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The *Star-10* Transceiver — Part 3

In Part 3 of this series we conclude with the remaining circuits used in this high-performance transceiver, along with the final test results, which support the specifications presented in Part 1.

KW7CD Photo

This photo shows a back view of the *Star-10* transceiver prototype during final assembly. The sensory electronics are shown on the left, the power linear amplifier assembly (with fans on the heat sink) is in the center, and the master reference unit (MRU) is on the right.

Mission

The *Star-10* transceiver has been a unique research experience into understanding what can be done from the laws-of-physics point of view in receiver and transceiver dynamic range performance. This research has been performed over a period of five years, with parts, technologies and packaging means available to me at the time. The transceiver has been implemented with some unique parts that may no longer be available. The *Star-10* development has been a purely scientific endeavor intended primarily to understand what could be done to achieve ultimate receiver performance. Although the results have been outstanding, slightly better results may be possible using newer technologies and parts. The *Star-10* project was not intended as a product. Its duplication is probably not economically feasible.

Errata

We regret that several errors have crept into the first two parts of this series. In Part 1, the power supply specification incorrectly listed the TX max dc power as 800 VA. The correct specification is 450 VA. Also in Part 1, the caption with the lead photo of the *Star-10* transceiver indicated that the electrical and mechanical design features a modular approach using eighteen double sided, plated through printed circuit boards housed in machined, *irradiated* aluminum assemblies. That text should have said that the circuit boards are housed in machined, *irridated* aluminum assemblies. Irridation is a chemical process by which the aluminum is etched to give it a frosty, textured surface that is fingerprint resistant.

In Part 2, an incorrect photo swap occurred after the issue went to the printer. The lead photo for Part 2 was intended to be a view inside the radio with the top cover removed. Instead, that photo shows a view inside the radio with the bottom cover removed. The caption does not describe what you see in the photo. (The correct photo — and caption — appear in the version of the article posted to the *QEX* Web site at **www.arrl.org/qex/2008/03/Drentea.pdf**. The correct photo is also reproduced here as Photo A. Visible from the left are the FSYNTH assembly (left side panel), the IF75BC assembly (top left), the automatically switched half-octave receiver band-pass and transmitter high power, low-pass filter bank assembly, and the DFCB command and control assembly and keypad mounted on the back of the front panel. Front panel, side panels, top and bottom are removable, allowing access to the assemblies.

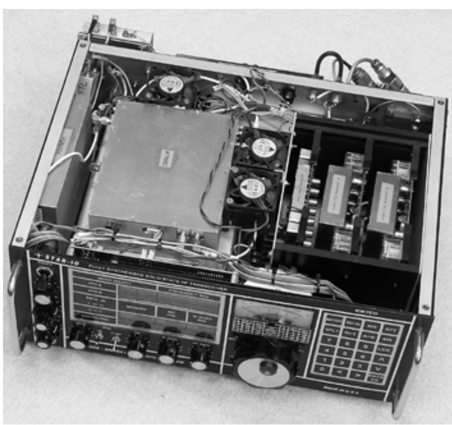


Photo A

On page 33 of Part 2, near the top of the center column the text says "The synthesizer in Star-10 goes a step further by generating the LO frequencies at ten times the required frequency range, or 770 MHz to 1050 MHz for improved phase noise performance after a division by 10, which facilitates a 6 dB improvement at the divided down 77 MHz to 105 MHz." The improvement in phase noise performance is 20 dB, not 6 dB—*Ed.*

Introduction

In Part 1 of this series, I presented a system design criteria for a modern double conversion transceiver, namely the *Star-10*. [Part 1 appeared in the Nov/Dec 2007 issue of *QEX*. That issue is currently out of print, but the *Star-10* article was the sample article from that issue. It is available on the *QEX* Web site at: **www.arrl.org/qex/2007/11/drent.pdf**. — *Ed.*] A complete discussion of how the transceiver works was also presented along with an introduction to the technologies used in the transceiver development. Also, in Part 1, I presented a set of predicted and actual performance specification numbers for the developed transceiver. A block diagram of the entire system was introduced in Figure 2 and ample composite dynamic range and system spurious analysis were presented in Figures 3 A, B, C and 4 A and B. In Part 2 of this series, I discussed in detail, the design and development of several major assemblies for the *Star-10* transceiver, particularly the IF75BC, BILAT AMP, FL75, FSYNTH, MRU, Half Octave Filter Banks, IF9BC, DFCB and the IF9RX. [Part 2 of this series was published in the Mar/Apr 2008 issue of *QEX*. That part of the article is also available on the *QEX* Web site at: **www.arrl.org/qex/2008/03/Drentea.pdf** — *Ed.*] I will next discuss the remaining assemblies, along with final thoughts regarding their development, key performance results and lessons learned from the entire project experience.

Product Detector Audio Frequency Assembly (PDAF)

Referring to Figure 2 from Part 1, the PDAF assembly provides final receiver conversion to audio frequencies of the detected signals after they have been filtered and conditioned (AGCed) for final detection in all modes of operation. A properly shifted BFO signal is provided from FSYNTH depending on the mode being used and commanded through the DFCB assembly. The PDAF assembly contains a high-level product detector using a class II mixer, a BFO buffer amplifier (another CA2832) providing injection to both the product detector and the transmitter mixer in IF9TX. An audio amplifier follows the product detector. In addition to audio amplification, it provides audio mixing functions in order to integrate audio feedback signals from the microprocessor as well as the CW side tone signals. A schematic diagram of the PDAF assembly is shown in Figure 27. The actual PDAF assembly implementation is shown in Figure 28.

Looking at Figure 27, the BFO signal coming from FSYNTH enters the PDAF assembly at J1. It is immediately amplified by the class A amplifier, U1, another CA2832 unit. This amplified BFO signal is further split by A1, which is a Mini-Circuits PSC2-1 part. Half the signal is passed on to J3, which distributes it to the transmitter mixer on IF9TX. The other half goes through a pad made of R4, R5 and R6 and is input to MIX 1, a high-level class II, SRA-1H mixer that serves as the product detector. This mixer was purposely selected for this function, as it is suitable for baseband frequency response output, compatible with audio frequencies, and has a reported IP3 of +28 dBm.

The conditioned 9 MHz IF receiver signal coming from IF9RX is input to the product detector mixer at J2. The mixed down audio product is matched and filtered via L1, C4, R7, R8, C5, L2 and C6, and is further processed by Q1 and U2 to be finally presented to U3, a TDA2003 audio block and output at J4-B. The L2, C5 and C6 audio low-pass filter is intended to suppress noise beyond 3 kHz. Tones from the CW side tone generator along with various feedback tones coming from the DFCB command and control

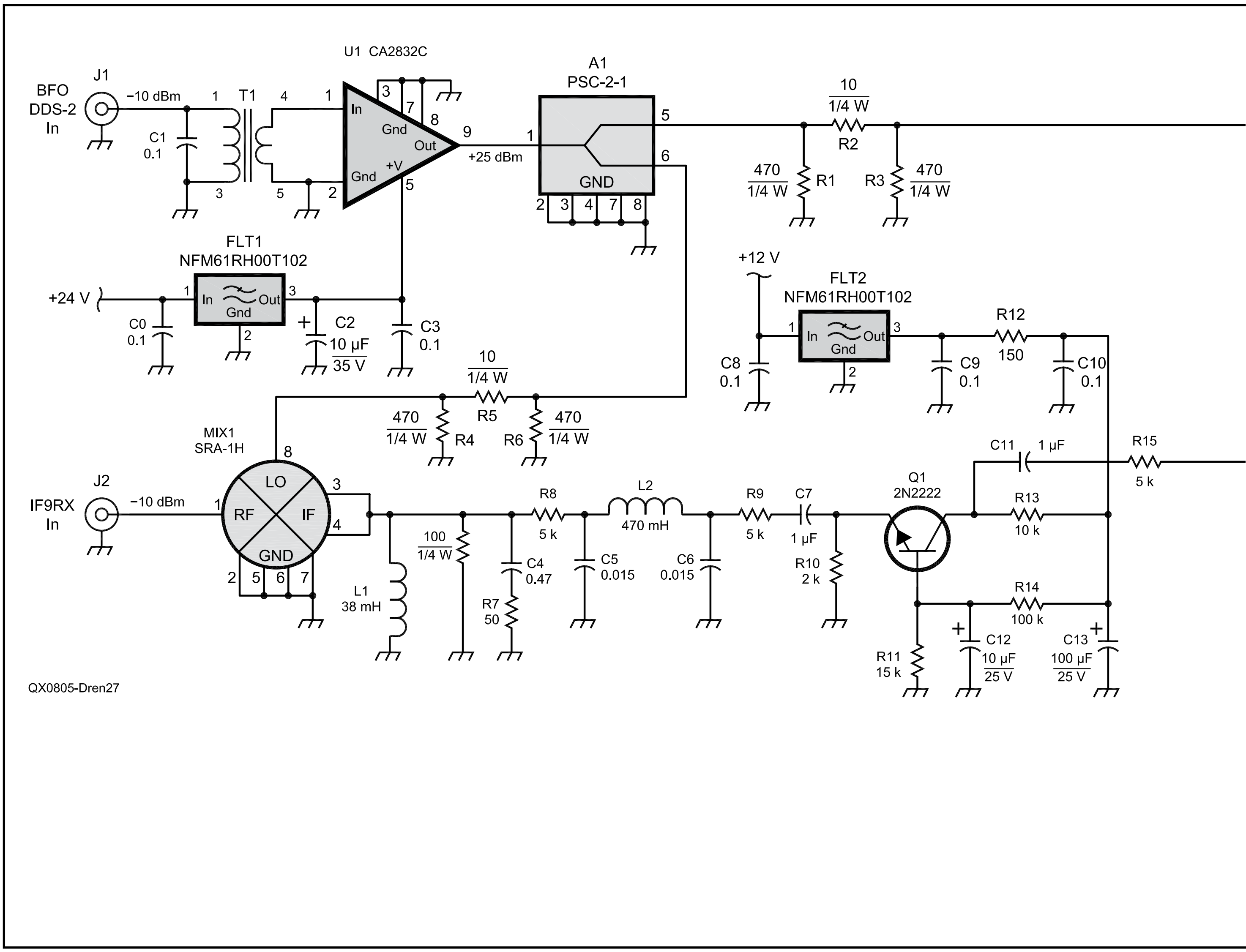


Figure 27 — Schematic diagram of the product detector audio frequency (PDAF) assembly.

assembly are audio-mixed and injected in this circuit via the J4-A connector as shown. In addition, volume control wires from the front panel audio control are input via this connector along with the MUTE signal from the T/R assembly, which silences the receiver via Q2 when transmitting.

