Directly Synthesized 47 GHz Local Oscillator

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February 18, 2007

Introduction. This note describes a means of directly synthesizing the local oscillator for a 47 GHz transverter. The 47 GHz calling frequency for U.S. amateurs is 47088.1 MHz. With low-side injection and a 2-meter *intermediate frequency* (IF) radio operating at 144.1 MHz, the required *local oscillator* (LO) frequency is 46944 MHz.

PLL Approach. A common means for generating such an LO signal is to use a microwave brick oscillator phase-locked to an internal *very high frequency* (VHF) *temperature-controlled crystal oscillator* (TCXO). Low-frequency TCXOs are better than VHF TCXOs, even after phase noise is scaled up in frequency[1], so it is advantageous to control the needed VHF frequency via a second *phase-locked loop* (PLL) tied to a precision 5 or 10 MHz frequency standard[2]. For example, Figure 1 shows a schematic diagram for phase-locking a 108.666667 MHz brick oscillator to a 10 MHz source. The brick oscillator cavity is tuned to the 18th harmonic (1956 MHz) and the step recovery diode/band pass filter output is tuned to the 6th harmonic of the cavity (11736 MHz). A final multiplication by 4 then yields 46944 MHz. Digitally dividing a sample of the brick TCXO output by the factor (16*163*2=5216) and comparing it with the reference frequency divided by the factor (16*15*2=480)[3] allows locking. The comparator voltage is low-pass filtered and applied to a varactor placed across the TCXO tank circuit to control its frequency. The CT1DMK PLL board has become popular for this task[4].

Issues. Unfortunately, the PLL approach has sometimes been associated with short-term frequency wobble. Whether this is due to VHF crystal parameters, loop filter settings, or something else, it results in the potential frequency stability of the reference not being realized. The PLL approach is also prone to locking difficulties, especially when operating portable under adverse conditions of temperature, vibration, and voltage level. Finally, the warm-up time of microwave bricks is often considerable (Figure 2)[5]. Consequently, a PLL-free, direct-synthesis source has been developed. Although certainly not mandatory for frequencies as "low" as 47 GHz, it is telling that WA1ZMS uses direct synthesis in his equipment for the higher microwave bands[6].

Direct Synthesis Example. Probably the most common way of directly generating a 46944 MHz LO signal is via a DB6NT multiplier chain[7]. This multiplier comes with a TCXO operating at 46944/(4*96)=122.25 MHz. The stability and repeatability of older units is often less than desired. While the newest temperature-control scheme is improved, it is still advantageous to provide 122.25 MHz externally, tied to a 5 or 10 MHz precision frequency standard. Figure 3 shows a schematic for doing this. The frequency standard signal is digitized and multiplied 20-fold to produce 120 MHz. It is

[1] Millimeter-Wave LO References and Phase Noise Considerations, Brian Justin, WA1ZMS, Microwave Update 2004.
[2] Such standards are available at reasonable cost through eBay.
[3] The final divisions by 2 produce square waves, needed when exclusive-OR phase detection is used.
[4] http://www.tapr.org/kits_reflock_ii.html?PHPSESSID=22ed6a52889620422891e0da762ede91.
[5] With an Isotemp OCXO 134-10 source, the directly synthesized 47 GHz LO settles to within 1 kHz of the steady-state value in 10 minutes.
[6] http://www.mgef.org/images/241v_synth.gif.
[7] http://www.kuhne-electronic.de/english/oscillators.htm.

also digitally divided by the factors 8 and 10 to produce 1.25 MHz and 1 MHz waveforms. These waveforms are digitally mixed in a NAND gate to produce power at 2.25 MHz. After amplification and filtering, the 120 MHz and 2.25 MHz signals are analog mixed to yield 122.25 MHz. After passing through a crystal filter to remove unwanted mixing products, and amplification by a *monolithic microwave integrated circuit* (MMIC) to the mW level, the relatively clean 122.25 MHz signal is input to a DB6NT multiplier in place of its crystal oscillator[8].

Hardware. Figure 4a shows an early picture of the hardware. Dead-bug construction techniques are used with the *integrated circuits* (ICs) mounted upside-down on a copper-clad circuit board. A 13.8-to-5 Vdc regulator IC is located on the upper left circuit board along with the digital ICs. 5 Vdc is distributed via orange wires and liberally bypassed at each active device. The X12 multiplication to 120 MHz begins on the digital IC board with Q1 and MAR-6 to the right, and ends with a separate circuit board to the far right with the Q2 high-Q tank circuit for final signal cleanup. A tracking generator/spectrum analyzer or signal generator/power meter are helpful for maximizing the power at 120 MHz and minimizing power at other multiples of 10 MHz. Such equipment is likewise helpful in maximizing the 2.25 MHz power relative to power at other mixing frequencies. The Q3 and Q4 high-Q tank circuits (circuit boards on the bottom left and right) must peak at 2.25 MHz to accomplish this. Adding or subtracting capacitance from 4700 pf may be needed to do this, or the 1 uh inductor turns might be squeezed or stretched. The standard level (7 dBm LO) SBL-1 mixer is soldered upside down near the 120 MHz Q2 output to minimize lead length. Pins 2,5,6, and 7 can then be grounded via the case.

