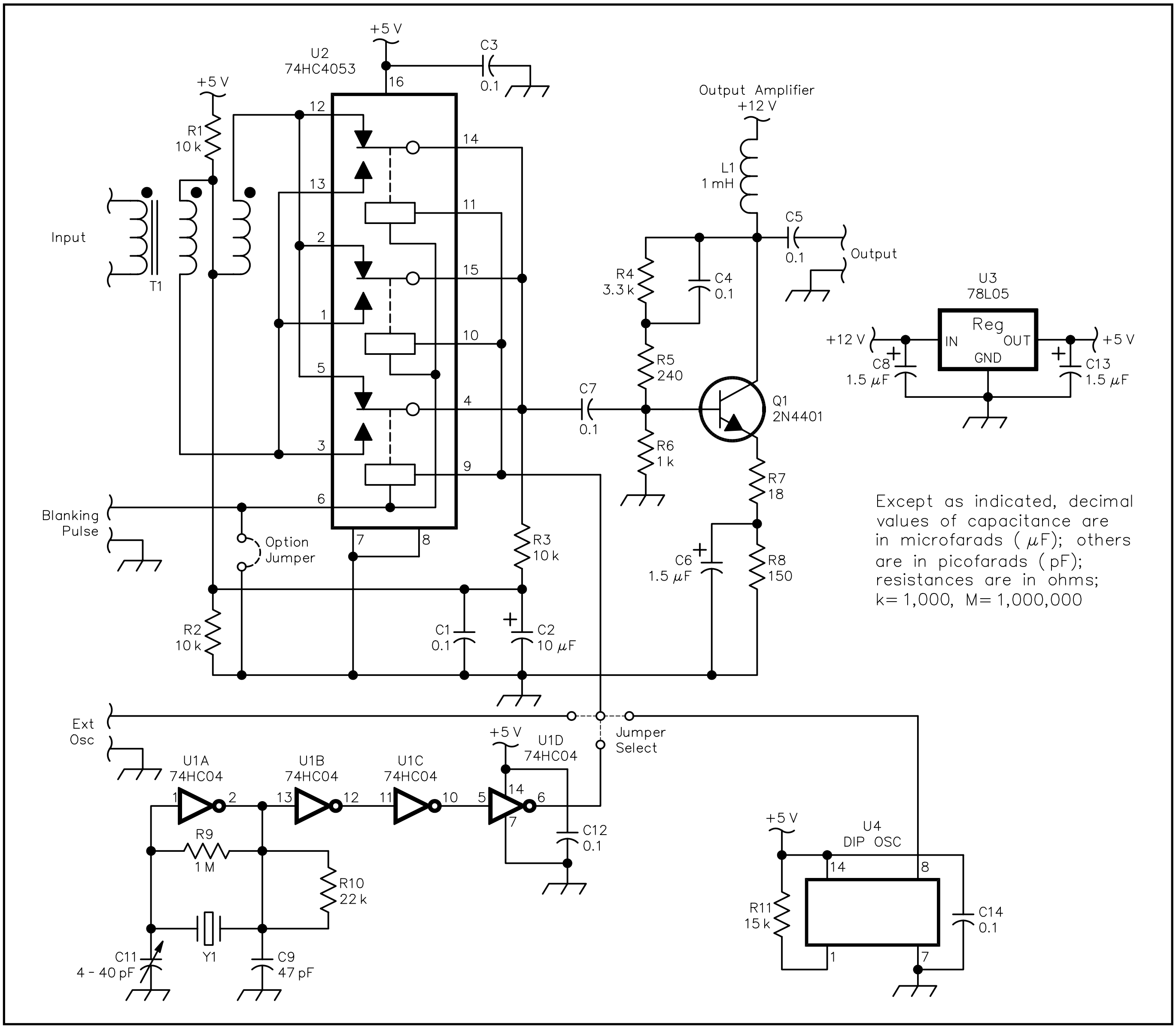


Figure 2—LF upconverter schematic diagram. DigiKey (tel 800-344-4539; www.digikey.com) part numbers shown in parentheses unless otherwise noted.

