By Bob Larkin, W7PUA

The DSP-10: An All-Mode 2-Meter Transceiver Using a DSP IF and PC-Controlled Front Panel

Part 1—What's neat about this 2-meter transceiver is that most of it is in *software!* Your PC is its front panel. You can operate it as a stand-alone QRP rig, with an amplifier or with UHF and microwave transverters!

ALL PHOTOS BY JOE BOTTIGLIERI, AA1GW

The complexity of amateur all-mode transceivers has grown to the point that their construction is generally left to commercial manufacturers. For many of us, merely envisioning the total number of components required to build such a project is overwhelming! Duplicating the mechanical structure of a modern front panel seems to require a machine shop and the talents of an artist. So, like most hams, I have usually gone shopping and come back with a factory-made transceiver.

This time, I built the transceiver myself.

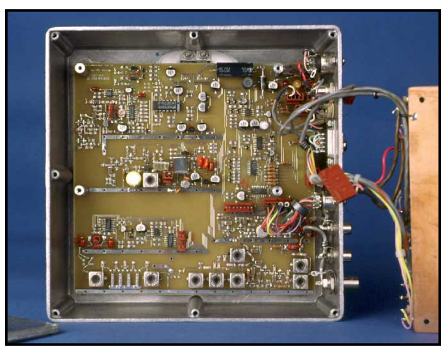
Over the years, several things have changed that make such a homebuilt radio a possibility once more. Digital signal processors (DSP) are available at low cost. These devices allow considerable simplification in transceiver construction by using software to replace much of the hardware. Once the software is written, it is possible to get the hardware functions working with very little effort. As a bonus, with DSP we can perform some types of filtering and signal processing that would be impractical to implement in hardware.

PC availability nowadays is such that one can be dedicated to controlling a transceiver. This means we can have a front panel, smart controls and all the "bells and whistles" that we want without drilling a single hole!

The benefits of moving portions of a radio's circuit action into software are affecting the designs of commercial radios.[1] A number of products now available use a PC and appropriate software to create the front panels. Final IF and audio-stage implementations in DSP are becoming more common. As the performance of digital/analog conversion hardware improves, expect to see the percentage of radios operating in DSP to increase further.[2] This project gives you an opportunity to see how such a radio is designed—and the chance to build your own!

The DSP-10 Transceiver

The DSP-10 is a low-power, all-mode 2-meter transceiver using DSP at the last IF and audio stages. You control the radio via a PC acting as the virtual front panel. A built-in audio spectrum analyzer allows you to see what is happening at the audio level. A number of features make this rig particularly well suited for use as an IF radio for UHF and microwave transverters.



An inside view of the transceiver with the DSP assembly removed.

[1]Notes appear on page 41.

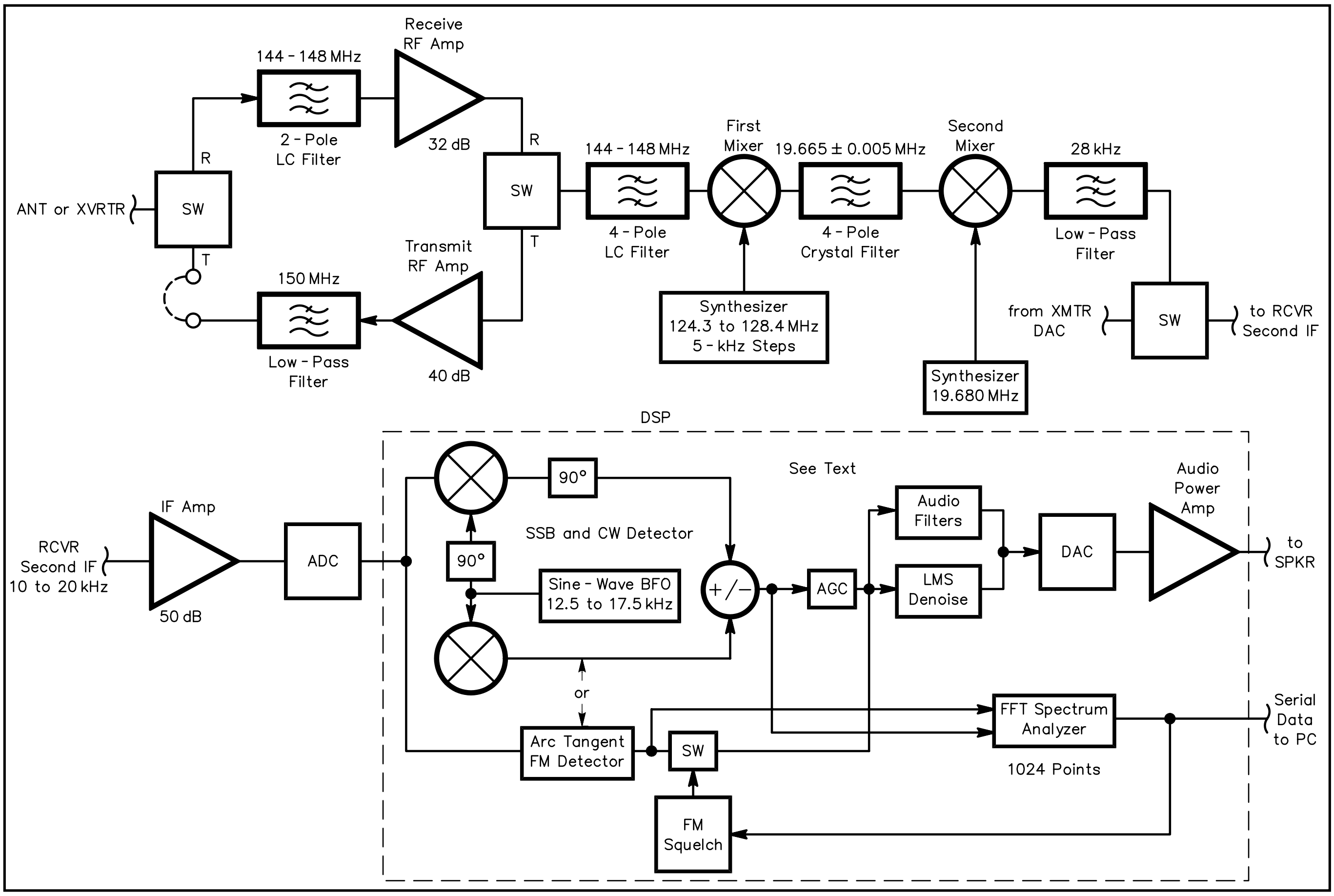


Figure 1—This transceiver block diagram shows the receive path and the hardware portions of the transmit path. Most of the circuits are bidirectional, being used for transmit and receive. The dashed line at the output of the 150-MHz low-pass filter indicates the signal path to the TR switch during transmit. Two frequency conversions shift the signal from 146 MHz down to the 15-kHz IF. All IF and audio processing is done using DSP. One detector is used for SSB or CW and a second detector for FM. Fine tuning for the SSB/CW modes comes from the 12.5- to 17.5-kHz *software* BFO.