In the final hardware (Figure 4b), a cascade of 122.25 MHz crystal filters is used to reduce the unwanted lower-sideband mixing product and close-in spurs at +/- 250 kHz (Figure 5). A low-pass filter is also included to remove frequency content around multiples of 122.25 MHz. MMIC gain follows with the net gain padded by a fixed attenuator to provide the 0 dBm drive specified for the DB6NT MKU 12 LO unit, option 01 (it works with only slightly reduced output when driven at –6 dBm). Figure 4c shows the 122.25 MHz source driving a DB6NT LO unit connected to a high-power DB6NT 47 GHz transverter in place of the Frequency West PLL LO (which instead is terminated by a 50 ohm load). The FT-817ND IF radio is out of view on the far right. This setup was used to measure the warm-up frequency behavior of both LOs by noting the CW zero-beat frequency versus time for a 47088 MHz precision marker source. Figure 6 shows a complete low-power 47 GHz radio mounted on a plywood board atop a Bogen 3051 tripod with 3057 head. A 7 amp-hour rechargeable 12 Vdc battery is used to power the transverter and the FT-817ND IF radio. The DB6NT 47 GHz transverter is connected to an Andrew 1' 40 GHz dish as described in a companion article[9]. Even a dish this small has only about a 1-degree beamwidth, so a Wayfinder V2020 digital compass has been mounted on it to assist aiming.

If chip components are used be careful not to flex the circuit boards as that can fracture such parts[10]. Since junk-box parts on hand were used, the values specified in Figure 3 are certainly not sacred. For example, any NPN transistor with a gain-bandwidth product on the order of 1 GHz should work fine. The inductance calculator at http://www.crystalradio.net/cal/indcal2.shtml and the free filter-design program available at http://www.aade.com/ may prove helpful in checking part substitutions and winding needed inductors.

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[8] http://www.km0t.com/pages/12ghzlo.htm describes how to do this. Alternately, the local oscillator can be purchased without a crystal oscillator but with an sma connector for external frequency input instead.
[9] Garry C. Hess, "47 GHz circular-rectangular antenna mount," Jan. 12, 2007 (contact author for copies).
[10] This will not be a problem if stiff/thick circuit boards are used; however, it was an issue with 20 mil FR-4 boards.

Direct Synthesis in General. The approach of Figure 3 also works for IFs other than 2 meters. For 432 MHz, the desired LO frequency is 46656 MHz. Dividing this by 4*96 gives 121.5 MHz. That can be generated from 10 MHz by multiplying by 20 as before, but now dividing the reference by both 4 and 10 (to obtain 2.5 MHz and 1 MHz) so the digital mixing operation produces power at 1.5 MHz. The final analog mixing operation of 120 MHz and 1.5 MHz produces power as desired at 121.5 MHz. For 1296 MHz, the desired LO frequency is 45792 MHz. Dividing this by 4*96 gives 119.25 MHz. That can be generated from 10 MHz by multiplying by 20 as before, but now dividing the reference by both 8 and 20 (to obtain 1.25 MHz and 0.5 MHz) so the digital mixing operation produces power at 0.75 MHz. The final analog mixing operation of 120 MHz and 0.75 MHz produces power as desired at 119.25 MHz. This frequency is rather far from the DB6NT design target of 122.25 MHz so output power will suffer. Rather than attempting to retune the various X2 microstrip filters, it probably would be better to simply follow the multiplier chain by an output GaAs FET amplifier stage to regain 16-dBm output.

The basic scheme used to directly synthesize VHF frequencies is shown in block diagram form in Figure 7[11]. Table 1 lists various frequencies of potential interest with multiplication/division factors and signs that produce them, in addition to the 122.25 MHz value focused on by this paper.

[11] Dave Robinson, WW2R, describes a generic direct-frequency synthesizer that outputs frequencies of the form R(C+/-(B/A)), where R is the reference frequency, B and C are multiplication factors, and A is a division factor (http://g4fre.com/dfs9096.pdf). He uses that approach to generate 96 MHz (R=10 MHz, C=9, B=3, and A=5), a frequency useful for an 1152 MHz LO and also for markers on the ham bands at 2304 MHz and above. This approach is preferable when the divide values of Table 1 are identical, since then digital mixing would not produce a frequency sum product unless the inputs differ significantly in phase.