Digital Signal Processing

Digital signal processing (DSP) can be implemented with the *Star-10* at baseband audio frequencies as shown in Figure 2 of Part 1. This can add further refinement to the transceiver's performance.

For DSP, I used the Silicon Pixels 16-bit DMA — Chroma SOUND, Audio DSP software, V 0.19 (**barberdsp.com/**). This requires the addition of a PC with a full duplex 16 bit sound card with the software installed.

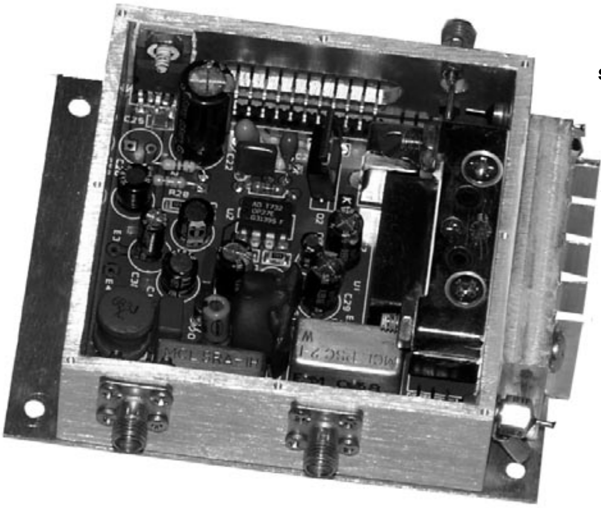
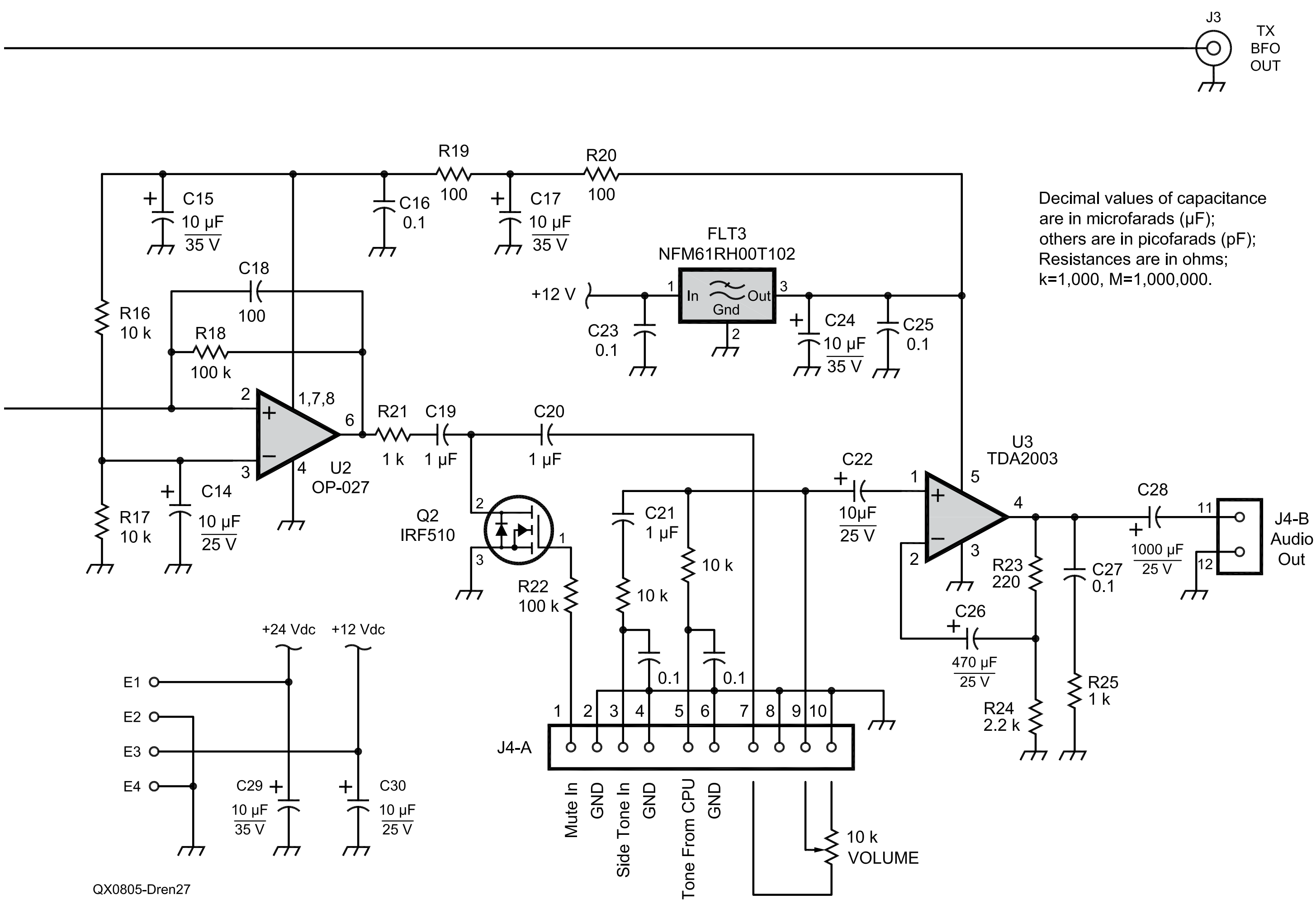


Figure 28 — This photo shows the implementation of the PDAF assembly. Visible at the right is the class A amplifier (another CA2832), which buffers the BFO signals for both, the receiver product detector mixer, as well as the transmitter mixer. The product detector is a high level class II mixer (SRA-1H), which is visible at the bottom right. The audio amplifier chip (TDA2003) is visible at the top left side of the assembly. Various other circuits are also visible.



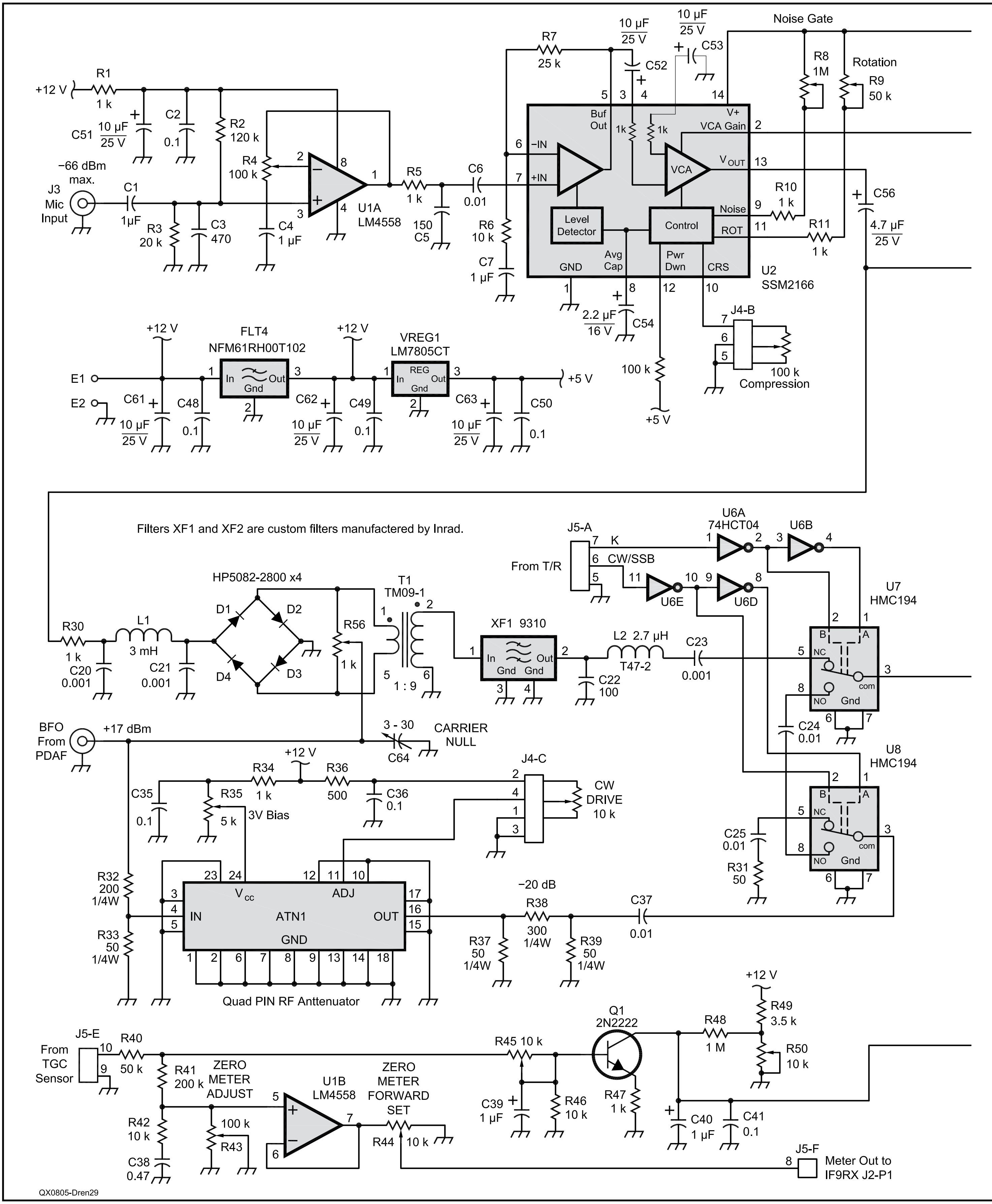
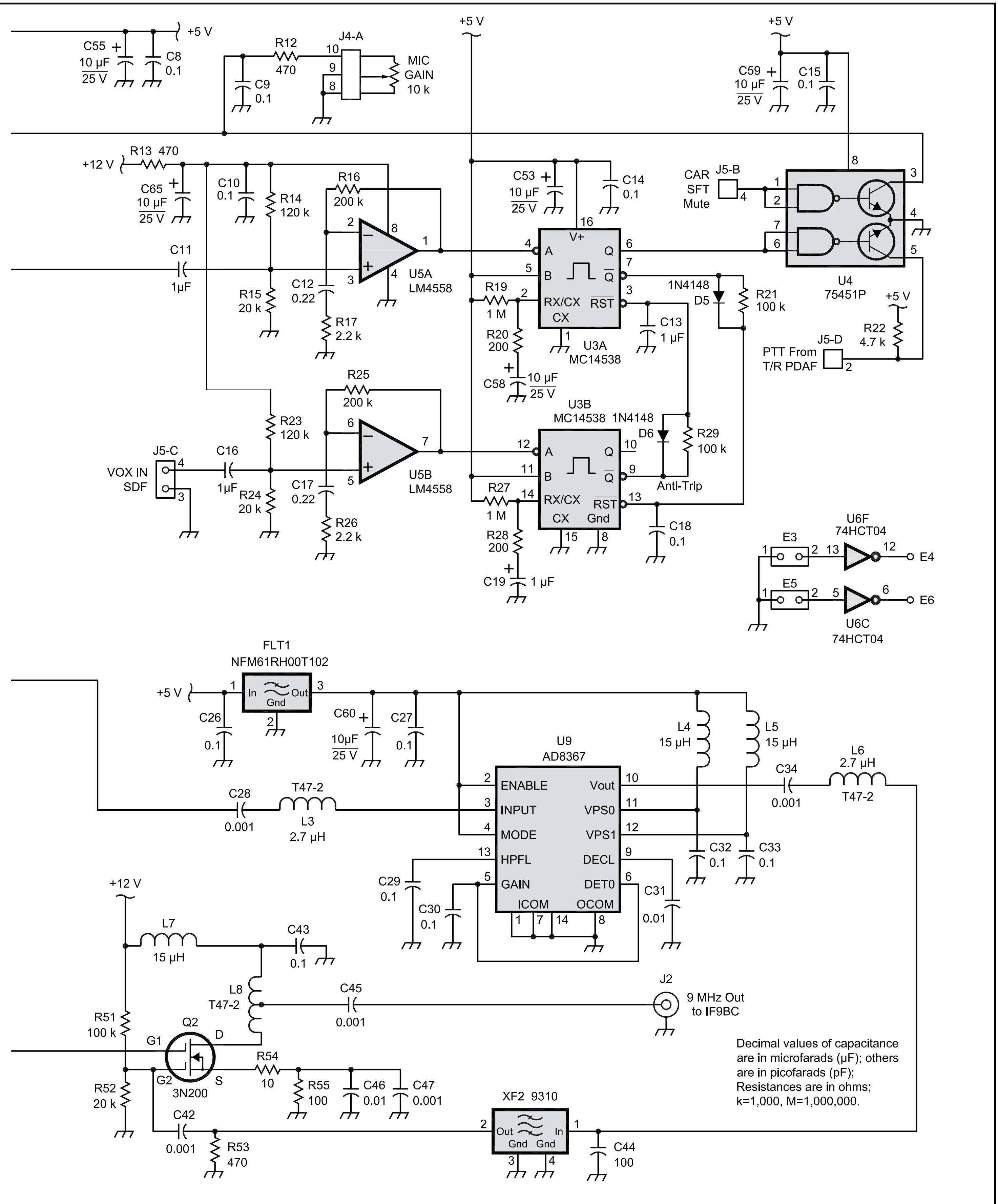


