A 1269MHz Transmit Converter with 70cm IF input

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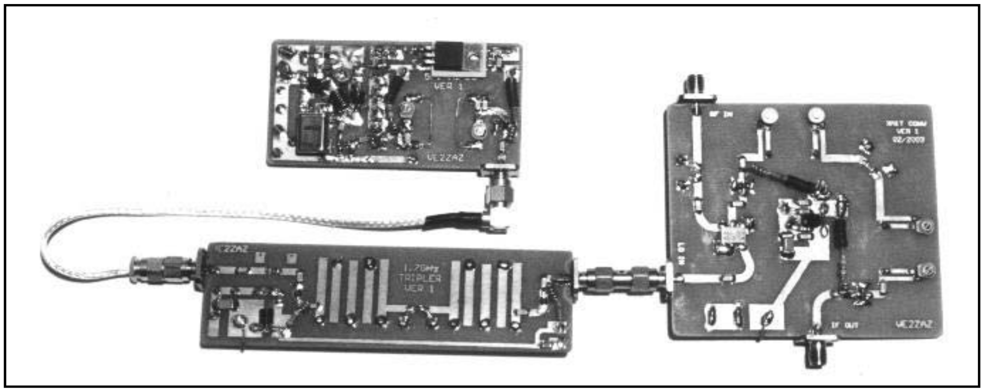

AO-40's Mode L-S is undoubtedly growing in popularity. This mode (1.2GHz uplink, 2.4GHz downlink) will become even more utilized as new satellites (Eagle, Phase 3E, Echo) are launched. Most AO-40 stations use a VHF-UHF transceiver with their S-band downconverter set for a VHF receive IF (for AO-40 mode U-S operation). Consequently, the need for a L-Band transmit converter that uses the UHF band as the transmit Intermediate Frequency (IF) becomes obvious. With such a transmit converter, the same receive downconverter can be used for both modes U-S and L-S.

Designing a L-band transmit converter that uses the 70cm band as the IF input is not trivial. One of the issues is that the third harmonic of the 70cm band falls right into the amateur radio L-Band: 432MHz x 3 = 1296MHz. One solution is to use the high end of the 70cm band, 448MHz as the transmit IF frequency. This pushes the third harmonic away to 1344MHz. Another issue with this type of converter is that the low side injection Local Oscillator (LO) frequency of 834MHz produces unacceptable mixing products which also fall right into the L-Band. This converter uses the following approach to overcome the issue: The LO frequency is selected for a high side injection at 1717MHz.

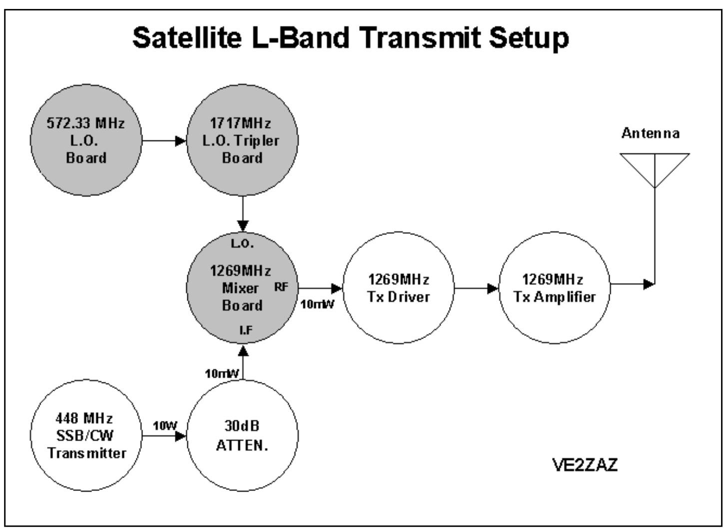

Figure 1: Proposed L-Band Transmit Converter setup using a 70cm IF Input

Finally, the above solutions can only work if selective bandpass filters are used to attenuate nearby spurious signals. This design uses two tuneable microstrip resonator bandpass filters on the 1269MHz output signal to achieve the required spurious signals attenuation.

The resulting transmit converter provides 10mW of RF output at 1269MHz with a 10mW drive at 448MHz. This is suitable for driving commercially available power amplifiers.

The converter is made of three small printed circuit boards[7]: The LO board, the LO tripler board and the mixer board. There are several benefits in breaking down the design into three boards:

- This type of project is easier to develop with a step-by-step approach, and as separate small PCBs,
- It provides the flexibility of using a commercially available LO board,
- It helps reduce coupling and interactions between the different stages, which might deteriorate performance,
- It simplifies the calibration process and troubleshooting.

As mentioned above, the proposed LO board can be replaced by an existing LO board such as the KK7B 540-580MHz LO design, which was manufactured by the hundreds by SHF Systems and by DownEast Microwave during the 80's and 90's. This board is nolonger commercially available though, hence the proposal of a new LO board in this article.