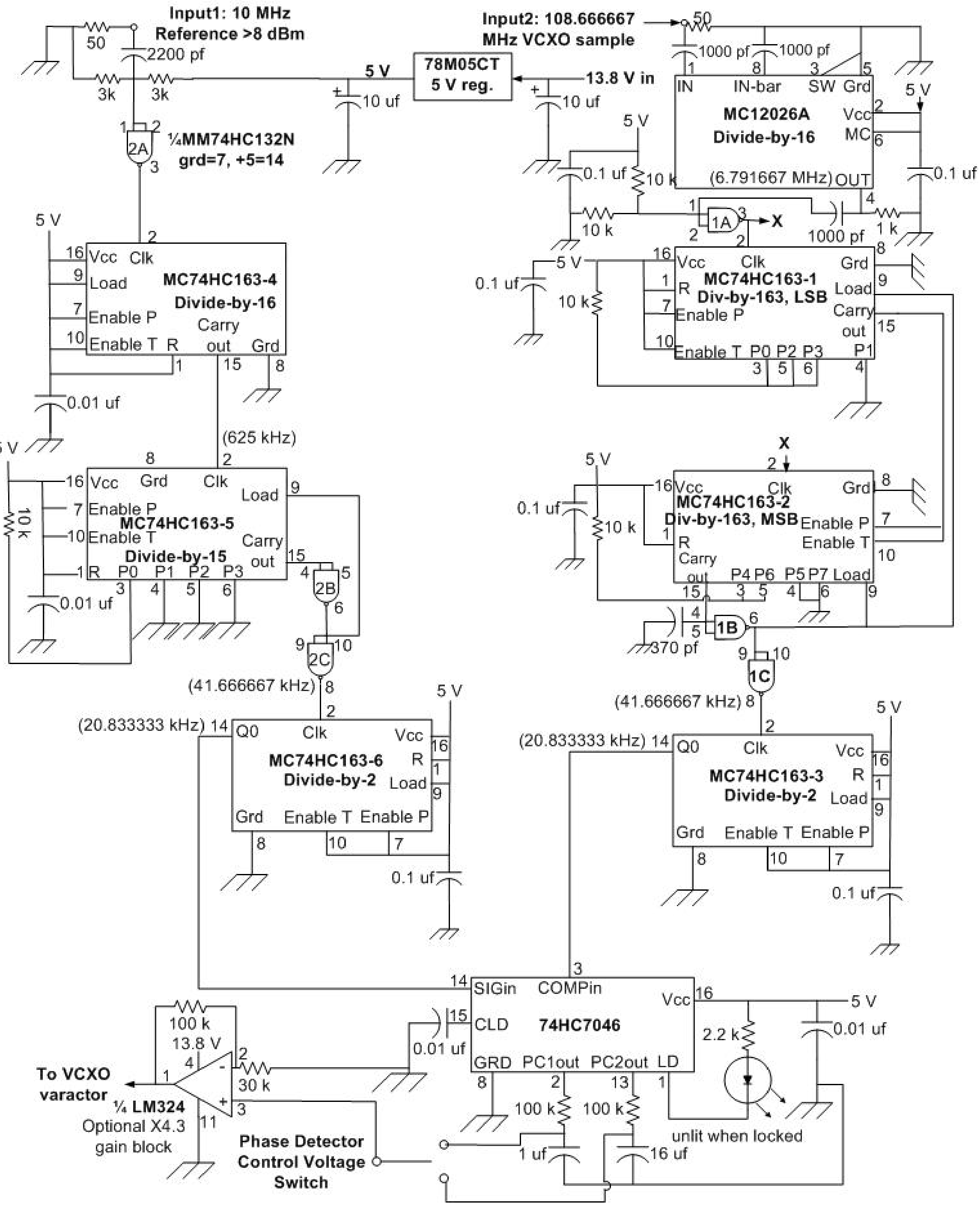

Figure 1 Block diagram of a 108.666667 MHz PLL.