Figure 29 — Schematic diagram of the IF9TX assembly. IF9TX performs all key transmitting functions as commanded by DFCB and using the BFO signals from the FRU — FSYNTH.


+5 V
C55
10 µF
25 V
C8
0.1
R12
470
J4-A
10
9
8
MIC
GAIN
10 k
C9
0.1
+5 V
+5 V
C59
10 µF
25 V
C15
0.1
+12 V
R13 470
C65
10 µF
25 V
C10
0.1
R14
120 k
R16
200 k
2
8
1
C53
10 µF
25 V
C14
0.1
16
V+
CAR
SFT
Mute
J5-B
4
1
2
3
4
7
6
5
8
U4
75451P
C11
1µF
R15
20 k
C12
0.22
3
4
U5A
LM4558
R17
2.2 k
4
A
Q
6
5
B
Q
7
R19
1 M
2
RX/CX
CX
RST
3
1
U3A
MC14538
R20
200
C58
10 µF
25 V
C13
1 µF
1N4148
D5
R21
100 k
+5 V
R22
4.7 k
J5-D
PTT From
T/R PDAF
2
R25
200 k
U3B
MC14538
1N4148
D6
R29
100 k
R23
120 k
6
7
J5-C
VOX IN
SDF
4
3
C16
1µF
R24
20 k
C17
0.22
5
U5B
LM4558
R26
2.2 k
12
A
Q
10
11
B
Q
9
R27
1 M
14
RX/CX
RST
13
CX
Gnd
15
8
Anti-Trip
R28
200
C19
1 µF
C18
0.1
U6F
74HCT04
E3
1
2
13
12
E4
E5
1
2
5
6
E6
U6C
74HCT04
FLT1
NFM61RH00T102
+5 V
1
In
Out
Gnd
3
2
C26
0.1
C60
10µF
25 V
C27
0.1
U9
AD8367
L4
15 µH
L5
15 µH
L6
2.7 µH
T47-2
C34
0.001
C28
0.001
T47-2
L3
2.7 µH
2
ENABLE
Vout
10
3
INPUT
VPS0
11
4
MODE
VPS1
12
13
HPFL
DECL
9
5
GAIN
DET0
6
ICOM
OCOM
1
7
14
8
C32
0.1
C33
0.1
C29
0.1
C30
0.1
C31
0.01
+12 V
L7
15 µH
C43
0.1
L8
T47-2
C45
0.001
J2
9 MHz Out
to IF9BC
R51
100 k
Q2
G1
D
G2
S
3N200
R54
10
R55
100
C46
0.01
C47
0.001
R52
20 k
C42
0.001
R53
470
XF2 9310
2
Out
In
1
Gnd
Gnd
3
4
C44
100
Decimal values of capacitance
are in microfarads (µF); others
are in picofarads (pF);
Resistances are in ohms;
k=1,000, M=1,000,000.

This excellent software is intended for *Windows 95/98/NT/2000/XP* and can provide a lot of additional functionality for the transceiver. Among the functions are: Noise reduction of SSB signals, automatic notch filtering for removing tones, band pass, low pass, high pass, and band stop (manual notch) filters. Filters can be user-defined, using the built-in graphical filter designer. Additional functions can be selected. Among them are pre-defined filters. One can just drag a filter from the design window to an empty button, and a new filter bandwidth can be designed into the menu. In addition, an AGC function can be selected. Since there is no such thing as a perfect AGC circuit, this can temper possible shortcomings in the previous analog AGC circuits of the transceiver under varying conditions.

The Chroma SOUND software addition further improves the already outstanding performance of the *Star-10,* which benefits from good image rejection due to the transceiver's high first up-convert IF, and a well behaved RF/IF signal processor, using up to 32 poles of cascaded quartz filters.

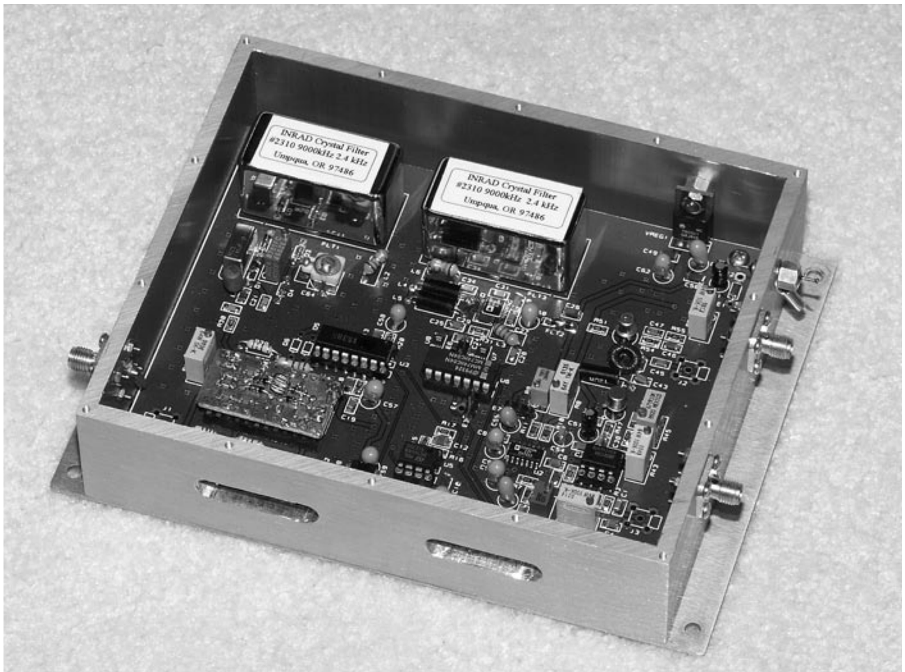


Figure 30 — Actual implementation of the IF9TX assembly. Visible at the top are the two cascaded 9 MHz, 2.4 kHz wide, Quartz crystal filters, which are similar to those, used in IF9RX. Another BIPA-like circuit (bottom left) is used as the CW drive control.

9 MHz Transmitter IF (IF9TX)

I will next discuss the design of the transmitter IF (IF9TX). Referring to Figure 2 from Part 1, the transmitter IF, IF9TX, performs all key transmitting functions as commanded by DFCB, using the BFO signals from the FRU — FSYNTH as buffered through PDAF. A microphone amplifier combined with a compression function and a VOX/ANTI-VOX function; condition the voice signals coming from the microphone. These signals are then input to a high level class II mixer, which in this case is made from individual components (unlike all other mixers in the system) in order to be able to control its balance. Carrier re-insertion and drive control are achieved in CW via the solid-state Hittite RF switches and another BIPA-like circuit used at 9 MHz in this application.

Transmitter gain control (TGC) is achieved automatically via a control loop fed from the TGC sensory assembly located at the back of the transceiver. This double RF sensor also provides RF power readings to the S-meter/RF Power meter via the T/R switching meter circuits located on the IF9RX assembly. There are two, eight pole — 9 MHz, 2.4 kHz wide — quartz SSB transmit filters cascaded in IF9TX, for a total of 16 poles of transmitted SSB selectivity. These filters are similar to the 2.4 KHz wide SSB filters used in the IF9RX assembly. The 16 poles were intended to keep the transmitted SSB signals within specific voice and intelligibility communications standards and not spread the information into adjacent channels. The resulting SSB signals sound crisp on the air with an audio response of 300 Hz to 2700 Hz. The schematic diagram of IF9TX is shown in Figure 29 and the actual implementation of the IF9TX assembly is shown in Figure 30.