C1, 3, 4, 5, 7, 12, 14—0.1 µF, 50 V ceramic (P4924).
C2—10 µF, 6.3 V tantalum (P2013).
C6, C8, 13—1.5 µF, 25 V tantalum (P2044).
C9—47 pF, 50 V NP0 ceramic.
C10—Not used.
C11—1-40 pF ceramic trimmer (SG1037).
L1—1 mH, 20 turns #30 wire on Amidon FT-50-J core.
Q1—2N4401 transistor, TO-92 case (2N4401).
R1, 2, 3—10 kΩ, 1/4 W.
R4—3.3 kΩ, 1/4 W.
R5—240 Ω, 1/4 W.
R6—1 kΩ, 1/4 W.
R7—18 Ω, 1/4 W.
R8—150 Ω, 1/4 W.
R9—1 MΩ, 1/4 W.
R10—22 kΩ, 1/4 W.
R11—15 kΩ, 1/4 W.
T1—20 turns #30 wirw wrap trifilar on Amidon FT-50-J or FT-50-75 core.
U1—74HC04 (TC74HC04AP).
U2—74HC4053 (TC74HC4053AP).
U3—78L05 +5 V voltage regulator, TO-92 case (NJM78L05A).
U4—Alternate DIP oscillator. See text.
Y1—4.000 MHz crystal, 20-pF load (X006).

cept of modularity and the flexibility it will give us in the future.

The low pass filter (see Figure 1) is a combination of a set of tunable AM broadcast-band rejection filters and a 7-pole 0.1-dB ripple Chebyshev filter with a cutoff frequency of 500 kHz.[4]

The 500 kHz cutoff of the Chebyshev filter was chosen to provide good performance right up to the start of the AM broadcast band. The filter loss is moderately low between 500 and 530 kHz. The 500 kHz choice provides more attenuation into the band while still working up to 530 kHz. Some amateurs involved in LF work have been experimenting with FCC Part 15 transmissions between 490 and 530 kHz (called *MEDFers*), so this converter will provide an excellent receiving capability for these weak signals in addition to the normal LF range.

The tunable band-rejection filters provide a capability to reduce local strong AM broadcast signals to the point where they do not introduce overload or intermodulation products in the receiving frequency range. These notches may also be needed to reduce strong stations if the filter is used ahead of a noise blanker. The tunable rejection filters can be omitted from construction if no local AM broadcast stations will be a problem. The filter combination passes signals down to dc, so the upconverter module will receive signals at 10 kHz and below.

With the use of a well-designed PC board that is available, we are able to measure the LPF rejection in excess of 110 dB in most of the HF range.

Upconverter Design

We built breadboards of both a CMOS switch version and a DBM version. Testing for intermodulation and overload characteristics indicated about the same performance could be achieved with either approach.

Better performance is possible with a high level DBM converter. This approach would use a +27-dBm, 1/2-W, low-phase-noise carrier with a special high-level DBM module, such as the Mini-Circuits RAY-6U or SMC CVP-206. A good example of such a design is found in the front end of the Cubic R-3030 receiver. They use the SMC CVP-206 mixer driven by a 3-stage amplifier that boosts the local oscillator from 0 dBm to +27 dBm. For additional information on this high-dynamic-range design, you can obtain the manual courtesy of Cubic Communications. It can be downloaded from the AMRAD Web site at **www.amrad.org/projects/lf/rx.** This high-level approach, while enticing, was rejected for this project because it increased the cost and complexity without adding substantial benefit.

We decided to use the CMOS switch design because the CMOS switch IC is readily available for under $1 while the DBM module costs around $6 and is usually only available with order minimums of $50. An additional consideration is the 74HC4053 version of the CMOS switch IC. It has a chip enable line that can be used to create a noise-blanking gate.