Three basic components are involved. A minimal amount of RF hardware (on a single PC board) translates the signal frequency up and down using the DSP of an Analog Devices demonstration board.[3] A DSP program processes the IF and audio portions of the radio signals. Finally, software running in the PC controls the DSP and presents a front-panel interface to you, the user.

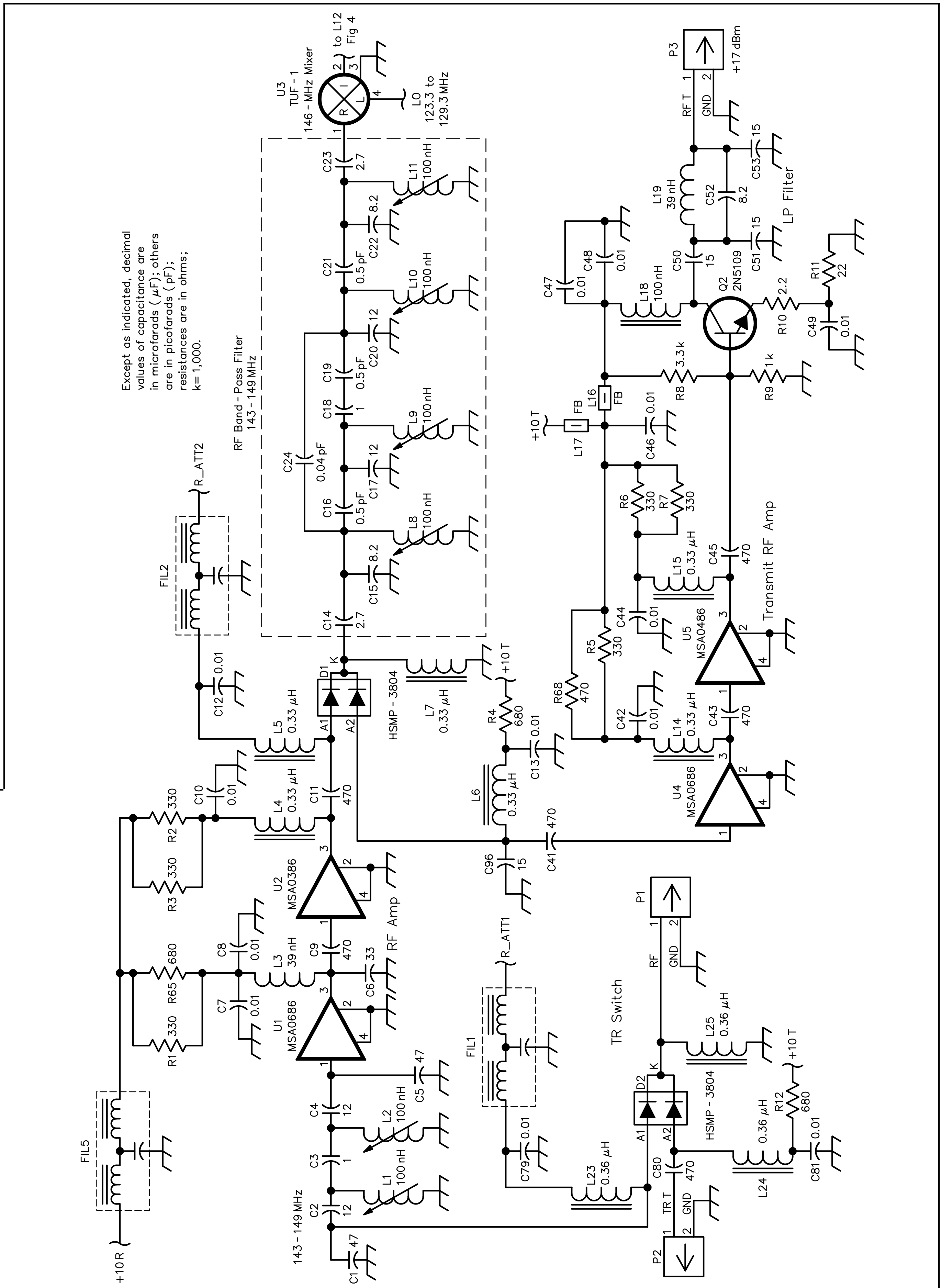
PC requirements are minimal. Almost any PC running DOS equipped with a 640 × 480 VGA display can be used. No extended or expanded memory is needed, nor is a math coprocessor required. The program can operate with very slow processors. Most of this transceiver's testing was done using a 20-MHz '386 laptop computer. Communication between the DSP and the PC is at 9600 baud.

Constructing a piece of electronic hardware requires a description through schematics, PC layouts and the like. To help you understand the inner workings of this radio—as a starting point for customizing your radio, or for building a new project altogether—this project's source code is available. (More on this in Part 2.)

Figure 1 is a block diagram of the trans-

Figure 2—(See facing page) The transmit and receive RF signal paths. Extensive RF filtering ensures a clean transmit signal and freedom from spurious signals during reception. All resistors on the main board are 5%-tolerance 1206 Xicon chips. These are available in small quantities from Mouser Electronics. Unless otherwise noted, all capacitors are 1206 or 0805 chips. Capacitor values less than 470 pF are NP0; values of 470 pF and greater are any general-purpose ceramic, such as X7R or Z5U. Component sources and abbreviations are listed in the sidebar "Parts Sources." Those identified generally are only one of several that manufacture or distribute equivalent parts. Equivalent parts can be substituted.