Looking at Figure 29, the microphone audio input enters the conditioning circuits at J3. The signals are amplified by U1A and are further compressed and conditioned via U2, an Analog Devices SSM 2166 chip.[1] This professional grade audio conditioner gives outstanding performance and control over the speech waveforms with very low noise and total harmonic distortion (typically 0.25%). It offers variable compression (set at 2:1 in maximum mode) and automatic noise gating to improve the intelligibility of the microphone signals by recognizing and compensating for various signal level conditions. This circuit also uses a "downward expansion" technique (noise gate), which allows smoothing out speech transitions between words while canceling out background noise for improved signal-to-noise performance. For DX work, this "wonder chip" provides gain that is dynamically adjusted by a control loop to maintain a given set of compression characteristics. This allows using more compression when necessary, to increase average power. A high degree of flexibility was built into this chip by providing programmable VCA (voltage controlled amplifier) features, rotation point and noise gate adjustments.

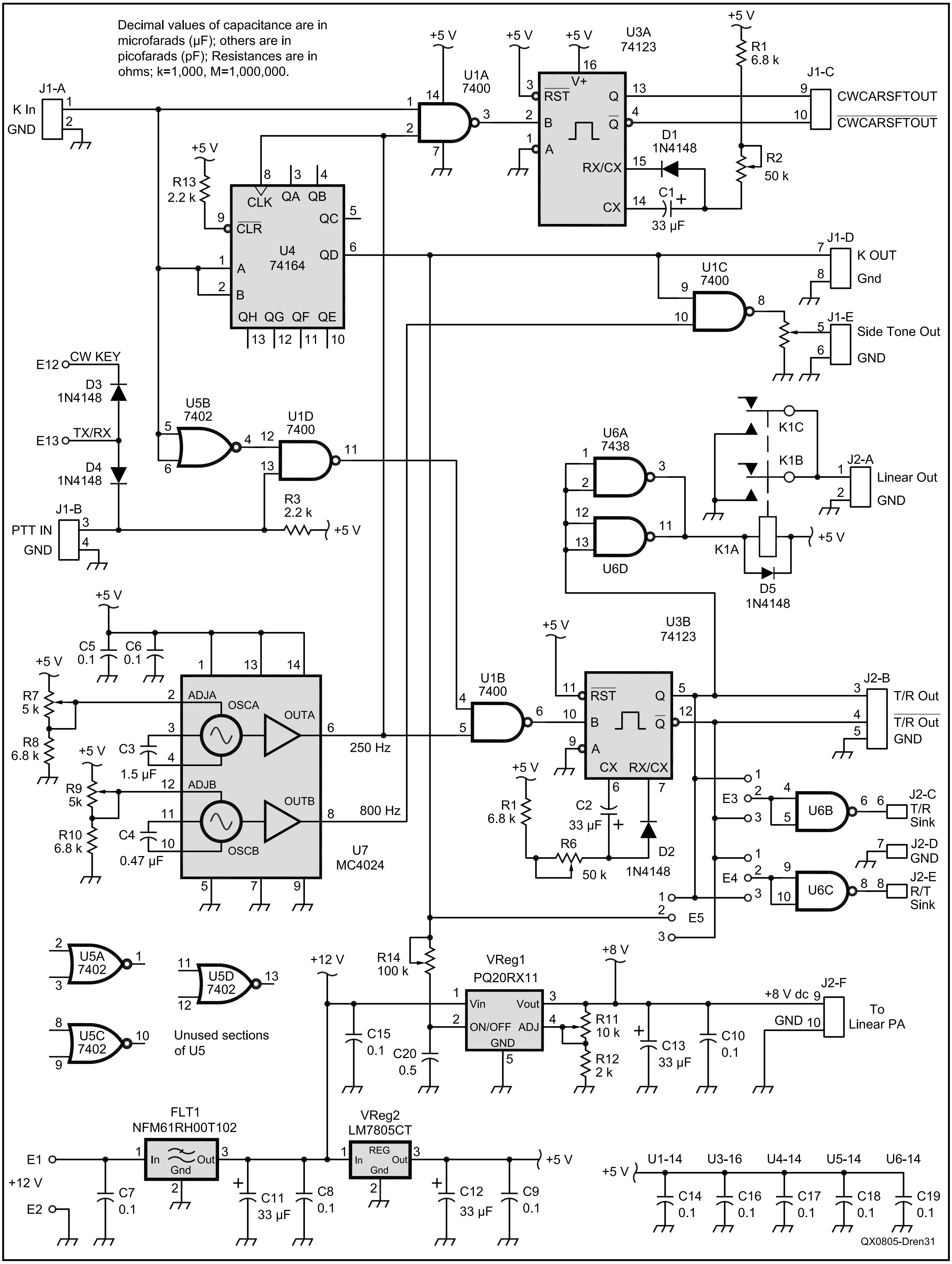
Looking at Figure 29, microphone gain is achieved from the front panel via J4-A. Compression level is also controlled from the front panel via J4-B. The actual controls are implemented via two concentric 10 kΩ potentiometers located on the left side on the front panel. The VOX/ANTI-VOX circuits are implemented via U5A and U3A andU3 B.

The conditioned microphone signal leaving the SSM 2166 variable compressor/noise gating device is input to a high level mixer via R30 and a low pass filter formed by L1, C20 and C21. The mixer is constructed of four matched HP 5082-2800 Schottky diodes.

Mixer balance is achieved via the combination of R56 and C64, which also serves as the BFO injection point for the various BFO frequencies (dependent on mode) selected from PDAF and coming from the FSYNTH via the PDAF assembly. It is at this point that the CW carrier is reinserted via the adjustable Quad PIN attenuator (Pi) ATN1 which is an exact replica of the BIPA circuit previously discussed in Part 2 of this series. CW drive

Figure 31 — Circuit diagram of the T/R control assembly. Various delays and commands are generated via one-shot logic circuits. A shift register (74164) is used to slightly delay the Morse code signals in order to allow the FRU — FSYNTH — to settle and lock-up between characters or character elements when switching between RX and TX and operating split. A dual clock (MC 4024) is used in conjunction with the shift register to generate the delayed Morse code characters as well as a keyed side tone signals.

[1]Notes appear on page 49.


Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.
J1-A
K In
GND
U1A
7400
+5 V
U3A
74123
RST
B
A
V+
Q
RX/CX
CX
R1
6.8 k
J1-C
CWCARSFTOUT
CWCARSFTOUT
D1
1N4148
R2
50 k
C1
33 µF
R13
2.2 k
U4
74164
CLK
QA
QB
QC
QD
CLR
A
B
QH
QG
QF
QE
J1-D
K OUT
Gnd
U1C
7400
J1-E
Side Tone Out
GND
E12
CW KEY
D3
1N4148
E13
TX/RX
D4
1N4148
U5B
7402
U1D
7400
R3
2.2 k
J1-B
PTT IN
GND
U6A
7438
U6D
K1C
K1B
K1A
J2-A
Linear Out
GND
D5
1N4148
C5
0.1
C6
0.1
R7
5 k
R8
6.8 k
R9
5k
R10
6.8 k
C3
1.5 µF
C4
0.47 µF
ADJA
OSCA
OUTA
ADJB
OSCB
OUTB
250 Hz
800 Hz
U7
MC4024
U1B
7400
U3B
74123
J2-B
T/R Out
T/R Out
GND
C2
33 µF
R6
50 k
D2
1N4148
E3
E4
E5
U6B
U6C
J2-C
T/R
Sink
J2-D
GND
J2-E
R/T
Sink
U5A
7402
U5D
7402
U5C
7402
Unused sections of U5
+12 V
R14
100 k
VReg1
PQ20RX11
Vin
Vout
ON/OFF
ADJ
GND
+8 V
R11
10 k
R12
2 k
C13
33 µF
C10
0.1
J2-F
+8 V dc
GND
To Linear PA
C15
0.1
C20
0.5
FLT1
NFM61RH00T102
In
Out
Gnd
VReg2
LM7805CT
REG
E1
+12 V
E2
C7
0.1
C11
33 µF
C8
0.1
C12
33 µF
C9
0.1
U1-14
U3-16
U4-14
U5-14
U6-14
C14
C16
C17
C18
C19
QX0805-Dren31

control is achieved from the front panel via J4-C as shown. Switching between SSB/AFSK and CW operation is achieved from the T/R assembly (and from PDAF) via J5-A and through the double RF solid-state switch arrangement at U7 and U8.

In either of the single sideband modes (upper or lower), the BFO is shifted accordingly and the 9 MHz SSB transmitter path coming from the mixer follows via T1, a TMO9-1 Mini-Circuits part and enters the first quartz filter XF1 (2.4 kHz) to go through the U7 solid state RF switch to be further amplified by U9 through the second quartz filter XF2 (2.4 kHz) and is finally output to IF9BC at J2. The transmitter gain control (TGC) (otherwise known as ALC) signals coming from the RF sensor assembly located on the transceiver's back (see leading picture) enter the IF9TX assembly at J5-E. The feedback signal is processed through Q1 (2N2222) and Q2 (a 3N200), which put the brakes on the IF/RF output coming out of XF2 at J2, always limiting the RF output of the transmitter to 100 W average.

When the transmitter is operating in the CW mode, the U7 and U8 solid state switches (Hittite HMC194) change the RF path from the SSB mode to insert the BFO signal directly into this path as controlled from the ATN1 CW drive and to be conducted through the U9 and XF2 path, through the TGC control circuits and to be output at the same J2.

Additional muting circuits are implemented via the T/R Switching Director assembly shown in Figure 2 of Part 1. DC power for the IF9TX is supplied as on any of the other *Star-10* assemblies, through on board tubular filters and regulators, as shown.

The IF9TX assembly is as unique as the IF9RX assembly. It accomplishes several transmit functions as commanded from the command and control assembly, DFCB assembly, the FSYNTH and the PDAF assemblies.

Transmit / Receive (T/R) Controller

The T/R control assembly in the *Star-10* is implemented using an all-digital approach. It operates in conjunction with the DFCB assembly, the IF9TX assembly, and the T/R Switching Director assembly. It accomplishes all T/R functions as shown in Figure 2 of Part 1.

The T/R assembly receives commands from the push-to-talk circuits, the VOX circuits and the CW key commands. Some of its functionality is also routed through the microprocessor in the command and control DFCB assembly. The T/R assembly outputs several control signals including the carrier shift commands in CW, the T/R control signals for closing the on-board high power linear amplifier switch-over relay circuit, the MUTE commands for IF9RX, PDAF and the Switching Director assemblies. In addition, it produces an 8 V dc bias control voltage to the power linear amplifier.

The T/R assembly is equipped with a dual square wave oscillator circuit (MC 4024), half of which provides keyed side tone audio signals to the audio mixer amplifier circuits in PDAF, the other half serves as a clock for a Morse code character shift register intended to delay slightly the code to the keying circuits on the IF9TX in order to allow the FRU — FSYNTH — to steer and lock-up between received and a transmitted frequencies when operating split and/or even between code characters when switching back and forth between the two split frequencies. The T/R control assembly is shown in Figure 31.