CONVERTER BLOCK DIAGRAM

Figure 1 shows a block diagram of the proposed satellite L-band Transmit setup. The elements in grey are detailed in this article. The 1269MHz Mixer board (center) is the heart of the system. It accepts a 448MHz IF input provided by a 70cm SSB/CW transmitter through a 30dB external power attenuator. The latter can be made using ordinary axial-lead 2W resistors[1]. The mixer's role is to translate this IF signal to 1269MHz by using a LO signal at 1717MHz. Mathematically presented, 1717MHz – 448MHz = 1269MHz. The 1717MHz LO stages are comprised of a 572.333MHz LO board and a 1717MHz LO tripler board (572.333MHz x 3 = 1717MHz).

The mixer board's R.F. output is sent to an external amplification chain, typically a driver stage and a power amplifier module. These are not developed here as they are available commercially either in a kit form or fully assembled[2].

1269MHz MIXER BOARD DESCRIPTION

Figure 2 shows the circuit schematic of the 1269MHz Mixer board. The circuit's focal point is A1, the mixer module, a Mini-Circuits ADE-11X. The mixer receives the SSB/CW I.F signal from the external UHF transceiver and 30dB power attenuator via an additional 13dB on-board attenuator and protection diodes. The attenuator brings the input to the mixer at a level of –3dBm. The mixer input side is also fed a 1717MHz LO signal, an unmodulated carrier at a level of +7dBm.

The mixer's output is amplified by 20dB using U2, a Mini-Circuits ERA-3 amplifier. Next, there are two stages of tuned resonator bandpass filter separated by a unpopulated (optional) pi-shaped