We ended up with an upconverter block that uses a CMOS switch driven at the conversion frequency to modulate the incoming LF band up to the conversion frequency (see Figure 2). The conversion frequency can be provided on board the module from either a crystal oscillator based on a CMOS hex gate IC, a DIP oscillator module or it can be provided externally. An amplifier is provided on the output to compensate for the conversion loss so the overall input to output gain is near 0 dB.

We initially used a value of 51 Ω to terminate the CMOS switch at R3. It seemed obvious. Then we were surprised to find that after some testing to look into a diplexer design or alternate termination value, that a simple 10-kΩ resistor provided intermodulation performance as good as with the diplexer and 50 Ω. With the diplexer, the bandwidth was limited to about 300 kHz. We decided to eliminate the diplexer and instead use just the simple 10-kΩ resistor.

Oscillator

We tried out one of the new programmable IC oscillator modules. The attraction was the ability to order a 7 MHz oscillator for a very reasonable price. So, an Epson SG-8002 was ordered programmed to 7 MHz. While it provided a nice looking 7-MHz square wave, further analysis showed it had phase noise that would preclude its use. While suitable for a computer processor clock type application, it was not suitable for our application. This phase noise would create a noise profile around any signals coming into the upconverter so that a strong LF beacon, for example, would be surrounded by noise that would cover up any weak or only moderately strong signal.

A simple oscillator based on a feedback loop around a pair of 74HC04 hex inverter worked well and did not have the high phase noise of the programmable oscillator. The option for a simple fixed-frequency DIP oscillator is retained, but use of a programmable version is not advised.

Performance

The input low pass filter module provides for attenuation over 110 dB from 2 to 30 MHz. This will keep feedthrough of the HF receiving frequency down to a very low level so weak LF signals will not be interfered with by some strong HF signal on the same frequency. The HF receiver used should have strong rejection of HF signals through paths other than the antenna connector. Most modern amateur-grade HF receivers/transceivers have good performance in this respect, but some SWL HF receivers do not. Most SWL receivers may be used with caution and with the addition of filters and shielding in some cases.

Throughput gain is approximately 0 dB; with a 0-dBM input signal at LF, a 0-dBM output signal at HF will result. The third order intercept point is at +14 dBm. The 1 dB compression point is at +1 dBm.

Field Testing

Once we saw these performance test results, we were anxious to take the upconverter to our cottage on the Outer Banks of North Carolina. We lined up the upconverter with a JRC NRD-525 receiver against our Ten-Tec RX-320 modified for LF. The new upconverter and NRD-525 worked just as well as the RX-320 throughout the LF band. No birdies or spurious signals were heard. The upconverter was a pleasure to use. With the NRD-525 it was just like listening to HF signals.

Construction

You can build this LF upconverter using simple hand tools and the PC boards that are available from FAR Circuits.[5] The construction concept provides a lot of flexibility on how the assembled PC boards are mounted for use.

LPF

The low pass filter consists of two parts; the AM broadcast rejection filters and the Chebyshev low pass filter (see Figure 3).

The AM broadcast rejection filters are constructed with Toko tunable inductors (L1, L2 and L3). L1 is in a parallel tuned circuit with C1 to establish the first rejection frequency. C1A is provided on the PC board to fine-tune the frequency of L1 and C1. L2 and C2 form a series tuned circuit and L3 and C3 form a second series tuned circuit. With the values shown, all three circuits tune from about 530 kHz to 700 kHz. To reject stations above 700 kHz, use capacitors of lower value to enable the circuits to be tuned higher.

After construction, use an RF voltmeter or oscilloscope on the output of the filter while connecting an antenna to the input. L1 and L2 can be tuned to minimize the same frequency while L3 can be used to minimize another frequency. Alternatively, a receiver with an S meter can be tuned to the offending station and used with the filter connected to an antenna to adjust L1, L2 and L3 to minimize the signal strength.