C24—0.04 pF "gimmick" capacitor constructed from a 0.2-inch length of #24 tinned wire spaced 0.05 inch above the adjacent PC-board pad.
D1, D2—HSMP-3804 dual PIN diode (HP HSMP-3804)
FIL1, FIL2, FIL5—470-pF pi filter, Panasonic EXC-EMT471BT (DK P9806CT)
L1, L2, L8, L9, L10, L11—100-nH variable inductor, 10 mm, Toko BTKENS-T1044Z (DK TK1402)
L3, L19—39-nH chip inductor (DK TKS1008CT.) This and all other chip inductors are from the Toko 32CS series.
L4, L5, L6, L7, L14, L15—0.33-µH chip inductor (DK TKS1019CT)
L16, L17—Ferrite SMT bead, 1206, 600 Ω at 100 MHz, Stewart HZ1206B601R (DK 240-1019-1)
L18—0.10-µH chip inductor (DK TKS1013CT)
L23, L24, L25—0.36 µH; 17 turns #26 enameled wire on a T-25-17 toroid core.
P1, P2, P3—2-pin 0.1-inch in-line header. This and the other multi-pin headers are all from the Molex 22-23-20*x*1 series, where *x* is the number of pins. (DK WM4200)
Q2—2N5109 NPN RF transistor (ME 511-2N5109)
U1, U4—MSA0686 with leads bent (HP MSA0686), or MAR-6 with leads trimmed and bent (MC MAR-6)
U2—MSA0386 with leads bent (HP MSA0386), or MAR-3 with leads trimmed and bent (MC MAR-3)
U3—TUF-1 mixer (MC TUF-1)
U5—MSA0486 with leads bent (HP MSA0486), or MAR-4 with leads trimmed and bent (MC MAR-4)


Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k=1,000.
RF Band-Pass Filter 143-149 MHz
U3 TUF-1 146-MHz Mixer
to L12 Fig 4
LO 123.3 to 129.3 MHz
RF Amp
Transmit RF Amp
TR Switch
LP Filter
U1 MSA0686
U2 MSA0386
U4 MSA0686
U5 MSA0486
Q2 2N5109
D1 HSMP-3804
D2 HSMP-3804
143-149 MHz
+10 R
+10 T
R_ATT1
R_ATT2
FIL1
FIL2
FIL5
P1
P2
P3
RF
GND
TR T
RF T
+17 dBm

ceiver, showing the receive path. This is a conventional double-conversion design. An RF amplifier builds up the signal sufficiently to overcome the first mixer noise. Two RF filters ensure that the image frequency, which is in the FM-broadcast band, is adequately rejected. The first-conversion synthesizer in the 125-MHz region is programmable in 5-kHz steps. The first mixer produces a first IF at 19.665 MHz, which is equipped with a crystal filter. This filter's bandwidth is about 12 kHz and provides image rejection for a second IF at only 15 kHz. This low-frequency second IF allows use of a low-cost audio analog-to-digital converter (ADC) to prepare the signal for the DSP.

All 15-kHz IF and audio-signal processing is done in DSP. The software BFO for SSB and CW can be programmed in steps smaller than 1 Hz; this is image-reject mixed with the IF signal to produce audio. At audio, you can select band-pass filtering[4] or a least-mean-square (LMS) denoise algorithm.[5] Following the audio processing, a DAC readies the signal for the audio-power amplifiers. At audio, a fast Fourier transform (FFT) spectrum analyzer is always operating, sending the resulting data to the PC through a serial port.

The FM detector also operates at the 15-kHz IF. No fine-tuning control is available for this mode, so it is tunable in 5-kHz steps, adequate for most applications. The spectrum-analyzer continues to operate on the detected audio for FM. The FM squelch is derived from the spectrum analyzer output by examining the level of the high-frequency noise.

The transmit path is essentially the receive path in reverse. The CW, SSB or FM signal is generated by the DSP at about 15 kHz. This signal is then double-converted to 2 meters using the same mixers and filters that are used in the receive path. A three-stage amplifier raises the power output to more than 20 mW. Provision is made to use external amplifiers to raise the power level further.

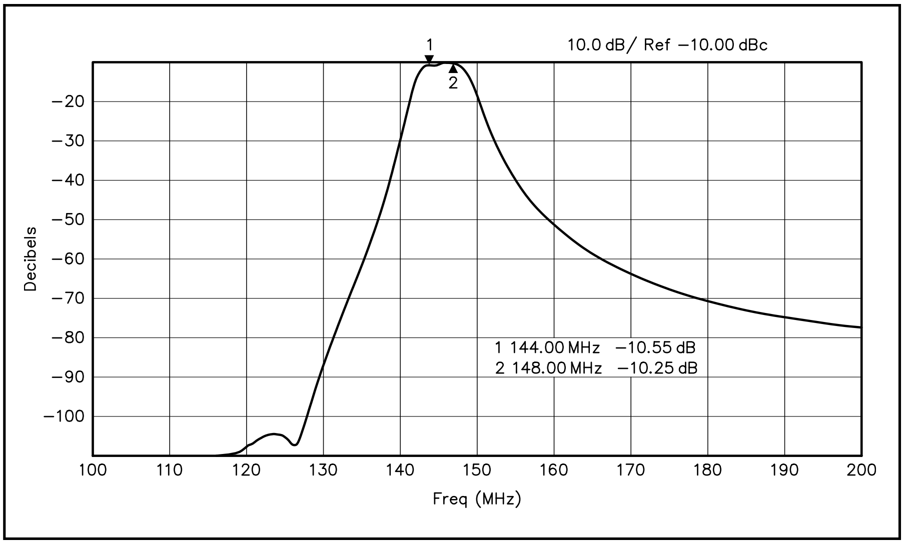


Figure 3—Measured response of the four-pole interstage filter. The greatest attenuation is on the same side as the first-conversion oscillator and the related image, yielding excellent spurious rejection during receive and transmit.

Transceiver Hardware

Figure 2 shows the received-signal path. Signals from an antenna (or a transverter) go to P1 on the main circuit board. A dual PIN diode (D2) is used for TR switching. The current through this diode is under PC control (through the DSP) and is used as an adjustable RF attenuator. This is a very simple way to achieve an attenuation range of about 18 dB. It is, however, a compromise method because the impedance seen by the following filter varies with the attenuation level. This, in turn, causes some distortion in the RF passband response. However, because the attenuation is set for minimum except when handling a strong local signal, this approach does not cause problems.

The signal passes through a two-pole filter consisting of L1, L2 and associated capacitors. This filter derives from a design by Rick Campbell, KK7B,[6] and has a 20-dB rejection 25 MHz out of band. The filter's insertion loss is about 2 dB. Two RF amplifier stages, U1 and U2, provide a gain of about 32 dB. This high gain level is needed to overcome the first-mixer noise. It does, however, make the front end more prone to overload.

Following the RF amplifier is a second dual-PIN-diode switch, D1. This, too, serves dual roles as a TR switch and as a variable attenuator for the receive path. Here is another 18 dB of RF gain control, again under control of the PC.

The four-pole bandpass filter built around L8, L9, L10 and L11 provides most RF-signal filtering. A conventional top-coupled, or Cohn, filter, it has its greatest rejection on the low-frequency side. C24 is added to produce a notch at about 126 MHz. A "gimmick" capacitor, C24's value is very small (about 0.04 pF) and consists simply of a piece of tinned wire placed near a PC-board pad. The filter response, plotted in Figure 3, shows this notch with an attenuation of about 97 dB. Rejection exceeds 85 dB for all frequencies below 128 MHz, which includes the conversion-oscillator and image frequencies. Filter-insertion loss is about 10 dB and is compensated for by the RF-amplifier gain.