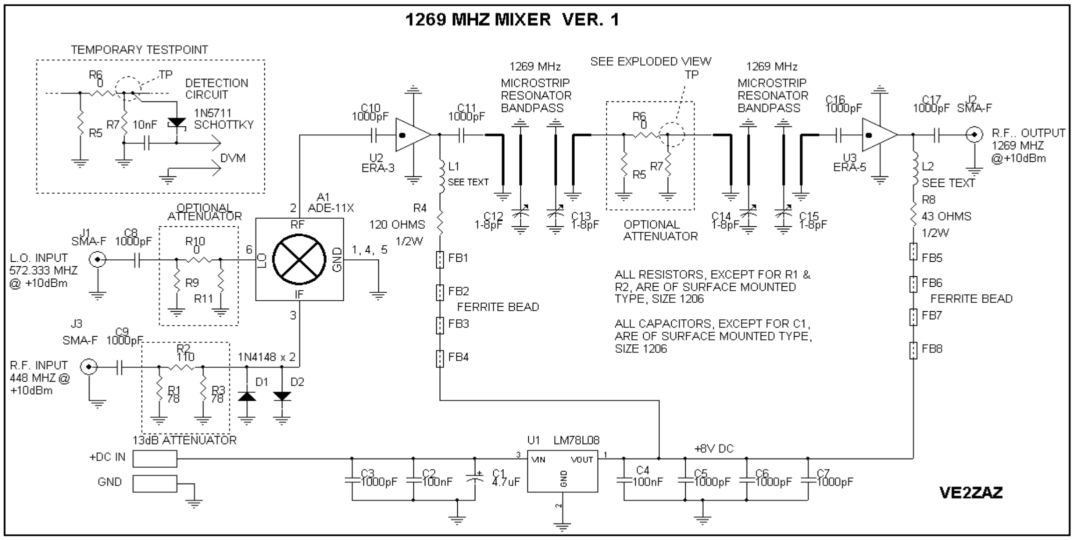

Figure 2: Mixer Board Circuit Schematic

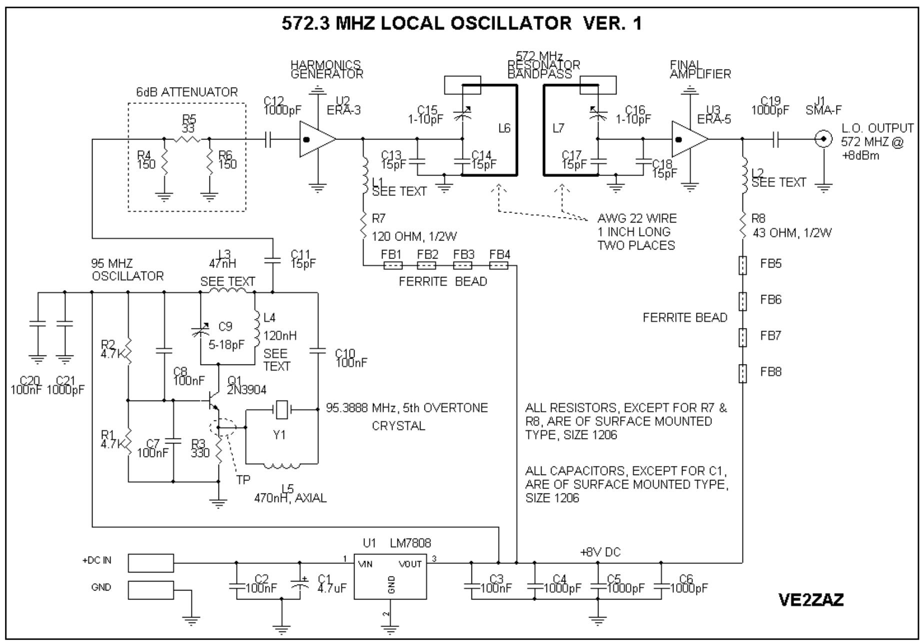

Figure 3: 572MHz LO Board Circuit Schematic

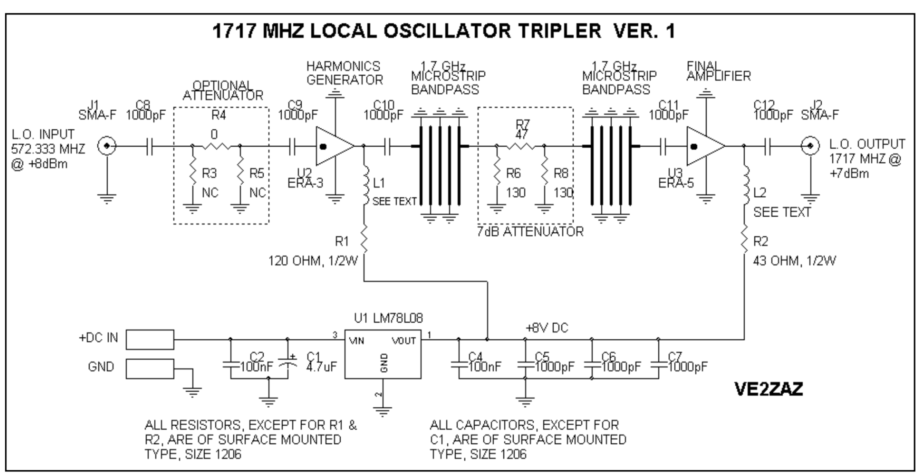

Figure 4: 1717MHz LO Tripler Board Circuit Schematic

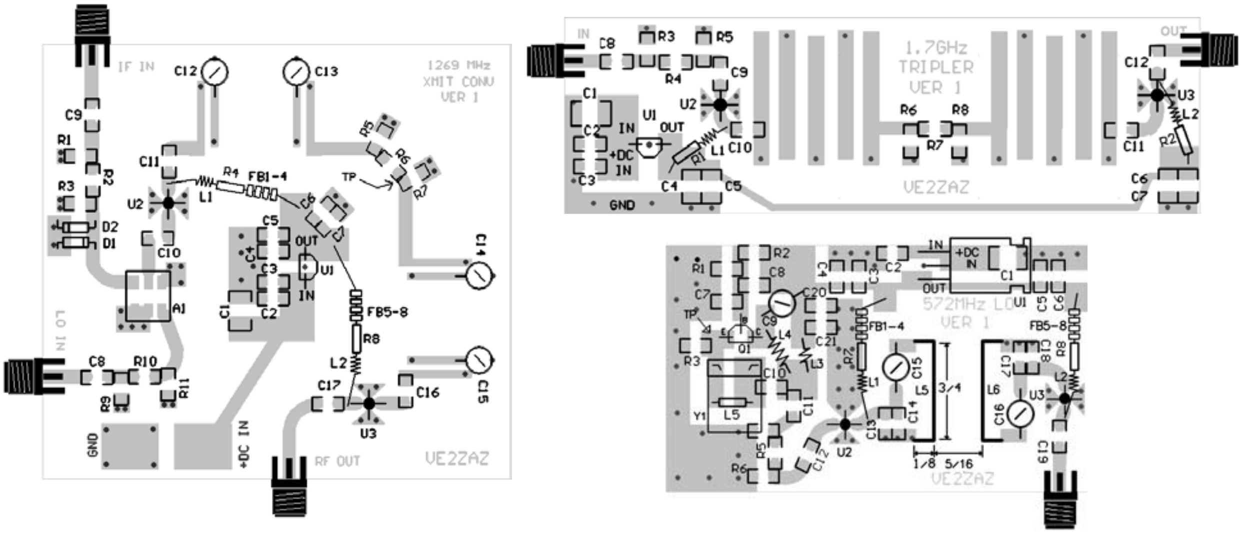

Figure 5: Layout for Mixer Board (left), LO Tripler Board (top-right) and LO Board (bottom-right). Boards

attenuator. The two filters provide the required spurious signals and harmonic attenuation for a clean 1269MHz output. The final stage provides another 18dB of gain using U3, a ERA-5 amplifier. The output is the required +10dBm SSB/CW signal at 1269MHz.