Looking at Figure 31, the PTT and/or Key functions are ORed together via the J1-A, E12, E13 and J1-B inputs. The signals are combined through the debouncing functions on DFCB as we previously discussed. A series of events are created upon key down or PTT, depending on the mode selected from DFCB.

In CW, the keyed signals are slightly delayed by a few milliseconds through the shift register at U4 (a 74164 shift register) and output through J1-D to be presented further to the IF9TX keying circuits. This delay is necessary to allow the synthesizer to settle down before shifting out the first CW character elements when working split between two different RX and TX frequencies. The delay is created in U4 as clocked by the 250 Hz oscillator A, at U7 (MC 4024). This short delay does not affect the operator perception of the transmitted CW keying. The 800 Hz side tone oscillator is implemented similarly at oscillator B of U7 (MC 4024). It is gated together with the delayed keyed Morse code and is output to the PDAF audio mixing circuits at J1-E.

Carrier shift commands are started through the logic circuit U3A, one half of a 74123 one shot. This one-shot circuit delays the release time of the shift commands briefly. The carrier shift command is output at J1-C. T/R commands are output through J2-A. These commands are intended for the external power linear amplifier switch over relay keying. Additional T/R control signals are output at J2-B and J2-C. The keyed regulated 8 V dc bias for the transceiver RF linear amplifier circuits is output via J2-F. This completes the T/R assembly description.

Power Linear Amplifier (PA)

The power linear amplifier for the *Star-10* is an adaptation of an off-the-shelf 100 W plus RF power brick available commercially. An initial amplifier was designed and developed following the Motorola application notes. This approach was abandoned later in favor of the current design because of parts availability. The power amplifier assembly is shown in Figure 32 A. The assembly has been mounted on a massive heath sink including the two fans visible in the back of the assembly as shown in Figure 32 B and C.

Looking at Figure 2 from Part 1, the transmitted signals are converted to the HF range by the H-mode mixer on IF75BC. The signals are further low pass filtered and amplified by the on-board class A amplifier (another CA2832 monolithic amplifier). This output is further presented to the power linear amplifier as shown.

The design of the RF power amplifier block is typical of 13.7 V power amplifier design. The first stage in this amplifier is operated in class A. Frequency response is compensated with feedback via a capacitor in parallel with the first transistor emitter resistor. Then the signal is amplified further by a low power push-pull amplifier. The output of this low power amplifier is coupled to the high power final push-pull amplifier stage. Additional feedback circuits are used throughout to keep gain relatively flat over the entire HF range. Cooling control is achieved by sensing temperature changes via an on-board thermistor, and using comparators, which activate the two fans when temperature exceeds 100°F. Higher fan speeds can also be achieved automatically. The output of the power linear amplifier is then passed to the half octave low-pass filter banks as previously discussed. From there, the RF signals go through the sensory electronics (see Figure 32C left), which in turn, feed the TGC circuits on IF9TX as previously discussed.

Other Assemblies (IF9NB)

Among the other assemblies in the *Star-10* are the Switching Director assembly, which provides additional muting circuits for the IF9BC, and the wide band IF amplifier and noise blanker assembly — IF9NB — as previously discussed in Part 1. This assembly provides wide spectrum analysis functions at 9 MHz, noise blanker detector functions to be fed to the BIPA circuit in IF9BC, and an oscilloscope function via a fixed conversion to 455 kHz.

Looking at Figure 2 from Part 1, the IF9NB assembly uses the 500 kHz wide IF signals from IF9BC. It amplifies them and triggers the one shot blanking circuits, which in turn blank the receiver through BIPA in IF9BC. The schematic diagram for IF9NB is shown in Figure 33.

Looking at Figure 33, the 9 MHz wide IF signal (500 kHz) from IF9BC enters at J1. It is amplified and AGCed by the AD8367 amplifier at U1. From here, the wide signals are fed to the 2N2222 amplifier and the squaring circuits at Q1 and Q2. Another part of the signal is fed through a second path to a CP643 amplifier, Q3, to be output to an external spectrum analyzer with a 500 kHz bandwidth for viewing band activity at J2. To facilitate the spectrum analysis display function of the IF9NB, a modified SoftRock-40 SDR board was tested by KG6NK in a fixed 9 MHz receiver configuration, together with pertinent software and a PC equipped with a 16 bit audio card. This worked quite well over a displayed bandwidth of 20 kHz. The 16 bit card limited the dynamic range displayed. A 24 bit audio card would probably have given better results, but it was not tested.

The noise blanking function works as follows. The clipped signals (by CR1) from Q2 trigger one half of an adjustable pulse width one-shot, 74HCT123 at U2A. Pulsed blanking signals are output to BIPA via J5. Pulse width control is achieved from the front panel via the J5 connector as shown. A separate 9 MHz IF narrow signal coming from IF9RX is fed to the assembly via J3. It is converted to 455 kHz via a simple NE602 converter at U3. The on-chip local oscillator is a fixed quartz crystal, X1, oscillating at 8.545 MHz. The 455 kHz IF output is filtered via a 3 kHz wide Murata ceramic filter and is further amplified by a MAR-7 amplifier at U4. The oscilloscope signals are output at J4. This circuit is still being tested. This completes the IF9NB assembly description.

Switching Power Supply and Power-ON circuits

A special switching power supply (ATX-4) was built expressly for the *Star-10* by Phil Eide, KF6ZZ. The requirements called for a dual-output secondary (13.7 V dc and 24 V dc), triple EMI filtering, high speed over-voltage protection (that actually works), over-current protection, and a fast control loop to correct for anything the *Star-10* may demand. The design was derived from the ATX-1 design published in *QEX.*[2] ATX-4 is essentially the same as ATX-1. The demanding EMI control requirements, however, were imposed on the design, along with the most important design criteria, which was full protection of the expensive CA2832 amplifier blocks ($100 each) on the 24 V line.

Although beyond the scope of this article, the design of the ATX-4 has been very involved due to the radio frequency interference (RFI) requirement imposed on the power supply. Extreme EMI filtering has been used and the result has been outstanding. The ATX-4 has been used extensively

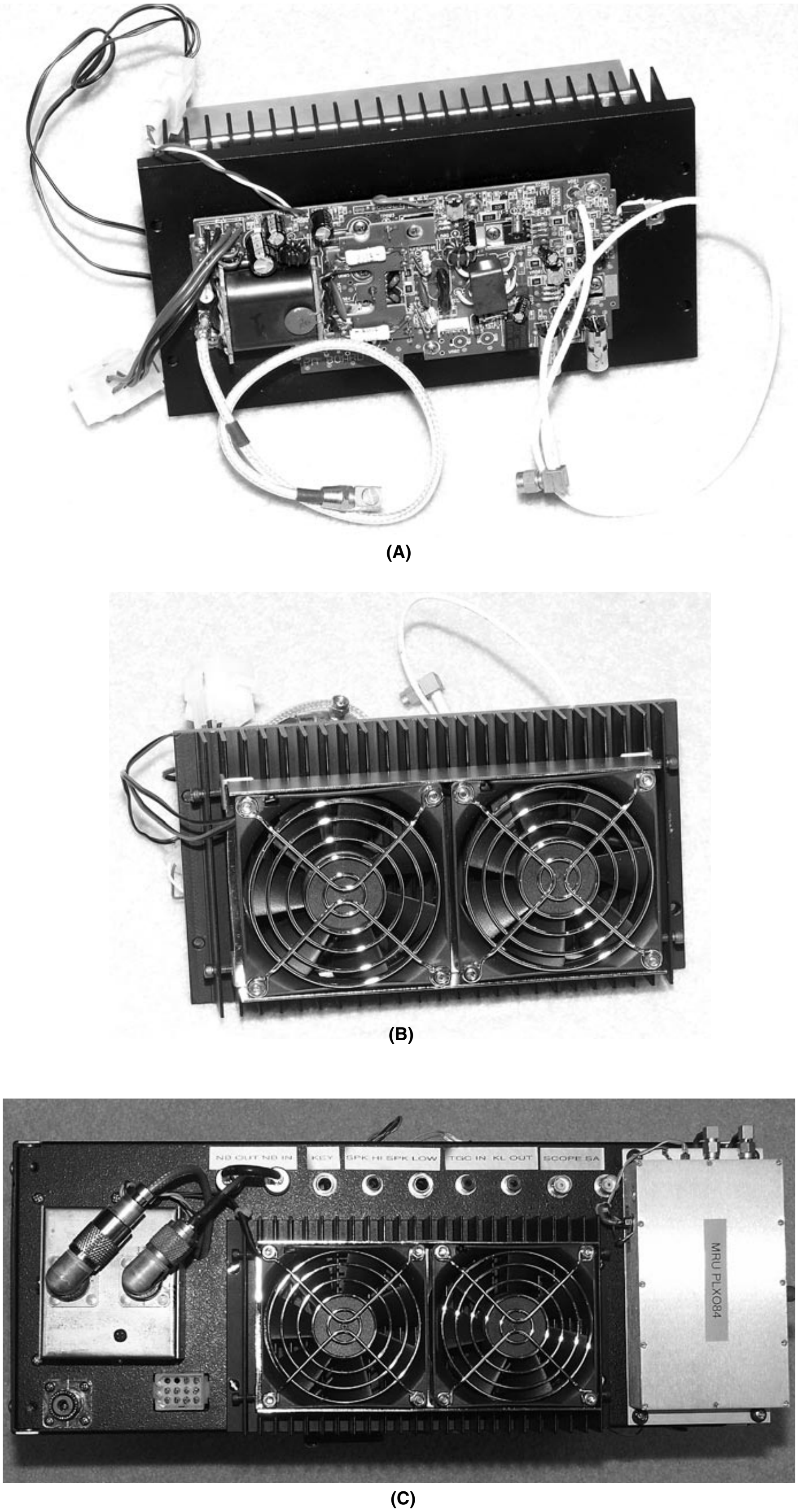


Figure 32 — Part A shows a photo of the RF power linear amplifier. B shows the cooling fans that are an integral part of the RF power linear amplifier assembly. They are mounted on the black anodized heat sink on the back of the assembly. The back of the *Star-10* transceiver is shown in Part C. The RF power linear amplifier and cooling fans are in the center. Sensory electronics are on the left and the master reference unit (MRU) is on the right.

with the *Star-10* and provides a totally clean RF environment on all bands of interest.