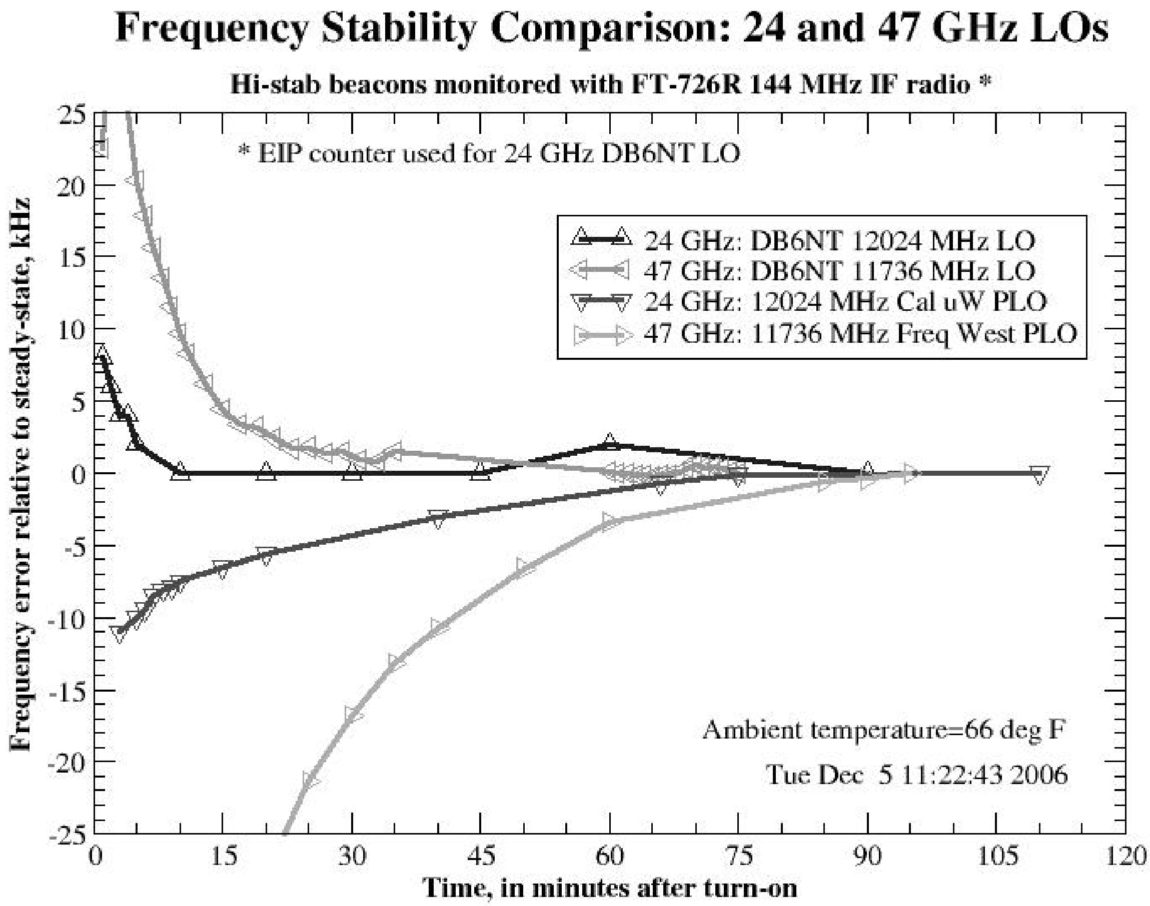

Figure 2 Warm-up measurements of various LO sources.