L4, L5 and L6 are constructed using

The upconverter enclosure.

Figure 4—The upconverter.

toroid cores wound with either #30 wire wrap wire or magnet wire. Slightly larger magnet wire may be used as long as the turns will fit on the toroid core. For example, the #30 wirewrap wire with its insulation has the same diameter of #25 magnet wire. #24 magnet wire may fit on the toroid core, but any larger wire is doubtful and larger wire will not improve the filter performance noticeably.

To get the most consistent response of the filter, the capacitors called out in the parts list are 2% accurate (C4, C5, C6, C7) and are paralleled with smaller capacitors (C4A, C5A, C6A, C7A) to get close to the specified value. Specific target values are shown on the schematic. The more commonly available 5% capacitors may be used, but performance around the lower end of the AM broadcast band may be more uncertain (although the stop-band performance in the HF band should be unaffected).

Note that the filter PC board will accommodate other parts values for other frequencies and applications. The section using L1, L2 and L3 may be omitted using a jumper wire instead. Likewise, other Toko inductor values may be used to reject LF nondirectional beacons or other signals in locations where they are strong enough to cause problems. Take notice that L1 is about 10% of the other two inductors. This provides similar rejection bandwidths for all sections.

Upconverter

The upconverter is built on a PC board (Figure 4) that includes the upconverter circuit, the output amplifier and the crystal oscillator. The upconverter circuit uses a wideband input transformer, which we have standardized on and it goes down to 10 kHz. The output of the CMOS switch is fed to the output amplifier, which makes up for gain loss and provides high impedance for the CMOS switch, while feeding a low impedance 50-Ω load. In our testing, we found that using a 2N4401 transistor gave a slight improvement in IMD performance over a 2N2222A or 2N3904. These may be substituted for only a slight loss in performance.

The crystal oscillator provides the switching frequency to the CMOS switch. The crystal oscillator uses a 74HC04 hex buffer connected as an oscillator and buffer. This circuit has been tested at 4 and 7 MHz and has worked well with low phase noise, an important aspect for this application. Other frequencies can be used but may require some changes in C9, and C11.

We found slight variations in IMD performance among manufacturers of the CMOS switch. A demanding application might warrant trying different brands to select for the very best IMD performance.

Strapping Options

During construction, several straps must be put in for the LP filter and the upconverter to function. On the LP filter, an option is included to put a 36-Ω resistor in series with the input connector. When used with the AMRAD active antenna, this resistor will avoid having an out-of-band load with too low impedance, which would give rise to higher levels of intermodulation distortion.

If the notch filters are not desired, use a wire strap in place of L1. L2 and L3 can be eliminated.

On the upconverter board, a set of strapping options is provided to select the onboard oscillator or an external source. The external source should be a square wave with CMOS digital logic type levels of 0 and +5 V. Be careful not to use a sine wave signal generator that goes significantly below 0 V.

There is also a blanking pulse input to the upconverter that must be strapped to ground for the upconverter to work if the blanking signal is not used.

Power Supply

We use the same power supply design (see Figure 5) that was used for the AMRAD Active Antenna, but deleted the unused components, C2, L1 and T2. Adjust the VOLTAGE ADJUST potentiometer for an output voltage of 12 V.

A regulator onboard the upconverter board regulates the 12 V input down to +5 V for the integrated circuits.

Mounting

The PC boards provide a lot of flexibility for mounting and connections. We used $^1/_2$-inch high aluminum 4-40 threaded standoffs to mount the boards