The ac power to the *Star-10* power supply is switched on and off from the front panel of the radio via a small power switch. This switch acts as a TTL level shifter to a solid state ac power relay (REDAC) located in a custom-made ac power strip in which the ac power cord of the power supply is inserted. The 5 V TTL voltage is derived from four AAA rechargeable batteries located under the bottom panel of the transceiver. The batteries are constantly being trickle charged by a small 6 V dc charger.

Four microprocessor cooling fans are used to cool the assemblies containing CA2832 amplifiers in the transceiver. These acoustically quiet fans use specially selected, dual-speed brushless motors that have been chosen on purpose because of their superior RFI performance. They are powered via a separate 12 V dc power supply in order to provide the greatest immunity to the receiver from RFI.

Putting it all Together

As previously mentioned, the *Star-10* final assembly has been the culmination of several years of RF design and development. It reflects modern state-of-the-art approaches to HF transceiver implementation. Its realization encompassed the many phases of engineering and development usually encountered in a complex commercial or military piece of equipment, from the system design through the circuit and software design, the multiple brass boarding, the complex testing and packaging into the final form factor as described in this series.

The *Star-10* packaging is complex and modular. All assemblies with the exception of the DFCB are enclosed in irridated machined aluminum RF enclosures available from COMPAC Corporation. These assemblies are mounted on two major shelves in the main enclosure as discussed in Part 2 of this series. These custom shielded assemblies are held together with multiple miniature flat screws, forming RF gaskets to provide better than 80 dB of isolation up to a GHz. The slots for interface connectors have been machined into the enclosures, thanks to Brendon Holt, KC5VCW. He donated his time and equip-

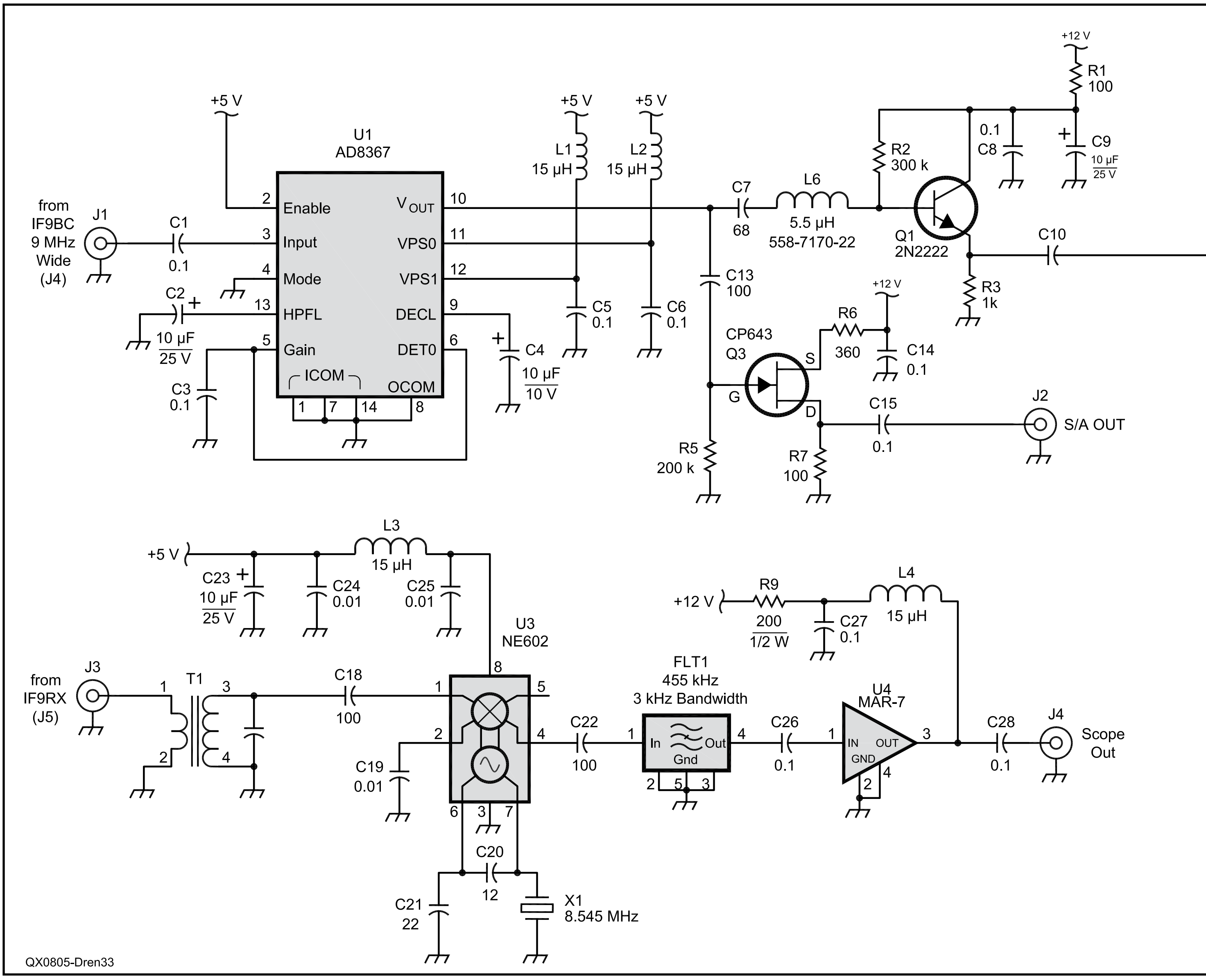


Figure 33 — Here is the schematic diagram of the IF9NB assembly. This assembly provides wide spectrum analysis functions at 9 MHz, noise blanker detector functions to be fed to the BIPA circuit in IF9BC, and an oscilloscope function through a fixed conversion to 455 kHz.

ment to the *Star-10* cause.

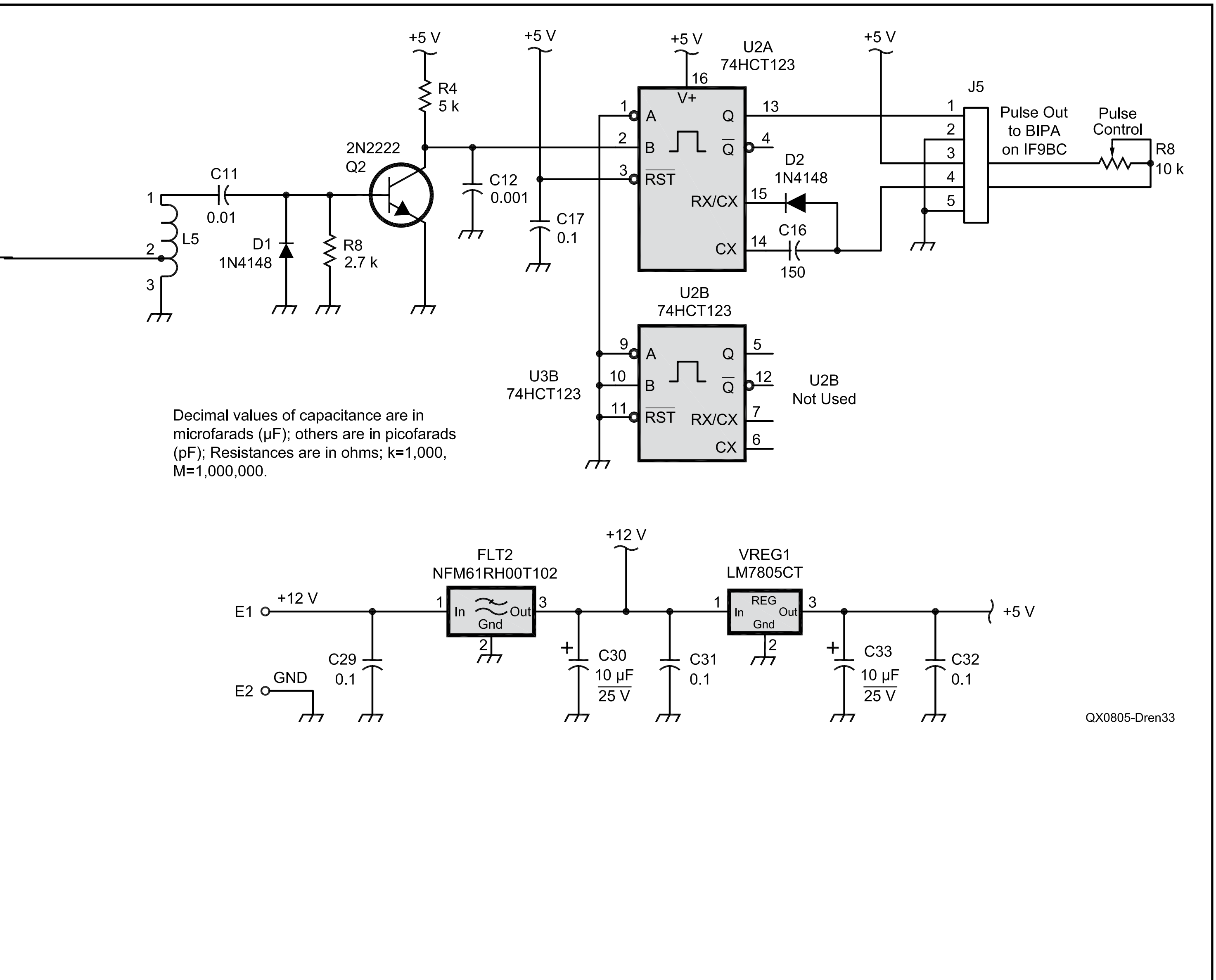
The *Star-10* circuit boards have been specially designed to install directly in the various sizes of machined aluminum boxes. They have been laid out expressly for the boxes and have been professionally executed on G-10 double sided circuit board material with plated through holes using multiple stitched ground planes, surface mount technology (SMT), along with hybrid assemblies.

The main enclosure was manufactured using aluminum panels that were professionally bent, sand blasted, irridated and painted with hammer baked black paint except in the areas where they meet, for RF shielding contacts. This enclosure was fabricated thanks to James Moon of M&R Sheet Metal & Mfg, Inc, in Tucson, Arizona.

The front panel is made of two large black anodized aluminum plates sandwiched together. They have been machined differently with respect to each other using cut-outs to hold the DFCB and keypad assemblies behind and hide them under panel holes, using flat screws and spacers. Thick film (0.8 mm Ortho Type III) membrane dials were manufactured from scratch using precision line artwork, photomechanical negative contact techniques and a large process camera. These dials have been sandwiched between the two anodized panels as shown in the transceiver main pictures. They are transparent in some areas to show through the displays, along with areas that have been selectively painted behind with silver paint to match the white silk-screened information painted on the black anodized front panel. Thus, a black and silver/white composite front panel resulted. I think this has a very "clean" look.