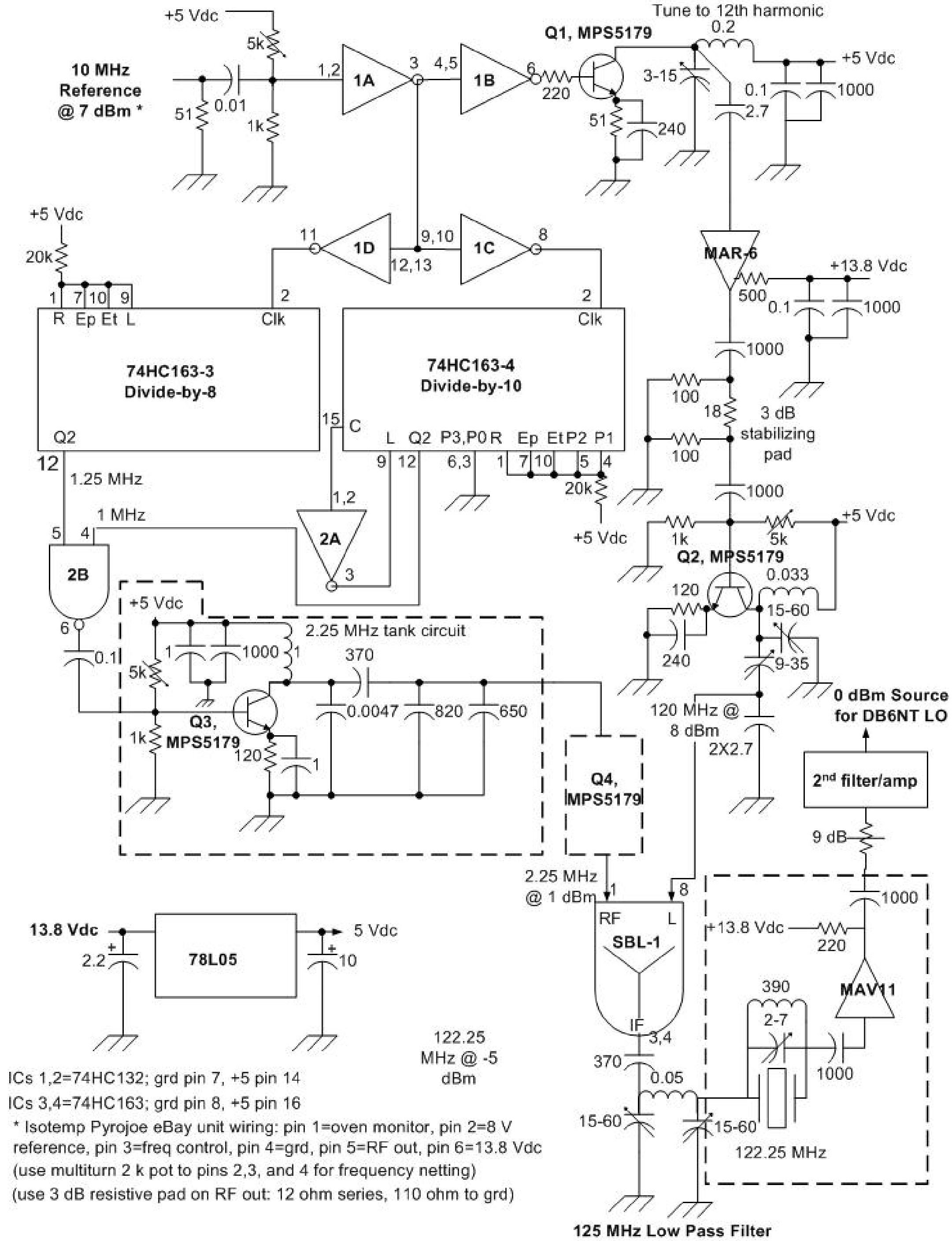

Figure 3 Block diagram to synthesize 122.25 MHz from a 10 MHz frequency standard.

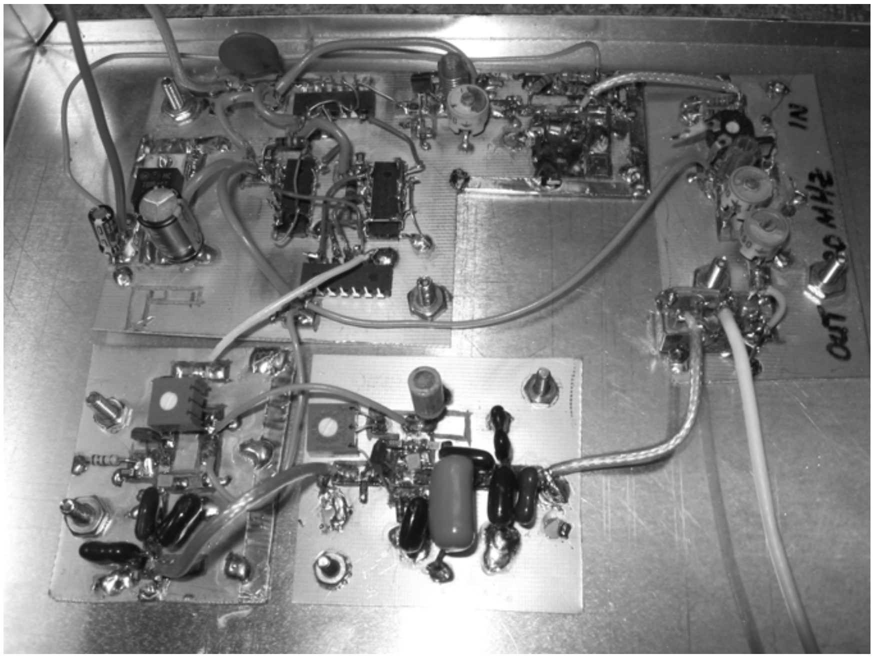

Figure 4a View of hardware, up to mixer that outputs 122.25 MHz + spurs.