A Mini-Circuits TUF-1 double-balanced mixer (U3) converts the 2-meter input signal to a 19.665-MHz IF. When transmitting, U3's signal passes through the RF filter, goes through TR switch D1 and arrives at the first transmit amplifier (U4) at a level of about –27 dBm. Two MSA amplifiers (U4 and U5) and Q2, a 2N5109 operating class A, provide a gain of about 40 dB to raise this level to +13 dBm (20 mW). The measured 1-dB compression point of this amplifier is +18 dBm, making it very linear at the operating point. A low-pass filter consisting of L19 and three capacitors (C51 through C53) reduces the transmitter harmonic levels. The transmitter output does not go directly to the PIN-diode TR switch D2. Instead, the lines go to a pair of connectors identified as P2 and P3 that attach to rear-panel jacks. Such routing allows the transceiver to be connected to a transverter or a power amplifier without the need for another TR switch. P2 and P3 can be connected together for stand-alone QRP operation.

First and Second IF

As shown in Figure 4, the receive path accepts a 19.665-Hz signal from the first mixer, U3. A four-pole crystal filter using low-cost standard crystals (X1 through X4) provides selectivity. The series-crystal configuration used has a rejection notch at a frequency above the passband.[7] This rejects the image before the second mixer. L12 and L13 along with C25 and C29 form **L** networks that step up the 50-Ω impedance to the 1.5 kΩ required by the filter. Figure 5 is the measured response of this crystal filter. The plot does not extend far enough to show the out-of-band response, but at the image frequencies above 19.690 MHz, the rejection is greater than 70 dB; passband insertion loss is just over 1 dB.

A second TUF-1 double-balanced mixer, U15, converts the received signal to the next IF at 15 kHz. A three-pole, elliptical, low-pass filter, built around L32, restricts the band of signals passed on to the IF amplifier. The cutoff frequency of this filter is about 28 kHz.

Next, the received signal is amplified by a 50-dB low-noise amplifier using Q1 and U10A. This circuit is essentially the same as that used by KK7B in his R2 receiver,[8] but the roots of the grounded-base IF appear to go back to Roy Lewallen, W7EL.[9] No active power-supply decoupling is needed because the lowest frequency amplified (set by C32) is a few kilohertz. D4 and R15 disable Q1 during transmit. This circuit provides flat response to frequencies well beyond 20 kHz and provides the gain needed to drive the DSP board ADC. CMOS switches U12A and U12B determine whether the ADC is connected to the IF amplifier for receive or to the microphone for transmit.

Received signals are converted to digital

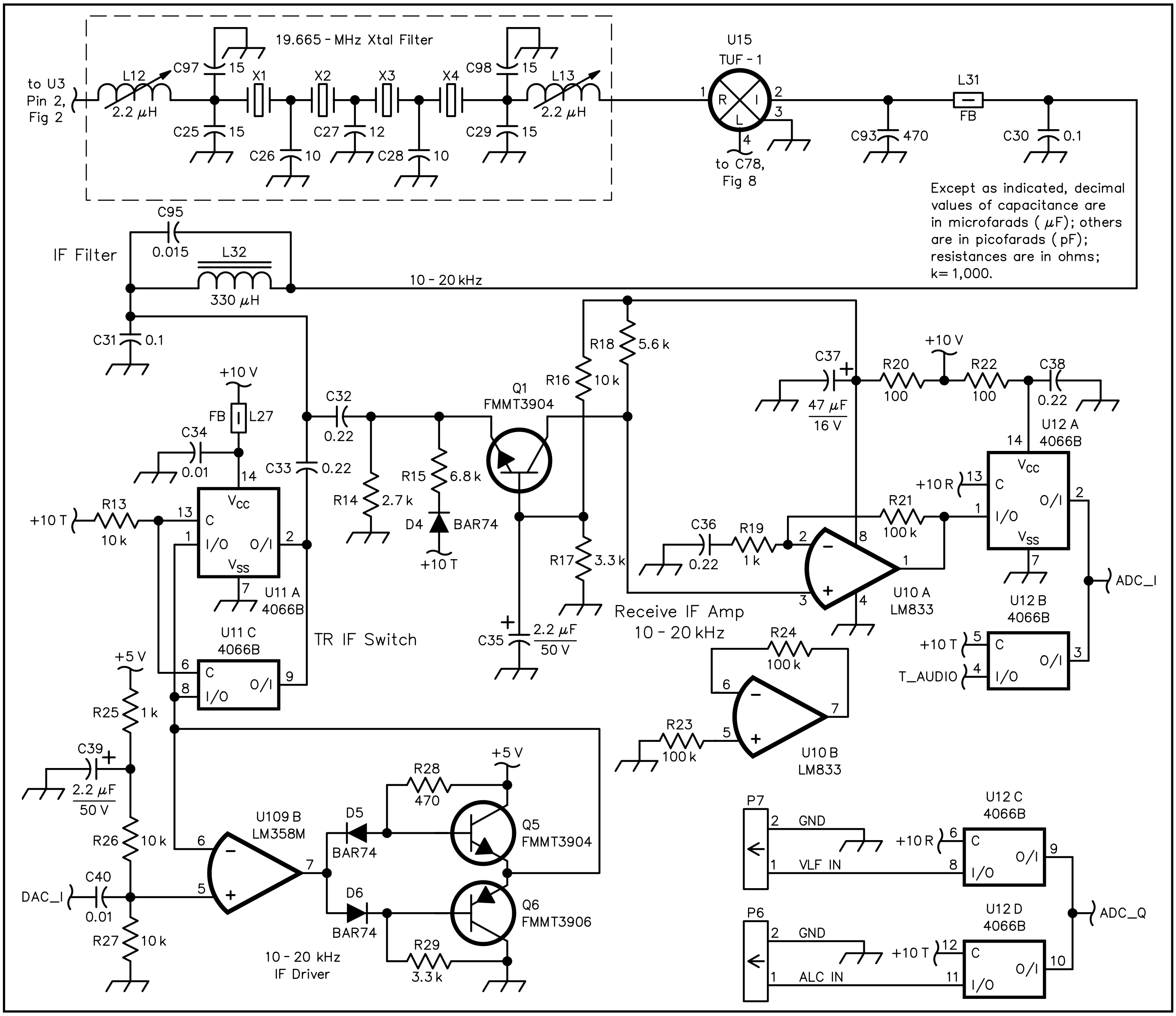


Figure 4—First- and second-IF circuitry. The crystal filter and second mixer, U15, are used for transmit and receive. The IF amplifier is bypassed by CMOS switches for transmit. Some component designators differ from *QST* style.