The *Star-10* assembly and testing came to full fruition during a three-week-long period in a well-equipped laboratory, courtesy of KG6NK, as shown in Figure 34. It should be noted that without the right testing tools, such a project could have not been completed. Although very intense, the final assembly went together without any major problems. There were no showstoppers.

Although the packaging was very tight, the radio performed as designed. As with any new design of this magnitude, slight changes had to be incorporated in some of the circuits and the inter-assembly interfaces during the



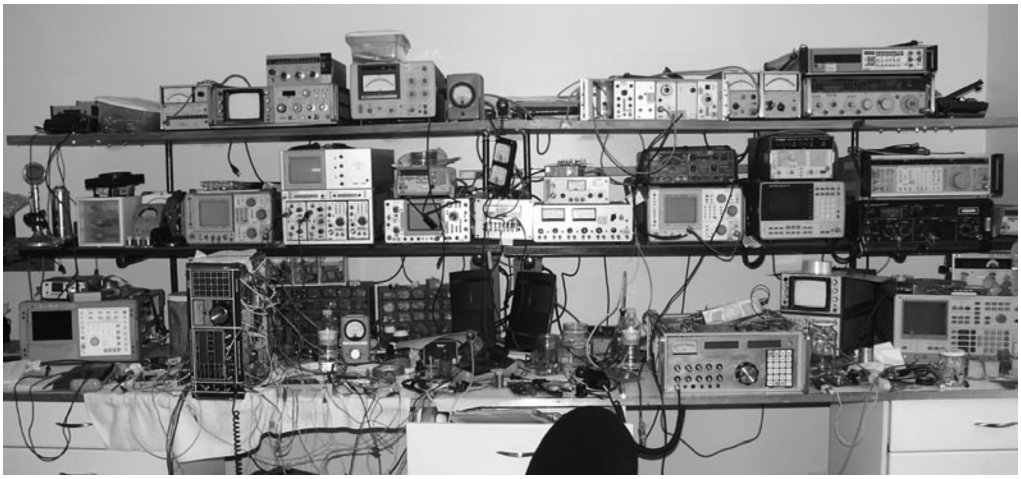


Figure 34 — The well-equipped KG6NK laboratory was used to complete the final wiring and testing of the *Star-10* transceiver. KG6NK's indisputable troubleshooting skills proved invaluable in the design, assembly, testing and especially in the final stages of the implementation.

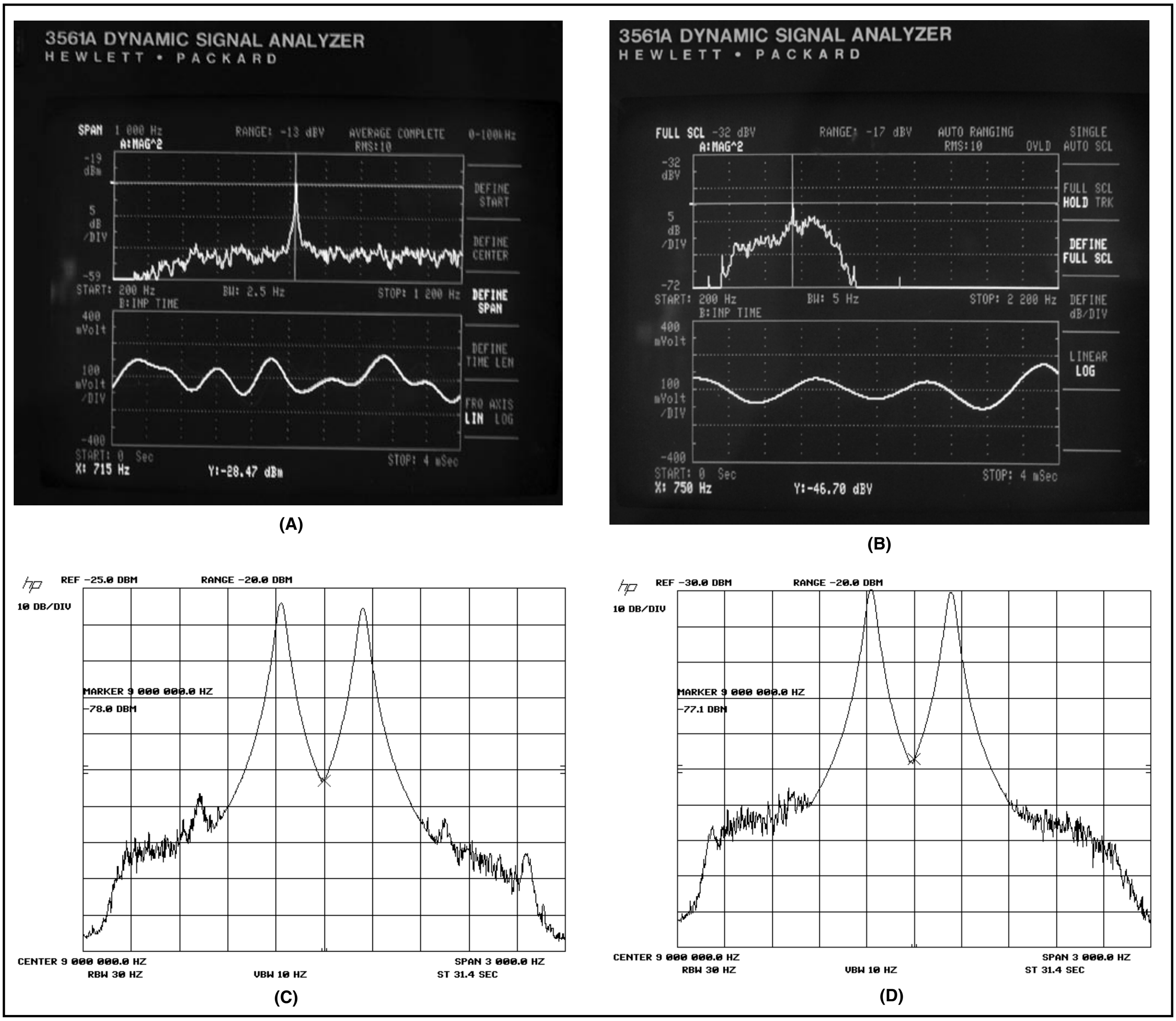


Figure 35 — Blocking dynamic range (BDR) at 5 kHz offset using 2.4 kHz ultimate bandwidth is shown in Part A. (Note: The values are expressed in dBm.) Part B shows the blocking dynamic range (BDR) at 5 kHz offset using 500 Hz ultimate bandwidth. (Note: The values are expressed in dBV.) The in band (2.4 kHz) receiver performance with two tones spaced at 500 Hz is shown in Part C. With the –15 dBm (S9+50 dB) signals applied at the receiver's input, in band spurs were 55 dB down. Part D shows the in band (2.4 kHz) receiver performance with two tones spaced at 500 Hz. With two RF signals 500 Hz from each other at –63 dBm (S9+10 dB) spurs were way down.

final assembly. These modifications have been introduced gradually until the system became stable. Most troubleshooting focused on finding and repairing pesky little contacts in silver or tin over gold connections in the signal connectors. Some of the coaxial cables have been found to be length sensitive and had to be cut to exact sizes. Several SMA type tubular, mil spec, RF attenuators have been occasionally inserted between RF assemblies. Comprehensive laboratory tests followed the final assembly.

A series of on the air tests followed. Reports from many DX stations proved that the transceiver's intelligibility in pile-ups is superior with the signal being picked up on the first or the second call despite the fierce competition. With the exception of some preliminary audio and compression level testing, crisp audio was always reported, proof of the microwave synthesizer's outstanding phase noise performance. The variable compression and noise gating features of the microphone circuits worked as designed. The receiver performance was equally good. The receiver's phenomenal IP3 spurious free dynamic range, and especially the blocking dynamic range allowed copying S1 or S2 SSB signals in the vicinity of 30 dB over S9 signals at only 3 kHz away from the desired signal. The receiver shines especially on CW during contests, when signals can be easily separated with precision at 500 Hz or less from each other by employing all 32 poles of cascaded IF filtering. Split operation was tested thoroughly as well as the RIT, pass band tuning (shift), memory, S-meter linearity, scanning and all other features.

Performance and Tests

Performance goals and specifications were presented in Part 1 of this article series. Comprehensive tests were performed in the laboratory. The MDS of the *Star-10* with the preamplifier ON was measured at –136 dBm in a 500 Hz ultimate bandwidth (with BIPA at zero dB). This was determined using a new calibrated Agilent E 6380A test set generator and an HP-400GL AC voltmeter and an HP-3561A . To verify accuracy of the Agilent 6380A, these numbers were also checked using a Fluke 6071A generator and a Tektronics 495P spectrum analyzer. The results were similar. This MDS is in line with predictions from Part 1 and is comparable with results obtained from a modified FT-1000D with the preamplifier ON. A test against the IC-7800 was also performed.

The 1 dB compression point of the FT-1000D with the preamplifier ON was found at –10 dBm. The 1 dB compression point of the *Star-10* receiver with the preamplifier ON and without the AIPA and or BIPA attenuators activated was found to be 0 dBm

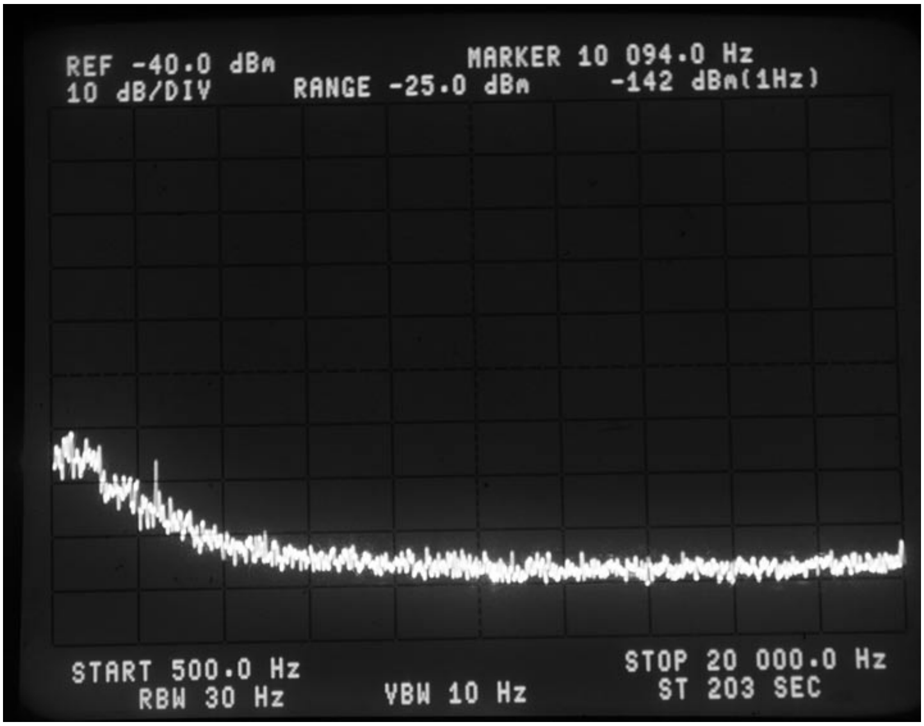


Figure 36 — The absolute phase noise measurement capability of the HP-3585A spectrum analyzer was calibrated using two HP-8640 generators in a classic mixing type phase noise measurement system. This capability was –142 dBc/Hz as shown.