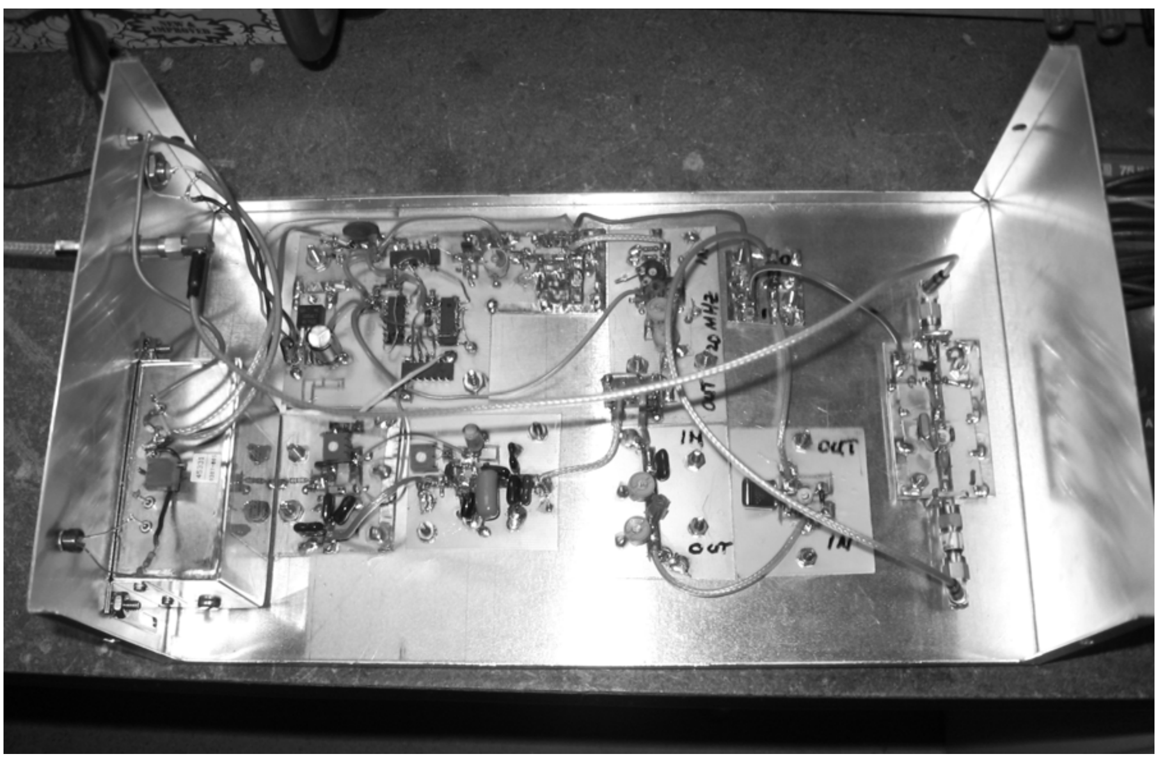

Figure 4b View of final hardware, including the 10 MHz Isotemp TCXO (lower left, with blue multi-turn frequency trim pot).

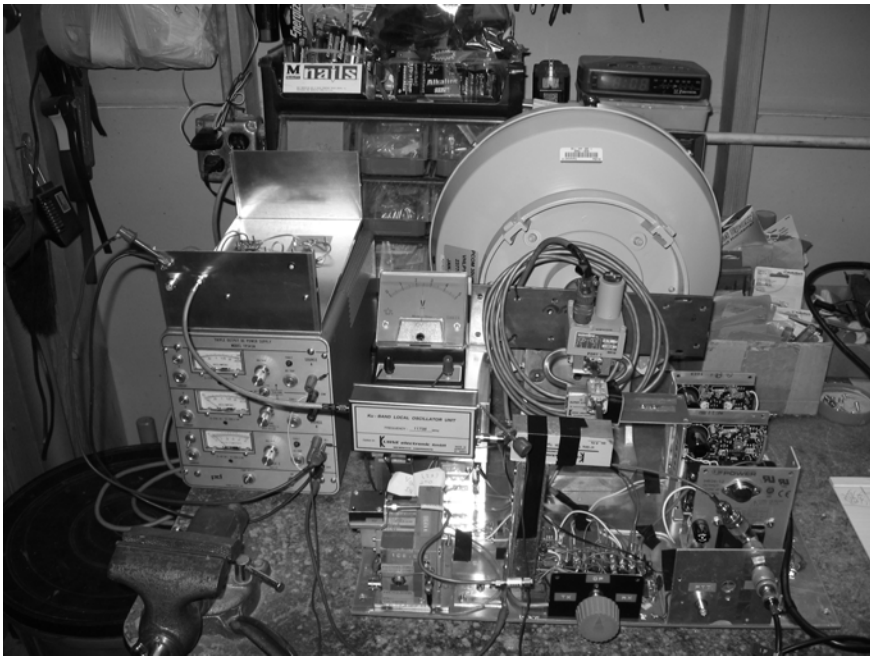

Figure 4c View of 122.25 MHz external source for DB6NT LO and 47 GHz transverter (FT-817ND IF radio is out of the picture to the right).

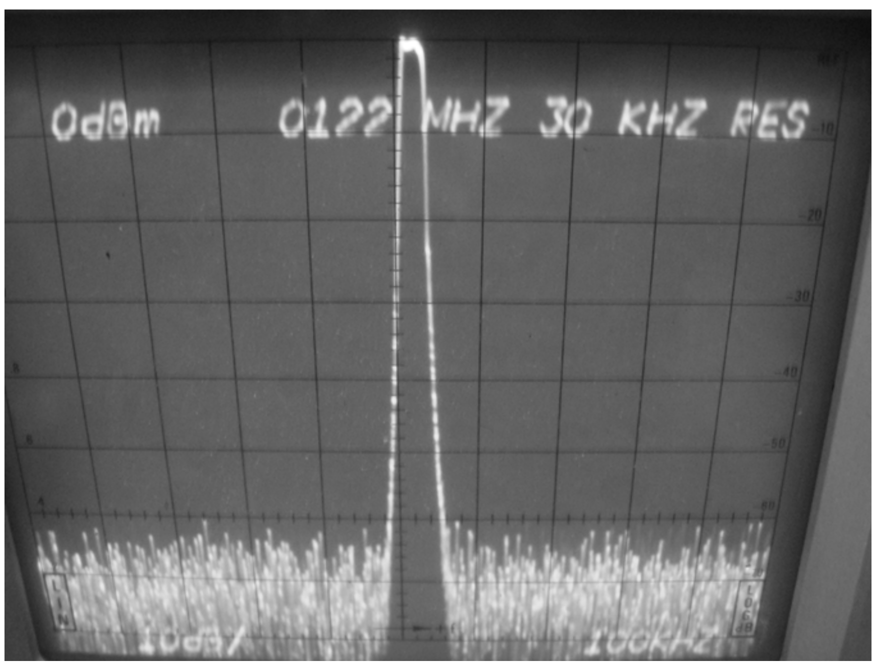

Figure 5 Close-in spectrum of the 122.25 MHz source (10 dB/div vertically, 100 kHz/div horizontally).