C35, C39—2.2-µF, 50-V surface-mount electrolytic (DK PCE3046CT.) This and the other surface-mount electrolytic capacitors are from the Panasonic HB series.
C37—47-µF, 16-V surface-mount electrolytic (DK PCE3033CT)
D4, D5, D6—BAR74 diode (DK BAR74ZXCT)
L12, L13—2.2-µH variable inductor, 10 mm, Toko BTKANS-9447HM (DK TK1413)
L27, L31—Ferrite SMT bead 1206 (DK 240-1019-1)
L32—330 µH; 52 turns #32 enameled wire on an Amidon F-22-43 toroid core.
Q1, Q5—FMMT3904 NPN transistor, SOT-23 (DK FMMT3904CT)
Q6—FMMT3906 PNP transistor, SOT-23 (DK FMMT3906CT)
U10—LM833M low-noise op amp (DK LM833M)
U11, U12—CD4066BCM (DK CD4066BCM)
U15—TUF-1 mixer (MC TUF-1)
X1, X2, X3, X4—19.6608-MHz crystal, Epson CA-301 type (DK SE3437)

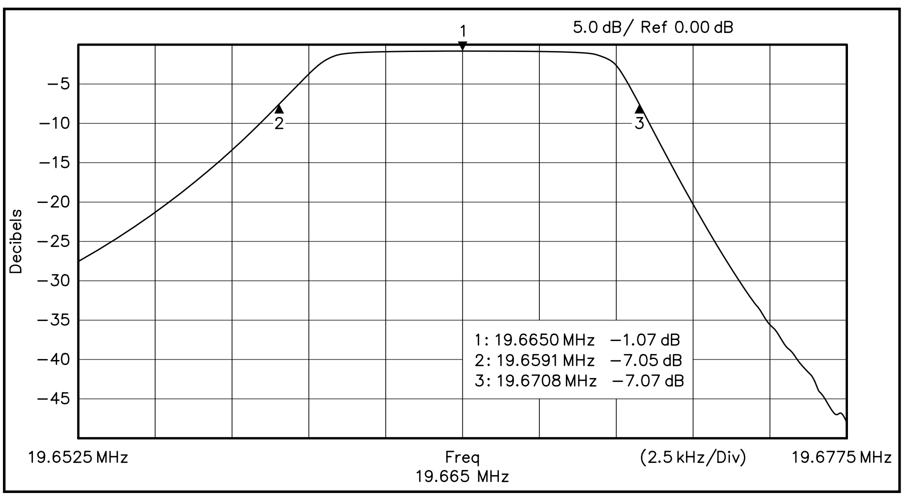


Figure 5—Measured response of the four-pole crystal filter. The 6-dB bandwidth is about 12 kHz to allow use on FM. For this IF, the conversion oscillator is on the high-frequency side at 19.680 MHz. This provides the best spurious rejection because the filter drops off fastest on the high-frequency side.

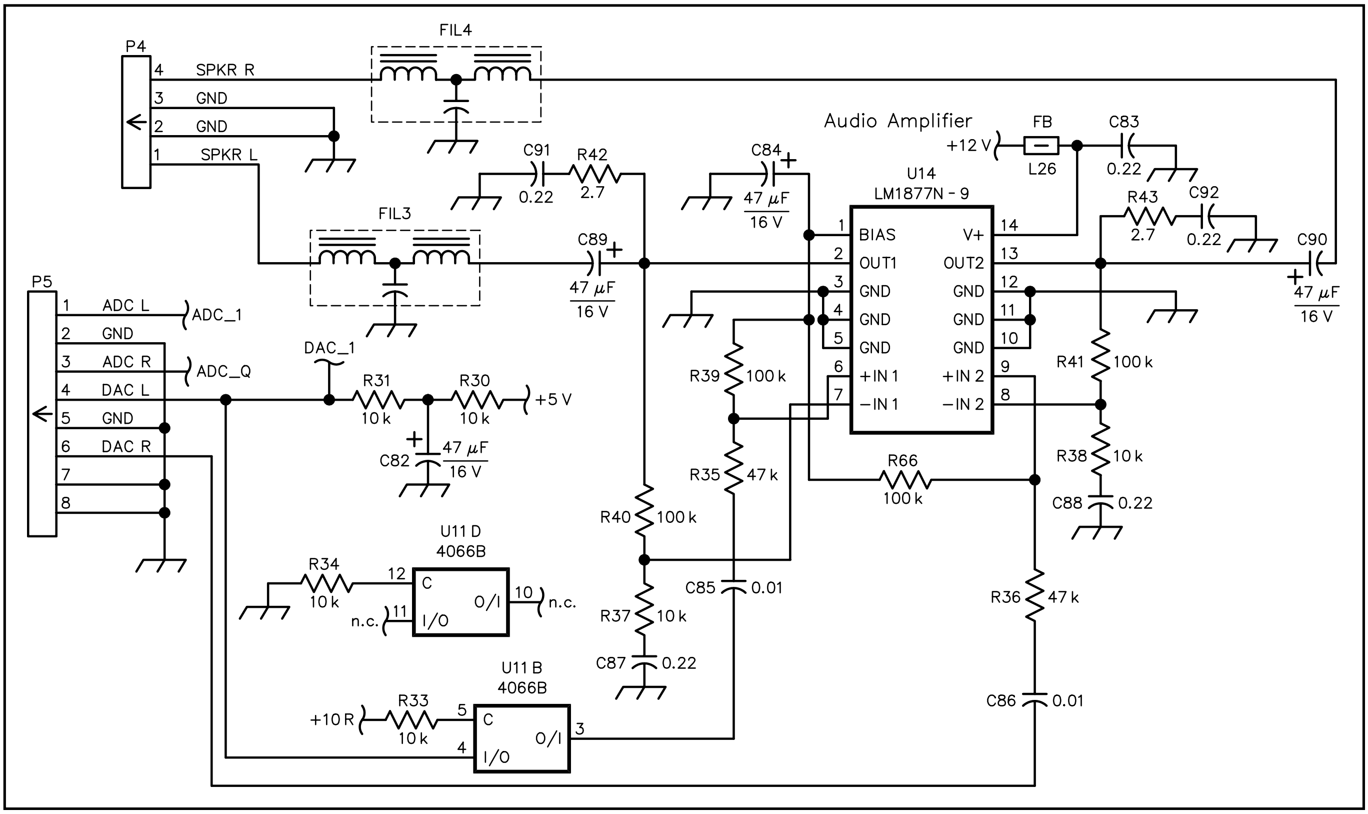


Figure 6—U14 is a dual, integrated audio-power amplifier. Both channels carry the same audio, although they could be designed for binaural operation because they are driven by a dual DAC. See the sidebar "Parts Sources" for details on component sources and notes on the components.