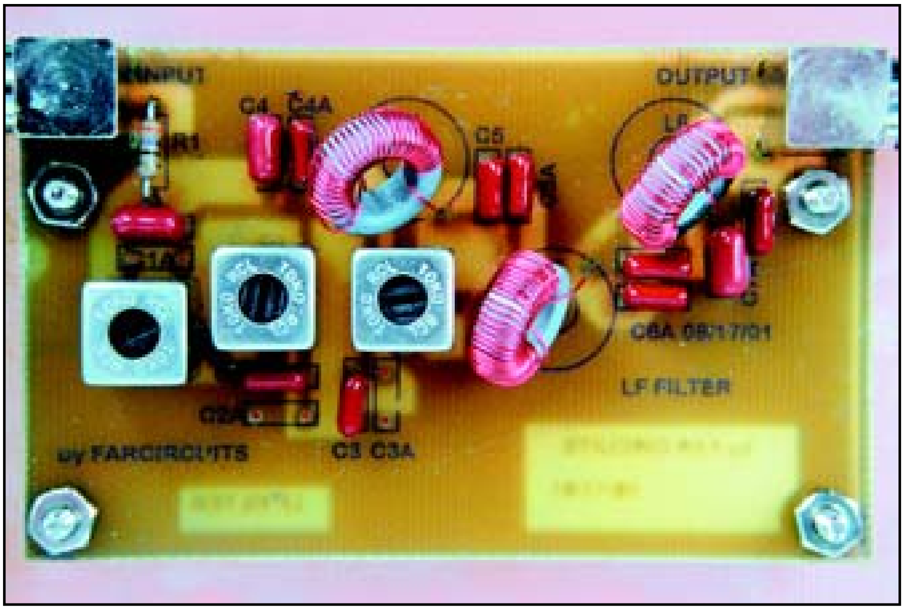


Figure 3—The low pass filter board.