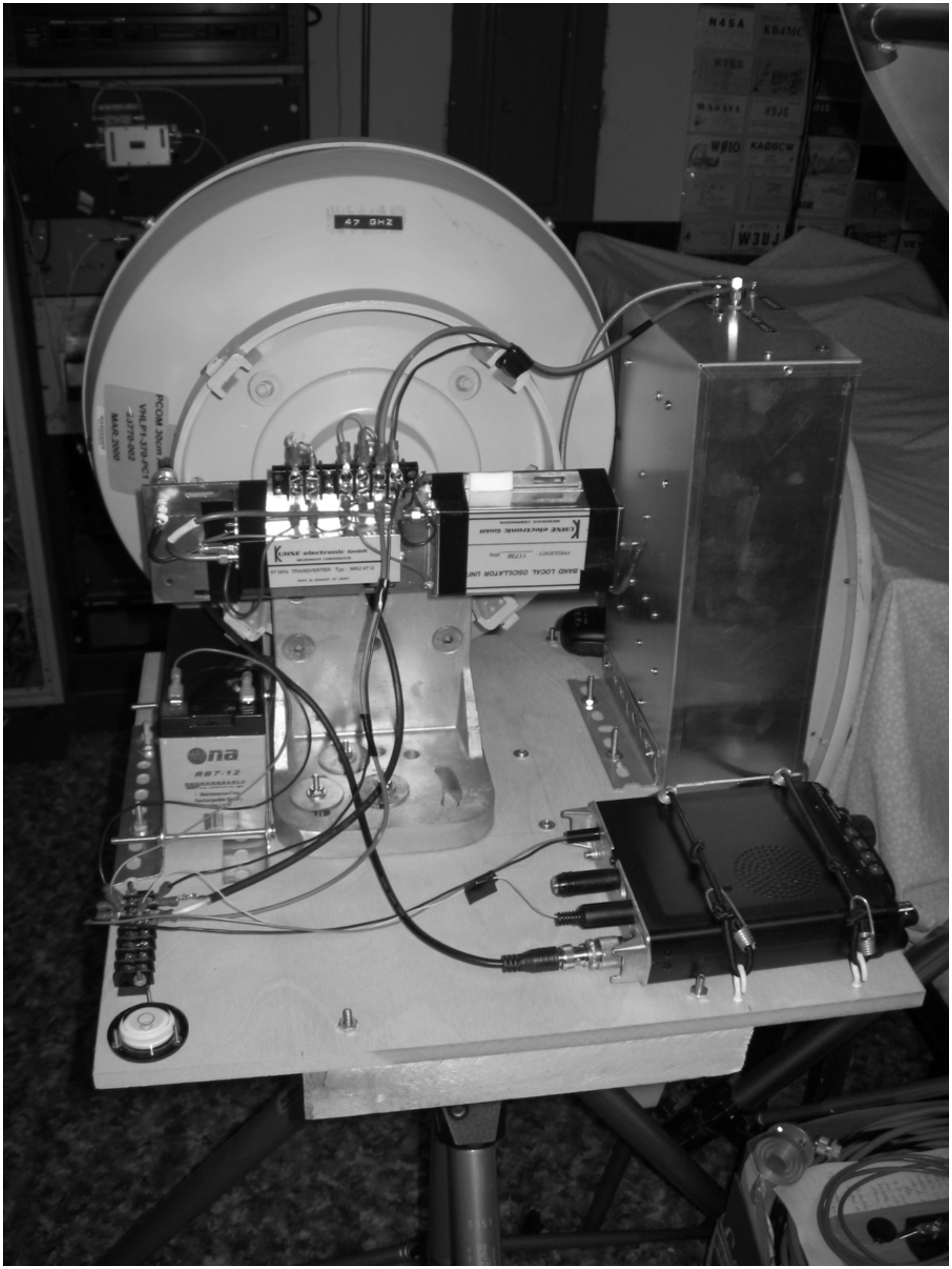

Figure 6 Low-power, direct-synthesis 47 GHz radio.