All active components on the board are supplied with a regulated and filtered +8VDC provided by U1, a 78L08 100mA voltage regulator. This voltage is applied through current-limiting resistors and inductors to the ERA amplifiers.

572MHz LO BOARD

As shown in figure 3, the 572MHz LO board is populated with a 95.3888MHz crystal oscillator. The oscillator uses a common base configuration. The circuit promotes Y1 crystal oscillation in the 5^{th} overtone mode of 95MHz. This is accomplished by C9, L3 and L4 which make a 95Mhz resonating LC circuit.

The oscillator's output is sent to the harmonics generator (U2) via a 6dB pi-shape attenuator. The harmonics generator is made of an ERA-3 amplifier driven into saturation. The harmonic-rich output is sent to a tuned resonator bandpass filter made of two wire loops run against the PCB surface, as opposed to using etched microstrip traces. This technique allows a reduction of passband attenuation and an increase of the filter's Q factor. The fact that the filter is of a tuned type drastically reduces its size as well. The filter passes the oscillator' s 6^{th} harmonic, 572.3333MHz, while attenuating other harmonic multiples of 95MHz.

The final stage, U3, provides another 18dB of gain using an ERA-5 amplifier. The output is a clean 572.3333MHz signal with an amplitude of +8dBm.

Active components on the LO board are supplied with +8VDC provided by U1, a 7808 1-Amp voltage regulator.

1717MHz LO TRIPLER BOARD DESCRIPTION

The 1717MHz LO Tripler board circuit schematic is shown in figure 4. The circuit accepts a 572.3333MHz signal at a level of +8dBm and feeds it into a harmonics generator, U2, made of an ERA-3 amplifier driven into saturation. The harmonic-rich output is sent to two stages of inter-digital microstrip bandpass filter separated by an 7dB pi-shaped attenuator. The two filters pass the 1717MHz component and attenuates other harmonics and spurious signals. The final amplifier stage, U3, provides another 18dB of gain using an ERA-5 amplifier. The output is a clean +7dBm output at 1717MHz.

Active components are supplied with +8VDC provided by U1, a 78L08 100mA voltage regulator.

ASSEMBLY

The following tools are recommended to assemble the boards:

- Tweezers to handle surface-mounted components,
- A fine tip soldering iron,
- A self-supporting magnifier or magnifying lamp.
- a static dissipating mat and accompanying wrist strap.

The converter boards detailed here are built on three small 1/16" thick G10 (glass-epoxy) PCB. All three PCBs have 50 Ohm impedance microstrip transmission lines. On all three PCBs, the top side holds the electronics and the traces; the bottom side has a solid ground plane. Plated-through vias stitch the top side ground points to the bottom ground plane.

Component location for the three boards is shown in figure 5. Parts list are shown in tables 1, 2 and 3.

Bandpass filter resonators on the mixer board and the LO tripler board are printed as microstrip traces right onto the top PCB surface. The 572MHz LO board has its bandpass filter resonators L5 and L6 made of 1" long wire elements. The elements should be bent in a 1/8"-3/4"-1/8" U-shape, as shown in figure 5. They must then be laid down against the top PCB surface and soldered over the pads with as little overlap as possible. This will result in a wire-to-wire spacing of approximately 5/16".

1206-size surface-mount capacitors and resistors are used everywhere. Nowadays, they are cheap and their parasitic inductance and capacitance are reduced compared to leaded components. This is important when working above 500MHz. All surface-mount capacitors and resistors required to assemble this project are provided along with the PCBs by the supplier [7].

SMA-female connectors are soldered to the PCB edges at shown locations. If cost is an issue for the builder, SMA connectors and cable that link the LO board to the LO Tripler board may be replaced with a short piece of coaxial cable. the center conductor gets soldered to the edge of the PCBs, right on the trace. The shield is soldered to the ground plane right under the PCB trace.

Soldering of the components should be performed in the following order: SMA connectors, Capacitors and resistors, inductors, voltage regulators, crystal. Soldering of the active RF devices (RF amplifiers, transistor) should be performed only after proper +8V supply regulation is verified.

Installation of the ERA amplifiers should be performed in the following manner. It is recommended that you use a static dissipating mat and a wrist strap as the amplifiers are ESD sensitive. First, pre-tin all four PCB pads. Then drop the amplifier in place and line up the pins with the traces. Make sure that the input pin is properly positioned. This pin is marked with a dot on the package and the pin tip is cut at an angle. First solder the two ground pins to the PCB pads. Then solder the remaining two pins. Care should be taken not to overheat the amplifier leads.