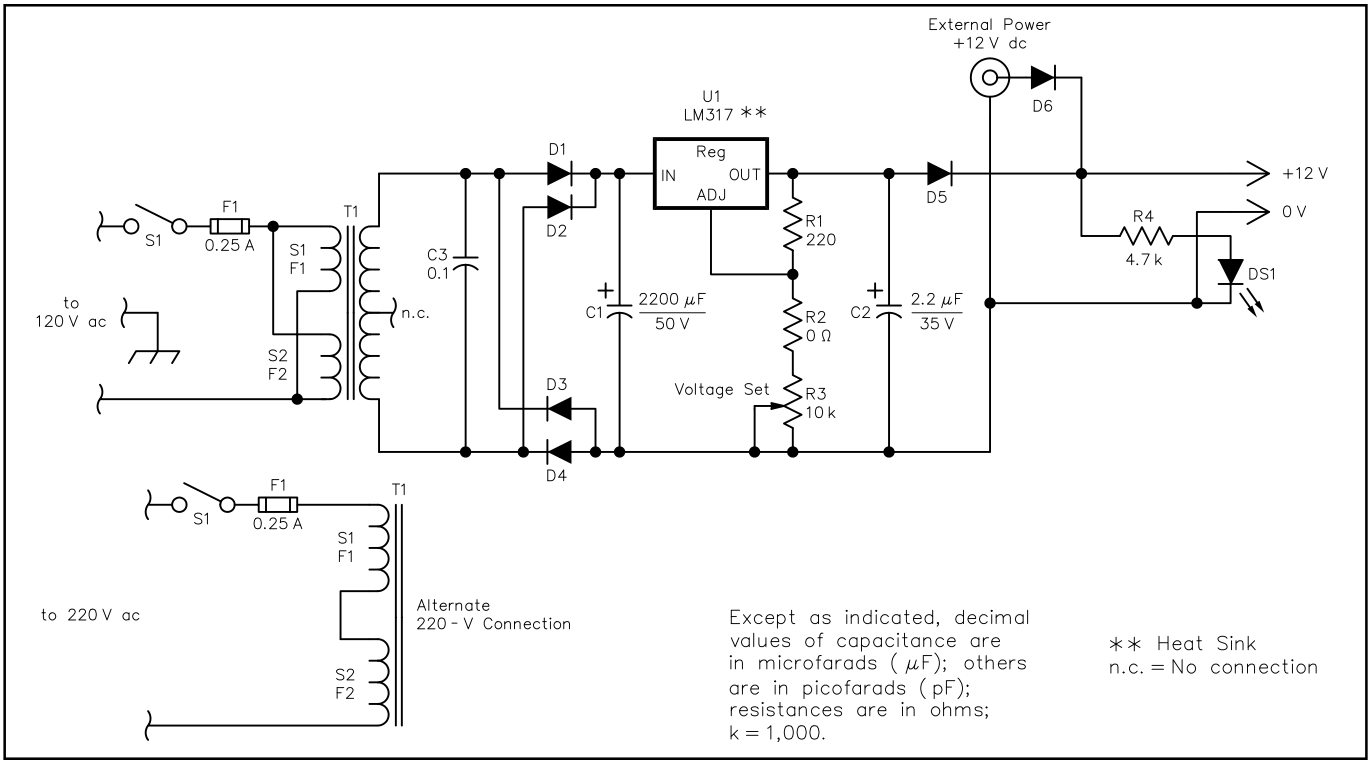
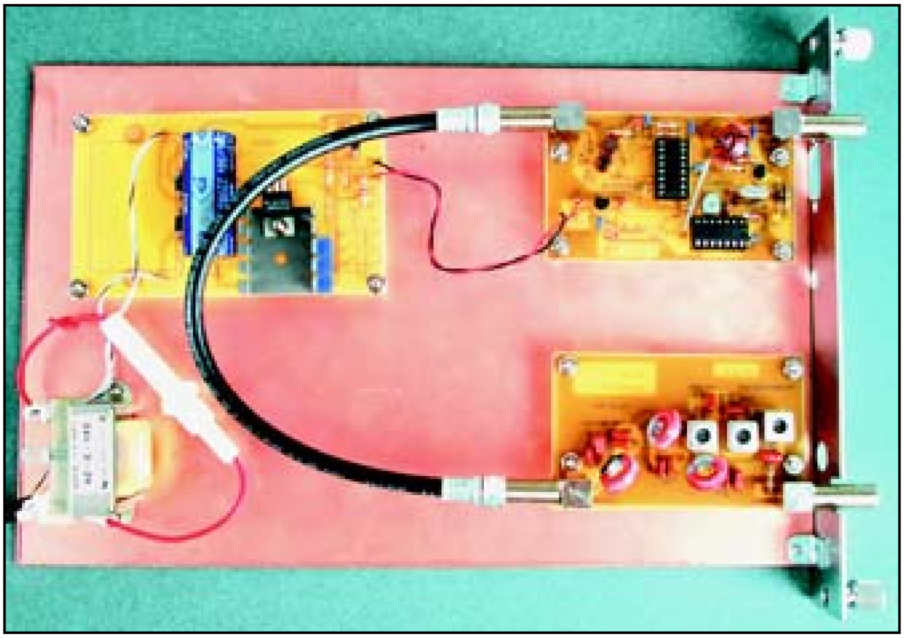


Figure 5—Power supply schematic diagram. RadioShack part numbers shown in parentheses.

C1—2200 µF, 50 V (278-1048).
C2—2.2 µF, 35 V tantalum.
C3—0.1 µF, ceramic disk, 100 V.
D1-D6—1N4003, 200 PIV, 1 A (276-1102).
DS1—LED (276-307).
R1—220 Ω.
R2—0 Ω resistor or jumper wire.
R3—10 kΩ multiturn potentiometer (271-343).
R4—4.7 kΩ (271-1330).
S1—SPST toggle (275-634B).
T1—24-V transformer, split-bobbin design, Signal Transformer CL2-40-24.
U1—LM317 adjustable voltage regulator (276-1778).
Misc—Heat sink for U1 (276-1363).

on a scrap piece of PC board material. The grounds on the PC boards connect to an area under each mounting standoff. This provides for a redundant and low impedance ground for each PC board. The PC boards can be arranged to suit the needs for a project box. During construction, each PC board can be laid on the mounting surface and the mounting hole centers marked with a fine point marker.