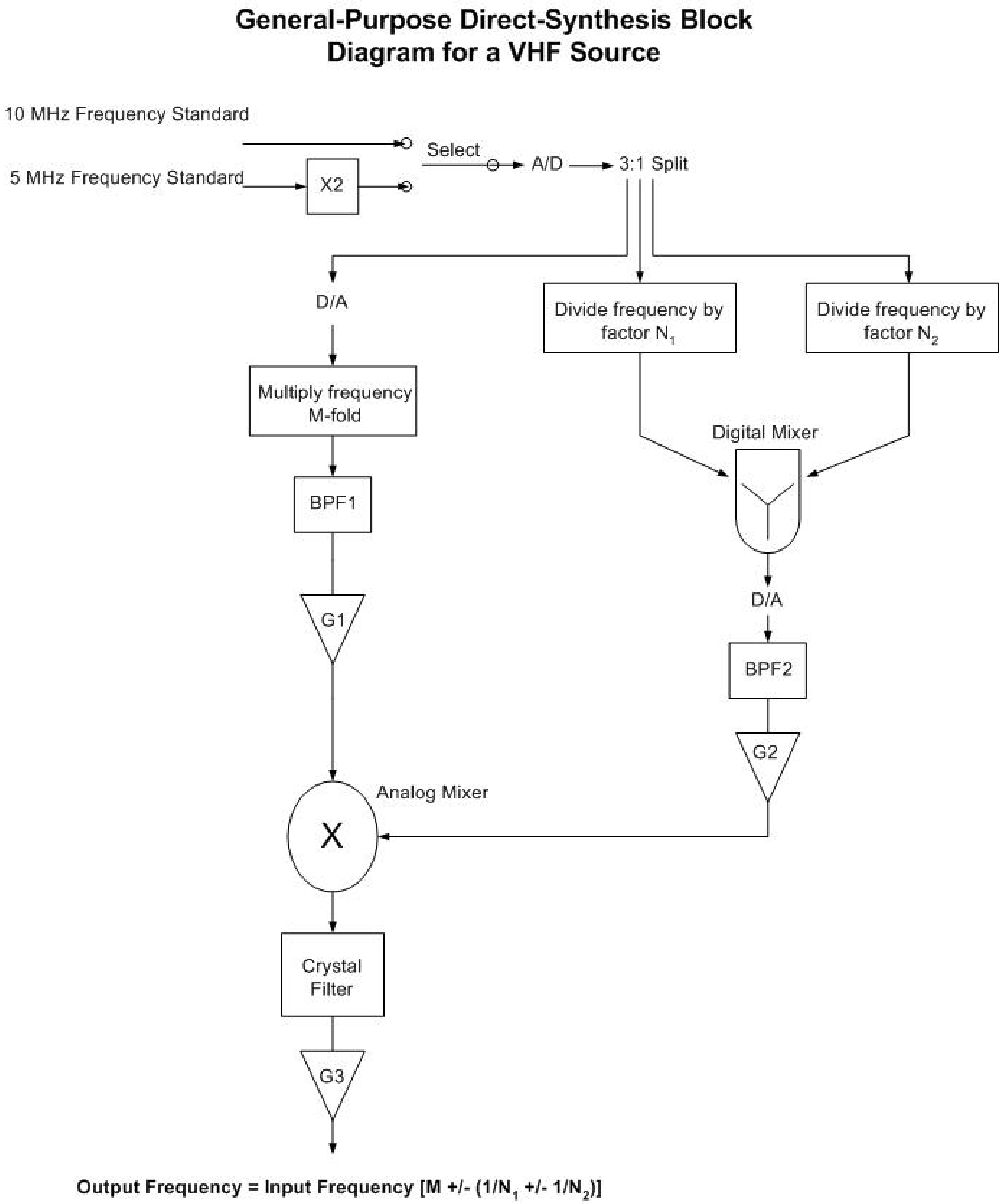

Figure 7 General-Purpose Direct-Synthesis Block Diagram for a VHF Source.

Table 1 Multiply/Divide factors for various frequencies of interest

F_{out}, MHz	F_{in}, MHz	F_{final}, MHz	M	N_1	N_2	Signs
126.0	10	24192 (X96 X2)	13	5	5	-,+
126.0	5	24192 (X96 X2)	25	5	na	+,na
125.25	10	24048 (X96 X2)	12	2	40	+,+
125.25	5	24048 (X96 X2)	25	20	na	+,na
122.625	10	47088 (X96, X4)	12	5	16	+,+
122.25	10	46944 (X96 X4)	12	10	8	+,+
112.0	10	24192 (X18 X6 X2)	11	5	na	+,na
112.0	5	24192 (X18 X6 X2)	22	5	5	+,+
111.333333	10	24048 (X18 X6 X2)	11	3	5	+,-
111.333333	5	24048 (X18 X6 X2)	22	3	15	+,-
109.0	10	47088 (X18 X6 X4)	11	10	na	-,na
108.666667	10	46944 (X18 X6 X4)	11	3	5	-,-
102.0	10	78336 (X96 X8)	10	5	na	+,na
96.0	10	1152 (X12)	10	5	5	-,+
		2304 (X12 X2)				
		3456 (X12 X3)				
		5760 (X12 X5)				
		10368 (X12 X9)				
		24192 (X12 X21)				