Each ERA amplifier has its supply fed via a resistor-inductor combination. It is actually made of an axial 1/2 watt resistor and a RF choke wound using one of the resistor leads. The other resistor lead holds several ferrite beads that act as additional RF blockage (in the case of the 1717MHz tripler board, the ferrite beads are not required). The inductor end can be soldered at the 1000pF SMT output coupling capacitor. The opposite resistor lead gets soldered to the PCB supply pad.

Pi-shape resistive attenuators are inserted in several locations on the boards to balance RF levels and reduce overload. Resistor values shown in the schematics are the ones recommended for typical applications. Also note that the resistive attenuators shown as optional should simply be bypassed with a 1206-size 0 Ohm resistor (also known as jumper). As an alternative, a copper strap of 1/10” width installed flat against the PCB and in line with the traces can be used.

On the 572MHz LO board, both the crystal (Y1) and the voltage regualtor (U1) are suspended by their leads above the board surface. Care should be taken so that their bodies do not touch other components underneath. Note that the voltage regulator does not require heat sinking.

Additional assembly details can be found on the author’s website[3].

TUNING AND TESTING

The following tools are useful to properly adjust and test this project:

- A Digital Voltmeter (required),
- An RF Voltmeter or equivalent (required, see workaround below),
- A non-conductive tuning screwdriver (required),
- A RF frequency counter (desirable),
- A RF generator (optional),
- A RF Spectrum Analyser (optional).

The RF Voltmeter is an asset for the radio experimenter. On the used market at hamfests, one can purchase this item for $100 or less. If none are available to the user, it is possible to make a basic one for a few dollars. A SMA-female PCB-mount connector, a 1N5711 Schottky diode, a pair of 100 ohm 1206-size surface-mount resistors and a 10nF capacitor are all that is required. Visit the author’s website[3] for more details.

A note of caution before going any further: Always disconnect the supply to the converter boards before disconnecting RF cables. The ERA amplifiers are somewhat sensitive to open circuit operation and may fail if their output is unterminated. This is especially true on this design since they are run at high output levels.

The first step in testing any electronic circuit is to check the supply voltage. All three boards provide a regulated +8VDC to the various stages. Apply a DC voltage of at least +11V (+14V typical) to the “+DC IN pads”. Use the bottom-side ground plane to connect the negative wire. Verify +8V presence before installing the ERA amplifiers.

After ERA installation, verify the 572MHz LO board operation as follows. Connect the RF voltmeter (with built-in 50 ohm termination) at the RF output connector. Apply DC voltage to the board. Begin by measuring the DC voltage at the output pin of U2, the ERA-3 amplifier. You should measure around +3.6VDC. Also verify U3, the ERA-5 for approximately +4.9VDC.

Next, connect your Digital Voltmeter (DVM) probes across R3 (point shown as TP on schematic) and adjust trimcap C9 until you measure a slight drop of voltage, typically 0.1V. Adjust the trimcap back and forth until you reach the minimum voltage. This is the “sweet spot” that provides oscillation.

The last adjustment step on the 572MHz LO board involves tuning the bandpass filter. Slowly adjust trimcaps C15 and C16 until you measure RF at the output connector. This may take a while as the optimum adjustment point is somewhat narrow. Alternate adjustment between the two trimcaps until you maximize the reading on the RF Voltmeter. You should normally measure at least +8dBm of RF output. Re-adjust C9 if necessary to achieve the required output. Connect a frequency counter (with proper attenuation added) to the RF output connector and verify for a frequency of 572.333MHz. This will confirm that you have tuned the bandpass filter to select the right harmonic. Disconnect DC supply.

Interconnect the LO board’s RF output with the LO tripler board’s RF input. Connect the RF voltmeter to the LO

Tripler board's RF outpout connector. Apply DC supply only to the Tripler board. Verify proper biasing on the ERA amplifiers on the 1717MHz Tripler board. Next, also apply power to the LO board. No adjustments are required on the Tripler board. Simply adjust LO board trimcap C9 again for an output of around +7dBm at 1717MHz. In doing this, you are actually slightly "de-tuning" the oscillator's tank circuit in order to control oscillation amplitude. Disconnect the supply to both boards, then reconnect it to verify that oscillation starts up again with the right amplitude.

Finally, you will test the mixer board for proper operation. To ease tuning of the 1269MHz bandpass filters, you should implement a temporary detection circuit, as shown on the circuit schematic in the exploded view of figure 2. This will allow you to tune the first filter stage more easily. Solder the anode end of a 1N5711 Schottky diode to the signal trace near R6. Then solder a 10nF capacitor between the diode's cathode and the ground pad of R7. Keep the diode leads short. Connect the diode-to-capacitor junction point to the + lead of the DVM and connect the DVM's – lead to ground. This will act as an RF detector.