We selected PC-mounting F connectors for the RF connections to the PC boards. Either straight or right-angle connectors can be used. These connectors were place in the corners, which allows right angle F connector to be turned 90° depending on application. PC-mounting F connectors are inexpensive and readily available from several sources. F connectors can be crimped on short pieces of coaxial cable to make up jumper cables.



All three boards installed in the enclosure.

We rejected BNC connectors due to expense and difficulty of making cables. We rejected RCA plugs because of connection reliability.

We mounted one of our LF upconverters in an old PC LAN box recovered from a dumpster and it looks quite attractive.

Operation

The LF Converter should be connected to a good LF antenna, like the AMRAD Active LF antenna,[6] and a good HF receiver. Select a conversion frequency in the LF converter that will provide convenient tuning on the HF receiver. A frequency of 4 MHz is particularly attractive because of the wide availability of 4-MHz crystals for computer use.

A 4-MHz conversion frequency provides the tuning range of 4 to 4.5 MHz, if your receiver covers this range. For example, if a conversion frequency of 4 MHz is used, the receiver can be tuned above 4 MHz *plus* the LF frequency. This would put 136 kHz at 4136 kHz on the dial. You can just ignore the “4” on the dial and directly read the LF frequency. If your re-

What about Phase Noise?

When you are using a mixer like the one in the LF upconverter, phase noise in the local oscillator will transfer to any signal that passes through the conversion process. If you are looking at only one signal in the band, the impact is limited. As more and more signals are added the impact can become significant. Here is how it happens.

If the phase noise is 100-kHz wide, each carrier in the conversion band has a noise skirt plus and minus 100 kHz of the carrier added to that carrier in the translated output. Thus, for this converter, a carrier at 100 kHz would have this noise skirt from 10 kHz (limited by the bottom response of the converter) to 200 kHz. A second carrier at 300 kHz would have a skirt from 200 kHz to 400 kHz. A third carrier at 500 kHz would have a skirt from 400 kHz to 600 kHz. Altogether, the presence of these three carriers creates noise artifacts across the entire range of the converter.

Tuning a receiver around the noisy oscillator we were testing, we found the noise skirt was only 30 dB down at 100 kHz away. With this much phase noise, the converter, with these three carriers, could only hear 48 dB below the strong carriers at best. Stations closer to the carriers would have been worse.

We plotted the noise curves in Figure A to show the difference between the simple crystal oscillator and the programmable oscillator. Note that the noise from the 74HCT04 oscillator is so low that we can only plot the measurement limits, not the actual noise. These numbers represent the noise with a 1 Hz bandwidth. With more normal bandwidths, like 300 Hz for example, the noise is 300 times or 24.2 dB higher. For a 3-kHz bandwidth, the noise is 3000 times or 34.8 dB higher. We must conclude these oscillators are unacceptable for RF work.

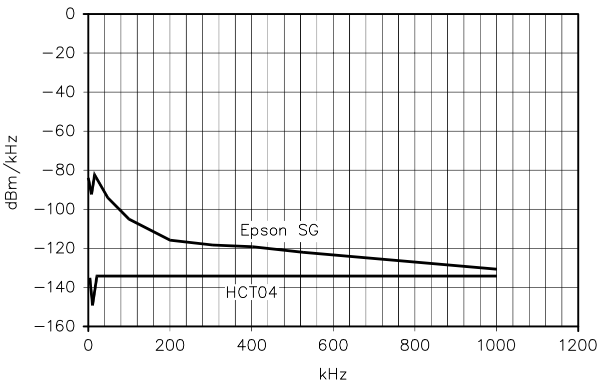


Figure A—The plotted noise curves show the difference between the simple crystal oscillator (HCT04) and the programmable Epson SG oscillator.