C82, C84, C89, C90—47-µF, 16-V surface-mount electrolytic (DK PCE3033CT)

FIL3, FIL4—470-pF pi filter (DK P9806CT)

L26—Ferrite SMT bead 1206 (DK 240-1019-1)

U14—LM1877N-9 dual audio amplifier (DK LM1877N-9)

data by the ADC operating at a 48-kHz rate. It is important that the alias frequencies above this be removed. This function is handled by filtering that is part of the DSP-board ADC. (All remaining processes for detection and signal filtering are performed in the DSP and are discussed later.)

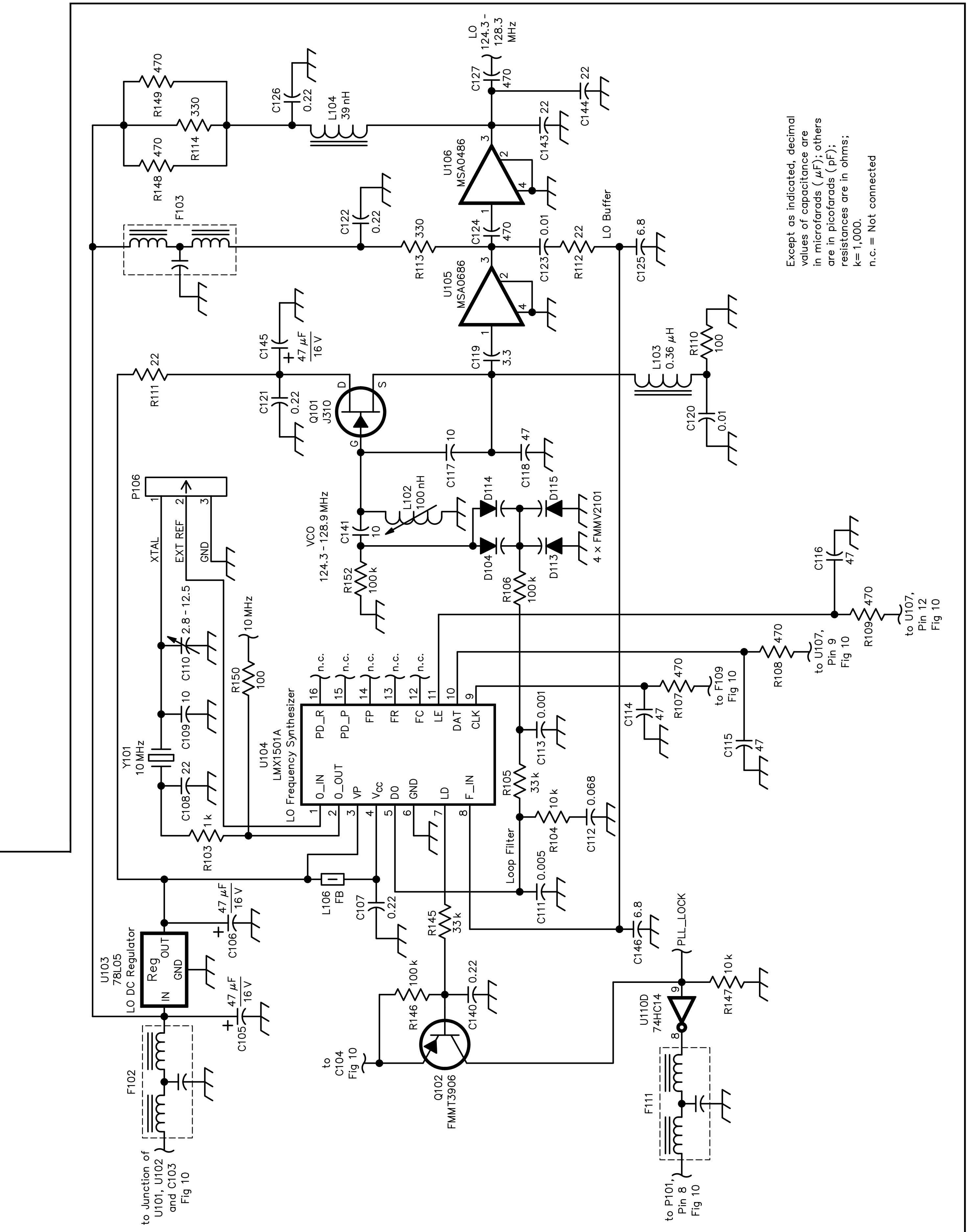
Following the DSP is a DAC on the DSP board that includes low-pass filtering of the analog signals. Next (see Figure 6) is a dual audio amplifier (U14) that raises the audio-signal amplitude to speaker level. (At this time, the audio sent to both channels is identical, but the use of binaural audio remains a future possibility.)

The transmitted signal in the 15-kHz range is produced by the DAC on the DSP board. In order to drive the 50-Ω port of mixer U15 (Figure 4), I added an amplifier consisting of op amp U109B and a pair of current-boosting transistors, Q5 and Q6. Here we have a case where the 50-Ω IF impedance of the mixer is not very convenient. Adding to the IF drive needs is the loss of the CMOS TR switch *on* resistance. To reduce the *on* resistance, two sections of 4066 switch U11 are connected in parallel. All of this gets a −10-dBm signal to the mixer.

From here, the transmit signal goes through the crystal filter to mixer U3 (Figure 2), ready to be converted to the output frequency. As I pointed out previously, the crystal filter has particularly high attenuation on the high-frequency side of the passband. This provides good attenuation of the 19.68-MHz conversion-oscillator signal that gets transmitted 15 kHz away from the desired output signal. In addition, the TUF-1 mixer has good balance to further reduce the level of this signal.

Figure 7—(See facing page) Frequency synthesizer for the first-conversion oscillator. This synthesizer has a 5-kHz step size.