Connect the LO tripler's RF output to the input marked "LO IN" on the Mixer board. Also connect your 448MHz RF source to the "IF IN" port on the Mixer board. This can be your UHF transmitter with at least 30dB of attenuation or it may be a signal generator. Connect the RF Voltmeter to the RF OUT connector on the Mixer board.

Apply DC power only to the Mixer board. Verify proper biasing on the ERA amplifiers on the Mixer board. Next, apply power to all three boards. Turn on your RF source to provide a +10dBm steady carrier into the mixer board. For transmitter users, recall that 10W into a 30dB attenuator makes 10mW, or +10dBm. Slowly adjust C12 and C13 to maximize the DVM reading. This may take a while as the optimum adjustment point is somewhat narrow. Alternate adjustment between the two trimcaps until you maximize the reading on the DVM. When finished, disconnect the DC supply from all boards, unsolder the anode side of the schottky diode and lift it away from the trace.

Next, reconnect the DC supply to all three boards. Adjust C14 and C15 in the same manner as above to optimize the output on the RF voltmeter (at output connector). Touch up C12 and C13 again to optimize the RF voltmeter reading. Touch up C14 and C15 again. The adjustments are now over. You should register approximately +10dBm of output power at 1269MHz.

Pi-shape attenuator resistor values shown in the schematics are the ones recommended for typical applications. Nevertheless, users with good RF knowledge might want to change attenuation values[8] to adjust levels and better suit their application.

PERFORMANCE

Figure 6 shows spectrum contents of the three board outputs. The 572MHz LO has all of its harmonics and spurious signals down at least 40dB below the carrier. The 1717MHz Tripler has all of its harmonics and spurious signals down at least 35dB below the carrier.

The most important plot shows that the 1269MHz output has its spurious signals and harmonics attenuated to at least 40dB below the +10dBm nominal output level. Note that the 1717MHz LO gets through at a constant –42dBm, regardless of the 1269MHz output level. This overall performance is fully satisfactory. Moreover, the additional external amplifier stage filters should also