ceiver does not go above 4 MHz, you will get equal performance but the inconvenient mental arithmetic needed in tuning down from 4 to 3.5 MHz. Another option is 7 MHz, which is an excellent choice since it puts the LF radio amateur bands in the 40-meter band range. However, inexpensive crystals are not generally available for 7 MHz. They would have to be ordered as custom crystals. We did find B.G. Micro, a surplus source that has them in stock. You can telephone B. G. Micro at 800-276-2206, contact them by e-mail at **bgmicro@bgmicro.com** or see their site on the Web at **www. bgmicro.com.**

Variations on a Theme

Transverter

If the upconverter board is fed with a low-level HF signal source, such as from an SSB transceiver or transmitter, it will convert it down to LF if the input frequency is the same as would be used to receive LF. The LF filter should be moved from the upconverter input to the upconverter output. Here, the filter will remove the input frequency and provide a clean LF signal. While SSB voice would probably not be used much on LF, CW, FSK or PSK31 would be a good choice. If using a transmitter or transceiver for the input signal source, it should have a dummy load across the output and an attenuator to bring the signal level down to 0 dBm or lower.

Receiver/Spectrum Analyzer

A computer controlled synthesizer or a sweep generator can be substituted for the crystal oscillator in the upconverter module. The upconverter output can then be filtered and detected to create a spectrum analyzer or an LF receiver. AMRAD has a PC controlled DDS frequency synthesizer design now and we are looking to have it available before long.

Noise Gate

The upconverter can be used as an RF gate for a noise blanker. It can be gated when converting frequency, or the conversion frequency can be strapped to ground and it will pass LF straight through. The gating signal is CMOS digital logic levels with 0 V for the gate to pass LF through and +5 V to block the passage of LF. The switching time of the gate is under 100 nsec. AMRAD has a synchronous and asynchronous noise gate generator to drive this under design and construction. When not used, this noise gate line must be grounded for the upconverter to work.

Acknowledgments

Many people helped with this project as they did with the AMRAD LF active antenna. We continue to receive all sorts of help, suggestions and encouragement from the AMRAD crowd that gets together to eat tacos and talk Amateur Radio at 12:30 each Saturday at Tippy's Taco House in Merrifield, Virginia. We must credit Fred Reimers, KF9GX, and his fine printed-circuit layout effort that gave us over 110 dB of stop-band attenuation.

Notes

[1] Doug DeMaw, W1FB and Jay Rusgrove, WA1LNQ, "A High Performance Low-Frequency Converter," *QST,* June 1977, pp 23-26.

[2] Tim Brannon, KF5CQ, "A High-Performance Low Frequency Converter," **www.lwca.org/library/articles/kf5cq/lfconvtr.htm**.

[3] William Sheets and Rudolf F. Graf, "Build This Low Frequency Converter," *Radio Electronics*, September 1989, pp 47-50.

[4] *The ARRL Handbook for Radio Amateurs*, 2001, Table 16.2, Line N=7, RC= 15.087%.

[5] Power supply, upconverter and low-pass filter PC boards are available as a single package from FAR Circuits, 18N640 Field Ct, Dundee, IL 60118; tel 847-836-9148; **www.farcircuits.net**. $12 plus $1.50 shipping and handling. $3 additional charge for credit card purchases. Illinois residents add 6.5% sales tax.

[4] Frank Gentges, "The AMRAD Active LF Antenna," *QST*, September 2001, pp 31-37.

Frank Gentges, KØBRA was first licensed in 1956 as KNØBRA and then KØBRA. He upgraded to Amateur Extra in 1964. He was later licensed as W3FGL and as AK4R but chose to go back to his old call when the FCC opened up that opportunity. He became an associate member of ARRL in 1953 and became a full member in 1956. He graduated as an Electrical Engineer from Kansas State University in 1965. He went to work for Rixon Electronics and then the US Navy and retired from the Navy in 1987. He is now president of Metavox, developing new tactile technology for profoundly deaf infants. You can reach Frank at 9251 Wood Glade Dr, Great Falls, VA 22066; **fgentges@mindspring.com**.

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