C105, C106, C145—47-µF, 16-V surface-mount electrolytic (DK PCE3033CT)
C113— 0.001-µF NP0 0805 ceramic-chip capacitor (ME 140-CC501N102J)
C111—0.005-µF film capacitor (DK P4720.) This and the other stacked-film capacitors are from the Panasonic V-series.
C112—0.068-µF film capacitor (DK P4731)
D104, D113, D114, D115—FMMV2101 Varicap diode (DK FMMV2101CT)
FIL102, FIL103, FIL111—470-pF pi filter (DK P9806CT)
L102—100-nH variable inductor, 10 mm (DK TK1402)
L103—0.36 µH; 17 turns, #26 enameled wire on a T-25-17 toroid core.
L104—39-nH chip inductor (DK TKS1008CT)
L106—Ferrite SMT bead 1206 (DK 240-1019-1)
Q101—J310 N-channel FET (NE J310) or MPF102 (RS 276-2062)
Q102—FMMT3906 PNP transistor, SOT23 (DK FMMT3906CT)
U103—78L05 voltage regulator, TO-92 (DK LM7805LACZA)
U104—LMX1501A frequency synthesizer (DK LMX1501A)
U105—MSA0686 with leads bent (HP MSA0686), or MAR-6 with leads trimmed and bent (MC MAR-6)
U106—MSA0486 with leads bent (HP MSA0486), or MAR-4 with leads trimmed and bent (MC MAR-4)
U110—MM74HC14M (DK MMHC14M)
X101—10-MHz crystal, 20-pF load capacitance, CR holder. Needed only if an external reference is not available. (IX 433463 10.0000 MHz)



Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k=1,000.
n.c. = Not connected
LO 124.3 - 128.3 MHz
LO Buffer
U106 MSA0486
U105 MSA0686
Q101 J310
VCO 124.3 - 128.9 MHz
4 × FMMV2101
U104 LMX1501A LO Frequency Synthesizer
Loop Filter
P106
XTAL
EXT REF
GND
Y101 10 MHz
U103 78L05 LO DC Regulator
Reg
L106 FB
PLL_LOCK
U110D 74HC14
Q102 FMMT3906
to Junction of U101, U102 and C103 Fig 10
to C104 Fig 10
to P101, Pin 8 Fig 10
to U107, Pin 12 Fig 10
to U107, Pin 9 Fig 10
to F109 Fig 10

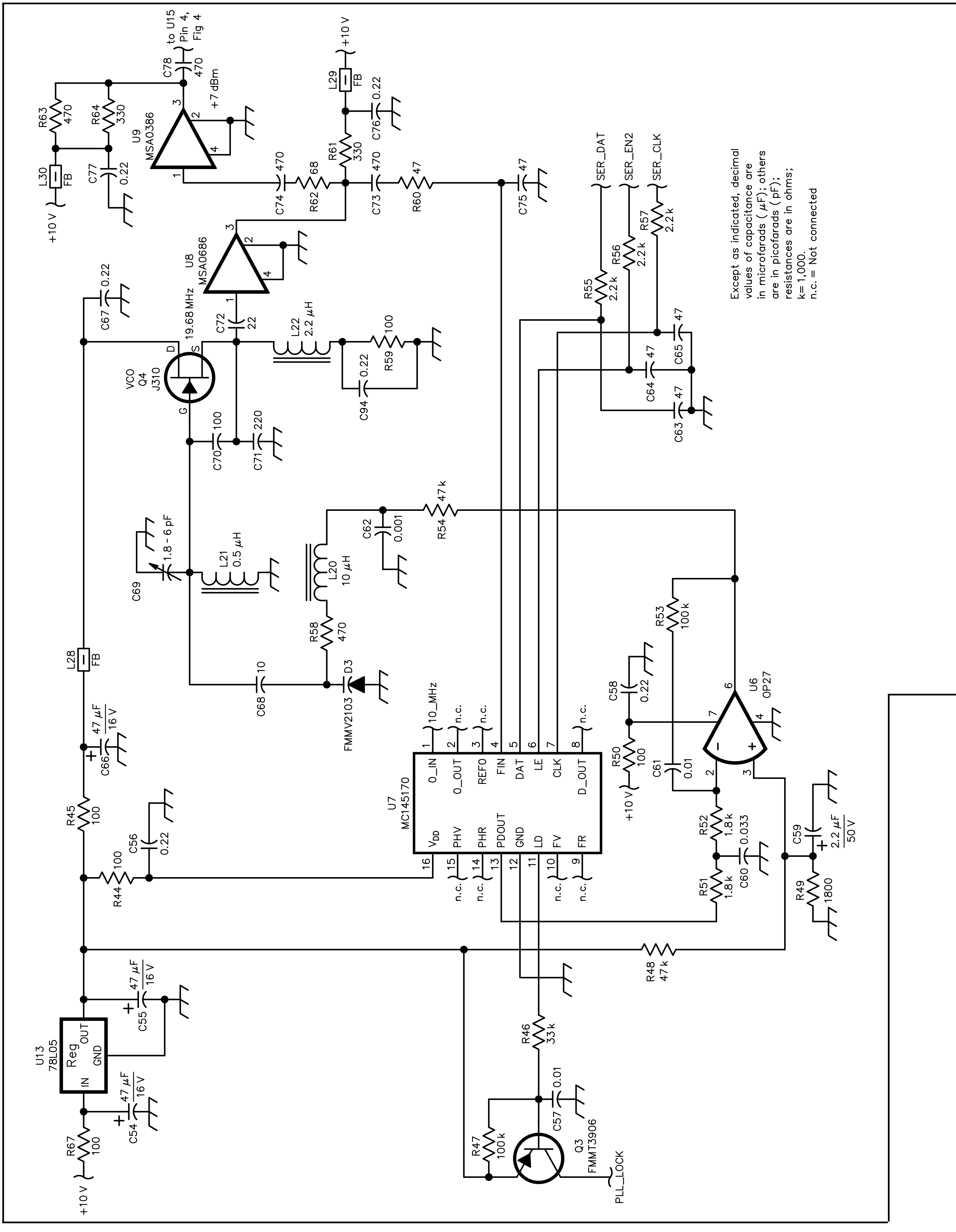

Except as indicated, decimal values of capacitance are in microfarads (μF); others are in picofarads (pF); resistances are in ohms; k=1,000. n.c. = Not connected
U7 MC145170
U6 OP27
U8 MSA0686
U9 MSA0386
U13 78L05
VCO Q4 J310
19.68 MHz
Q3 FMMT3906
D3 FMMV2103
+7 dBm
to U15 Pin 4, Fig 4
SER_DAT
SER_EN2
SER_CLK
PLL_LOCK
+10 V

Figure 8—Second conversion-oscillator frequency synthesizer. This synthesizer operates at a fixed frequency of 19.68 MHz with a 20-kHz reference frequency.