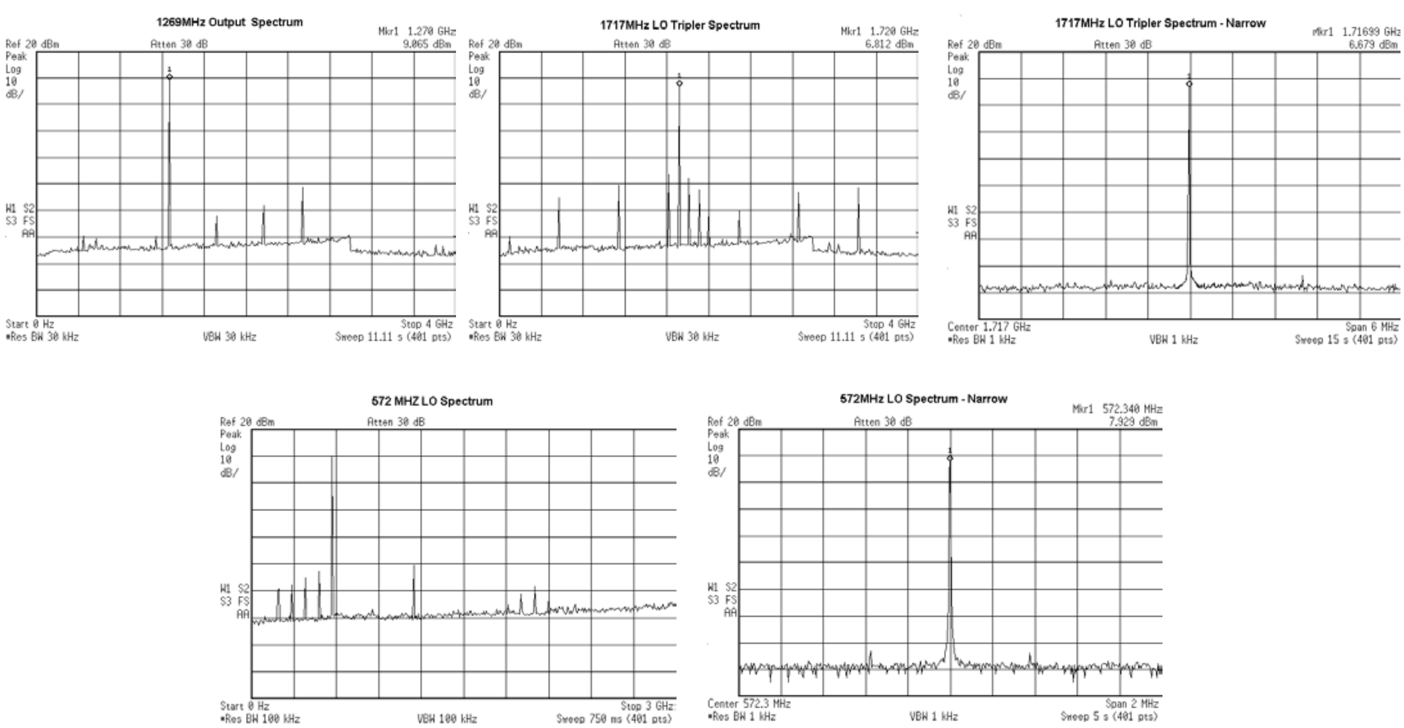

Figure 6: Spectrum contents of the three boards

contribute to the reduction of undesired spurious signals and harmonics.

The 1dB compression point of the 1269MHz output was measured at +11dBm.

Inter-modulation distortion (IMD) two-tone tests with 500kHz spacing have shown that the third order products are 45dB below the reference single-tone level of +10dBm (39dB below the two-tone level). Fifth order products are 60dB below the single-tone reference level.

Finally, a subjective listening test was performed using an Icom IC-PCR1000 as the receiver. SSB audio quality at the receiver's end appeared to be good. Furthermore, CW sounded clean, with no audible ripple.

Note that due to spectrum inversion resulting of high side LO injection, the opposite sideband mode must be selected on the UHF transmitter to obtain the desired transmitted SSB. In other words, a Lower Sideband signal transmitted into the 448MHz IF port will result in an Upper Sideband output at 1269MHz, and vice-versa. As well, note that an increase in UHF input frequency will translate into a decrease in L-Band output frequency.

One can expect the 95MHz oscillator frequency to drift until crystal temperature is stable. This drift will translate into a 1269MHz signal drift of 18 times greater, since : 95.3888MHz x 18 = 1717MHz. This may mean a warming time of 15 to 30 minutes. To help improve stability, the 575MHz LO board can be wrapped in thermally insulating material. Moreover, the entire converter can be left powered at all times.

A final caution will be to avoid overdriving the RF output beyond the +10dBm level. This would cause excessive compression on the signal and would deteriorate IMD performance.

ACKNOWLEDGMENT

The author would like to express his gratitude to Jacques Audet, VE2AZX. Jacques's support in RF filter design combined with his valuable advice helped make this long term project a reality.

SPECIFICATIONS

- **RF input:** 447-450MHz signal @ +10dBm maximum, any modulation mode.
- **RF output:** 1267-1270MHz signal @ +10dBm +/- 2dB, linear conversion, spectrum inverting,.
- **Conversion gain:** 0dB typical.
- **1717MHz LO input level:** +7dBm +/- 1dB.
- **Third Order products:** -45dB from two-tone reference level, measured at +10dBm nominal output level.
- **Output spurious signals and harmonics:** -40dBc or better, at +10dBm nominal output level..
- **1dB output compression point:** +11dBm.
- **DC input voltage range:** +11V to +20VDC
- **DC input current:** 350mA maximum (all three boards powered).

NOTES

1. The author also proposes a simple design for a DC-500MHz, 40W, 30dB attenuator on his website. Refer to note 3 for VE2ZAZ's website address.
2. Mitsubishi Electronics make hybrid amplifier modules that will take a 10mW L-Band drive and amplify it to 18W. These modules and accompanying electronics can be purchased from DownEast Microwave (http://www.downeastmicrowave.com). Also consult the ARRL literature for L-band amplifier construction articles.
3. VE2ZAZ's amateur radio website's address is: http://www3.sympatico.ca/b.zauhar .
4. ERA-3 and ERA-5 amplifiers, and the ADE-11X mixer can be ordered directly from Mini-Circuits Laboratories (http://www.minicircuits.com). Eventhough their website stipulates that minimum order is $100, the company will actually ship smaller orders. Considering their low cost, ordering additional amplifiers as spares is recommended.
5. The 95.3888MHz crystal can be ordered from crystal manufacturers such as Jan Crystals, ICM or West Crystals. Price is typically $20 plus tax and shipping. Crystal equivalent-model characteristics are: C_0 = 5.8pF, C_1 = 0.6pF, L = 5.0mH, Q = 80,000.
6. Surface-mounted chip capacitors and resistors, trimcaps, voltage regulators, axial resistors, diodes, transistor and SMA connectors can be purchased from Digikey (http://www.digikey.com) .
7. The set of three bare PCBs can be ordered from FAR circuits for $36 USD plus shipping. The PCBs are pre-drilled, tinned and have plated-through vias and component marking. All chip capacitors and chip resistors required for this project are also supplied with the PCBs. Please visit website http://www.farcircuits.net for more details.
8. Resistive attenuator design formulas are very well summarized at website address: http://williamson-labs.com/attenuator.htm

PARTS LIST – L-Band Tx Converter

Table 1: Mixer Board Parts List[6]

Qty	Designation	Description
1	A1	Mini-circuits ADE-11X mixer[4].
1	C1	4.7uF, 25V Tantalum
4	C12, C13, C14, C15	1-3pF, ceramic variable capacitor (trimcap), 0.200" lead spacing. Sprague-Goodman GKG3R015 or equiv.
2	C2, C4	100nF, chip 1206 size
10	C3, C5, C6, C7, C8, C9, C10, C11, C16, C17	1000pF, chip 1206 size
2	D1, D2	1N4148 silicon diode
8	FB1–FB8	Ferrite bead. J.W. Miller FB64-110
3	J1, J2, J3	SMA-Female, PCB mount, gold plated
2	L1, L2	Leads form resistors R4 and R8, wound with one-wire spacing, on 1/16" inside diameter, Typically 4 turns are possible.
2	R1, R3	78 ohms, chip, 1206 size
1	R2	110 Ohms, chip, 1206 size
1	R4	120 Ohms, axial, 1/2W
4	R5, R7, R9, R11	Resistors not populated.
2	R6, R10	0 Ohms, chip, 1206 size. Copper strap 0.1" wide as substitute.
1	R8	43 Ohms, axial, 1/2W
1	Temporary testpoint	1N5711 Schottky diode
1	Temporary testpoint	10nF, axial or radial
1	U1	LM78L08 voltage regulator, 100mA max.
1	U2	Mini-circuits ERA-3 MMIC amplifier[4].
1	U3	Mini-circuits ERA-5 MMIC amplifier[4].

Table 2: LO Board Parts List[6]

Qty	Designation	Description
1	C1	4.7uF, 25V Tantalum
5	C11, C13, C14, C17, C18	15pF, chip 1206 size
2	C15, C16	3-10pF, ceramic variable capacitor (trimcap), 0.200" lead spacing. Sprague-Goodman GKG10015 or equiv.
6	C2, C3, C7, C8, C10, C20	100nF, chip 1206 size
6	C4, C5, C6, C12, C19, C21	1000pF, chip 1206 size
1	C9	6.5-30pF, ceramic variable capacitor (trimcap), 0.200" lead spacing. Sprague-Goodman GKG30015 or equiv.
8	FB1-FB8	Ferrite bead. J.W. Miller FB64-110
1	J1	SMA-F Female, PCB mount, gold plated
2	L1, L2	Leads form resistors R7 and R8, wound with one-wire spacing, on 1/16" inside diameter. Typically 4 turns are possible.
1	L3	47nH. 3 turns of AWG-22 (diameter 0.025") solid enameled copper wire closely wound on 1/8" inside diameter.
1	L4	120nH. 7 turns, shaped identical to L3.
1	L5	470nH, axial inductor
2	L6, L7	1 inch long of AWG-22 (diameter 0.025") solid copper, U-shaped as 1/8"-3/4"-1/8".
1	Q1	2N3904 NPN transistor, TO-92 case
2	R2, R1	4.7 KOhms, chip, 1206 size
1	R3	330 Ohms, chip, 1206 size
1	R5	33 Ohms, chip, 1206 size
2	R6, R4	150 Ohms, chip, 1206 size
1	R7	120 Ohms, axial, 1/2W
1	R8	43 Ohms, axial, 1/2W
1	U1	LM7808 1-Amp. voltage regulator.
1	U2	Mini-circuits ERA-3 MMIC amplifier[4].
1	U3	Mini-circuits ERA-5 MMIC amplifier[4].
1	Y1	95.3888 MHz, 5th overtone, parallel resonant[5].

Table3: LO Triper Board Parts List[6]

Qty	Designation	Description
1	C1	4.7uF, 25V Tantalum
2	C2, C4	100nF, chip, 1206 size
8	C5, C6, C7, C8, C9, C10, C11, C12	1000pF, chip, 1206 size
2	J1, J2	SMA-Female, PCB mount, gold plated
2	L2, L1	Leads form resistors R1 and R2, wound with one-wire spacing, on 1/16" inside diameter. Typically 4 turns are possible.
1	R1	120 Ohms, axial, 1/2W
1	R2	43 Ohms, axial, 1/2W
2	R3, R5	Resistors not populated.
1	R4	0 Ohms, chip, 1206 size. Copper strap 0.1" wide as substitute.
2	R6, R8	130 Ohms, chip, 1206 size
1	R7	47 Ohms, chip, 1206 size
1	U1	LM78L08 voltage regulator, 100mA max
1	U2	Mini-circuits ERA-3 MMIC amplifier[4].
1	U3	Mini-circuits ERA-5 MMIC amplifier[4].