C54, C55—47-µF, 16-V surface-mount electrolytic (DK PCE3033CT)
C59—2.2-µF, 50-V surface-mount electrolytic capacitor (DK PCE3046CT)
C60—0.033-µF film capacitor (DK P4720)
C61—0.01-µF film capacitor. (DK P4713)
C62— 0.001-µF NP0 0805 ceramic-chip capacitor (ME 140-CC501N102J)
C69—1.8- to 6-pF variable ceramic capacitor (ME 24AA070)
D3—FMMV2103 Varicap diode (DK FMMV2103CT)
L22—2.2-µH chip inductor (DK TKS1029CT)
L20—10-µH chip inductor (DK TKS1037CT)
L21—0.5 µH, 12 turns #26 enameled wire on T-37-6 toroid core. Adjust inductance by moving turns.
L22—2.2-µH chip inductor (DK TKS1029CT)
L28, L29, L30, L31—Ferrite SMT bead 1206 (DK 240-1019-1)
Q4—J310 N-channel FET (NE J310) or MPF102 (RS 276-2062)
Q3—FMMT3906 PNP transistor, SOT23 (DK FMMT3906CT)
U6—OPA27GU Burr-Brown op-amp (DK OPA27GU)
U7—MC145170D frequency synthesizer (NE MC145170D)
U8—MSA0686 with leads bent (HP MSA0686), or MAR-6 with leads trimmed and bent (MC MAR-6)
U9—MSA0386 with leads bent (HP MSA0386), or MAR-3 with leads trimmed and bent (MC MAR-3)
U13—78L05 voltage regulator, TO-92 (DK LM780L5ACZA)

Parts Sources

Parts used in this transceiver are available from one or more of the following sources. Source abbreviations used in the parts lists precede the addresses.

DK: Digi-Key Corp
701 Brooks Ave S
Thief River Falls, MN 56701-0677
Tel 800-344-4539, 218-681-6674, fax 218-681-3380
http://www.digikey.com

IX: International Crystal Mfg Co
PO Box 26330
10 N Lee, Oklahoma City, OK 73126-0330
Tel: 800-725-1426, 405-236-3741, fax 800-322-9426

HP: Hewlett-Packard components are distributed by many companies such as Future Electronics, which has outlets in many cities
Tel: 800-655-0006
http://www.future.ca/links/

MC: Mini-Circuits Laboratory
PO Box 350166
Brooklyn, NY 11235-0003
Tel: 800-654-7949
http://www.minicircuits.com/

ME: Mouser Electronics
958 N Main St
Mansfield, TX 76063-4827
Tel 800-346-6873, 817-483-4422, fax 817-483-0931
sales@mouser.com; **http://www.mouser.com**

NE: Newark Electronics
4801 N Ravenswood Ave
Chicago, IL 06040-4496
Tel: 800-463-9275, 312-784-5100, fax 312-907-5217; **http://www.newark.com**

RS: RadioShack—see your local distributor.
RadioShack FAXBACK number: 800-323-6586 (24 hrs, 7 days)

Conversion Oscillators

The first-conversion oscillator, shown in Figure 7, ranges in frequency from about 124.3 to 128.4 MHz in 5-kHz steps. This is a simple single-loop synthesizer using U104, which contains the programmable frequency dividers and a phase detector. The VCO, Q101, is tuned by four varactors (D104 and D113-D115) in the standard parallel, reverse-connected configuration that improves the resonator Q at low tuning voltages. A separate 5-V regulator, U103, prevents interaction with other parts of the circuit through the power source. A pair of IC amplifiers, U105 and U106, raise the power level to 7 dBm and prevent strong signals from getting back to the VCO. At a 10-kHz offset, the phase noise is about –105 dBc.

A similar circuit is used for the 19.68-MHz fixed-frequency second-conversion oscillator (see Figure 8). This synthesizer uses an active loop filter built around op amp U6. The reference frequency of 20 kHz—along with the relatively low operating frequency—results in a clean spectrum. Buffers U8 and U9 produce a +7-dBm output level. At first, I tried using an LMX1501A synthesizer IC as is used for the first-conversion oscillator. It would appear to lock, but the output spectrum was very poor. After much experimentation, I found that the '1501A cannot be used below about 100 MHz because of the counter circuitry employed, although that restriction is not mentioned in the data sheets. (Eventually, I would like to use the same IC at U7 and U104.)

Both synthesizers used in the transceiver are referenced to a common 10-MHz signal. An internal crystal oscillator is ordinarily used and provides good frequency stability. For more-stringent applications, provision is also made for an external frequency reference. The availability of GPS frequency standards[10] allows us to achieve stability of a fraction of a hertz at 144 MHz.

Next Month

In Part 2, I'll cover the control functions, and talk about the software and transceiver assembly.

Notes

[1]Larry Wolfgang, WR1B, "Kachina 505DSP HF Transceiver," *QST*, Product Review, May 1998, pp 63-69, and Steve Ford, WB8IMY, "ICOM IC-PCR1000 Computer-Controlled Communication Receiver," *QST*, Product Review, Jul 1998, pp 62-65.

[2]Stan Horzepa, WA1LOU, "Softradio: The Future Is Now," *QST*, Digital Dimension, Jul 1997, p 88.

[3]The EZ-Kit Lite uses the ADSP2181 16-bit, fixed-point DSP produced by Analog Devices, Norwood, Massachusetts. The board includes an AD1847 dual 48-kHz ADC and DAC. Supplied with the board is complete development software, limited documentation and several demonstration programs. The cost is about $90. Information on the board, DSP and distributors is available at the Analog Devices Web site **http://www.analog.com**.

[4]All narrowband filtering is done at audio. The last conversion from IF to audio is done with DSP and has very high sideband rejection. For this reason, the filtering at audio is fully equivalent to IF filtering. In terms of dynamic range, the audio and IF are both 16-bit processes and can achieve the same ranges. With the current hardware, the ADC is the weak link in dynamic range for signals that are within the passband of the crystal filter.

[5]The LMS denoise algorithm is widely used to reduce the noise on signals by seeking out the coherent portions of the signal. The implementation in this transceiver is based on the article by Johan Forrer, KC7WW, "A DSP Based Audio Signal Processor," *QEX*, Sept 1996, pp 8-13. This project also uses the EZ-Kit Lite and has other useful information on programming this board.

[6]Rick Campbell KK7B, "A Single-Board No-Tune Transceiver for 1296", *Microwave Update 1993*, pp 17-38.

[7]The crystal filter is based on the principles set forth in the article by Wes Hayward, W7ZOI, "A Unified Approach to the Design of Crystal Ladder Filters," *QST*, May 1982, pp 21-27. Minor optimization was done with the *ARRL Radio Designer* program (available from Publication Services; see page 10 of this issue).

[8]Rick Campbell, KK7B, "High Performance Direct Conversion Receivers," *QST*, Aug 1992, pp 19-28. The amplifier circuit is discussed in detail in the follow-up note "Direct-Conversion Receiver Noise Figure," Technical Correspondence, *QST*, Feb 1996, pp 82-84.

[9]Roy Lewallen, W7EL, "An Optimized QRP Transceiver," *QST*, Aug 1980, pp 14-19.

[10]Brooks Shera, W5OJM, "A GPS-Based Frequency Standard," *QST*, July 1998, pp 37-44.

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