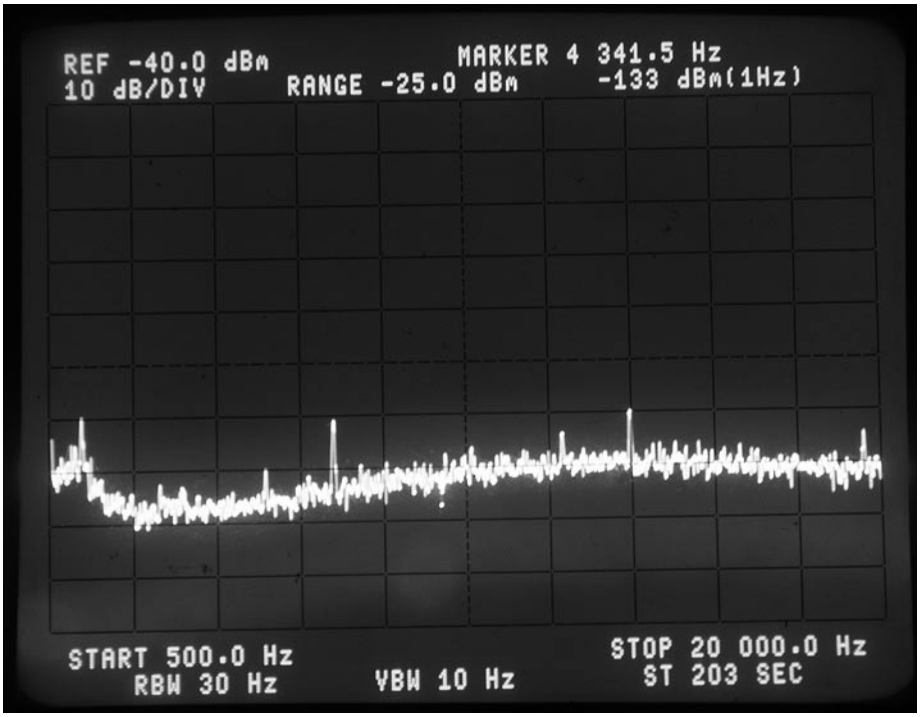


Figure 37 — Close-in phase noise performance of the FRU — FSYNTH — at 89.2 MHz (14.2 MHz) is –133 dBc/Hz. Phase noise performance has been tested and found to be uniform (within 1 dB) over the entire frequency coverage. The little spikes are spurs from the DDS, which are inside the loop filter, and cannot be eliminated. They are typically –100 dBc. These low spurs have not been audible in tests. See text.

(10 dB better). With AIPA and BIPA applied, the 1 dB compression point of the *Star-10* was found to be greater than +30 dBm. The receiver's composite linear dynamic range was found to be greater than 150 dB (500 Hz bandwidth, and all AGCs (AIPA + BIPA) turned on). This performance was listed in Part 1. The receiver's IP3SFDR was at least 130 dB using 20 kHz tone spacing (using a KW7CD test set with two combined quartz generators at 14.020 MHz and 14.040 MHz) and a 500 Hz bandwidth with the preamplifier on, and the AGC on. The *Star-10* receiver IIP3 was found at +45 dBm with the preamplifier on, just as predicted in Part 1.

The most demanding kind of dynamic range is, of course, the blocking dynamic range (BDR). *Star-10* receiver's blocking dynamic range (BDR) is due to an extremely crunch proof front-end design, the use of high-level mixers throughout, the superior microwave synthesizer used, and the superlative 32 poles of cascaded IF filters.

The *Star-10* blocking dynamic range was tested at 14.200 MHz using an HP-3561A dynamic signal analyzer as shown in Figure 35 A and B.

It was found that that with a –20 dBm interfering signal (the equivalent of an S9+ 53 dB signal) offset by only 5 kHz from the received frequency, the *Star-10* receiver can discern a –110 dBm signal (the equivalent of an S1 signal) with a 20 dB SNR when using the 500 Hz ultimate BW filter, with the preamplifier ON, no attenuators applied and no AGC action. The interfering signal level was then brought up to –8 dBm and even to 0 dBm before the –110 dBm desired signal at 5 kHz offset was finally blocked. This kind of interference is almost never encountered in real life, but the superior performance is very evident during contests and especially in the CW mode. The effect is very audible when tuning across a very busy band with signals bursting out of the MDS, and with little or no presence of nearby signals, a phenomenon not experienced with any other kind of transceiver I have ever tested. This radio is very quiet despite its sensitivity. As the band gets busier, the *Star-10* appears content, yet sensitive and very selective. In comparison with an IC-746 PRO or a 756-PRO that I tested against, there is no contest. These radios are just as sensitive (or even more so), but proportionally noisier than the *Star-10* when bands are busy (note: they bring the noise floor up due to IMD caused by a combination of factors including phase noise performance), while the *Star-10* pulls the signals out of the noise with ease.

Additional receiver tests were performed in the KG6NK laboratory using two in band RF signals 500 Hz from each other in the wide 2.4 kHz bandwidth. The measurements were observed at the second IF output. With two –15 dBm (S9+50 dB) signals applied at the receiver's input (in the 2.4 kHz BW) third order spurs were 55dB down. With two RF signals 500 Hz from each other at –63 dBm (S9+10 dB) spurs were way down. This is shown in Figure 35 C and D. This performance explains the superior experience observed with the *Star-10*, especially on CW during a busy contest.

The *Star-10* S-meter starts moving at an input signal level of –103 dBm (the equivalent of an S3). From this point on, the S-meter shows signals in linear dB (within 2 dB) up to an S9 + 40 dB (or –73 dBm + 40 dB = –33 dBm). Corrections for insertion loss of the various IF filters are automatically applied to the IF gain and S-meter upon filter selection, as discussed in the IF9RX section of Part 2. More AGC range could be used if applying the BIPA and AIPA controls. Automatic BIPA and AIPA control in the AGC loop(s) has not been implemented, leaving these controls in the manual mode. Using these controls has been minimal due to the outstanding dynamic range of the receiver.

The phase noise performance of the *Star-10* was measured directly at the synthesizer output using a phase-locked-loop measuring system involving a high level mixer, very linear amplifiers, filters and an HP-3585A spectrum analyzer which has the feature of reporting in dBm/Hz. The system was calibrated to display the noise directly in dBc/Hz. The offset from the carrier of interest was set from 500 Hz to 20 kHz. The instrument's capability was first verified by mixing two HP-8640 generator outputs locked to each other at 89.2 MHz (892 MHz initial FRU frequency divided by 10, or 14.2 MHz transceiver frequency). The resulting phase noise capability of the instrument is shown in Figure 36.

The FRU – FSYNTH — phase noise performance as implemented in the *Star-10* was found to be –133 dBc/Hz close-in, as shown in Figure 37. Better performance has been obtained by KG6NK in his version of the FSYNTH, as shown in Figure 38 A and C.

A –137 dBc/Hz (close-in) performance can be obtained from FSYNTH by tweaking the square wave DDS output level at the PLL phase detector input, separating ground planes between FSYNTH stages and by slightly changing the loop bandwidth. It should be noted that this performance is obtained because of the microwave frequencies used and only with a single VCO in the FSYNTH, instead of four as it is customarily done. Even better performance can be obtained with new microwave VCOs obtained from Synergy Microwave, the original manufacturer of *Star-10's* VCO. Experiments to improve on this performance are going on, with new VCOs

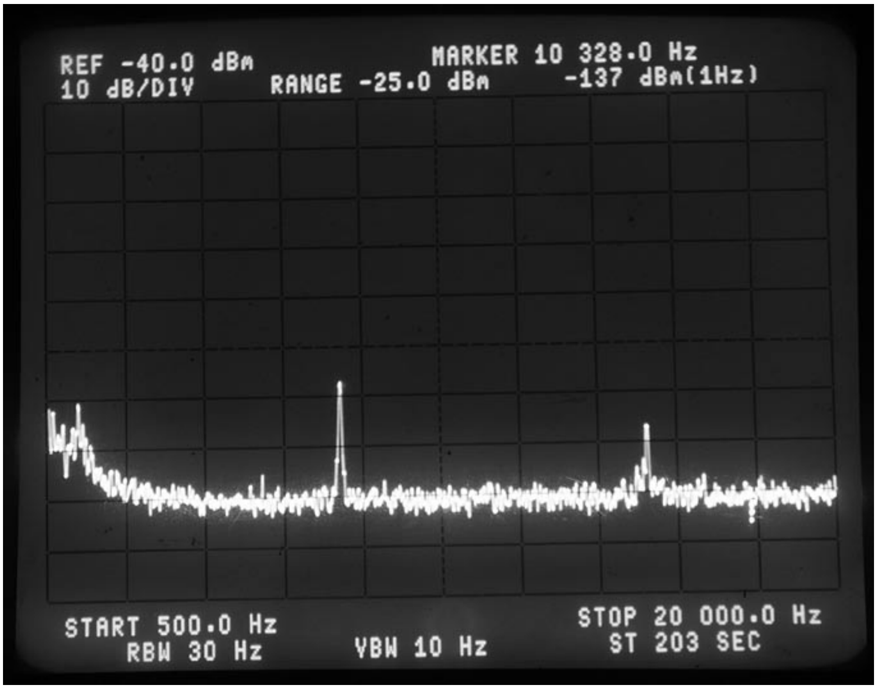


Figure 38A — KG6NK obtained –137 dBc/Hz close in phase noise performance from the FRU — FSYNTH — assembly by tweaking the circuits and widening the loop bandwidth. The previous in-band spur is –97 dBc. Listening tests proved that these spurs are not audible. Uniform performance (within 1 dB) has been obtained throughout the entire frequency range. The impact of the modifications on split operation lock-up and settling time have been analyzed and tested.

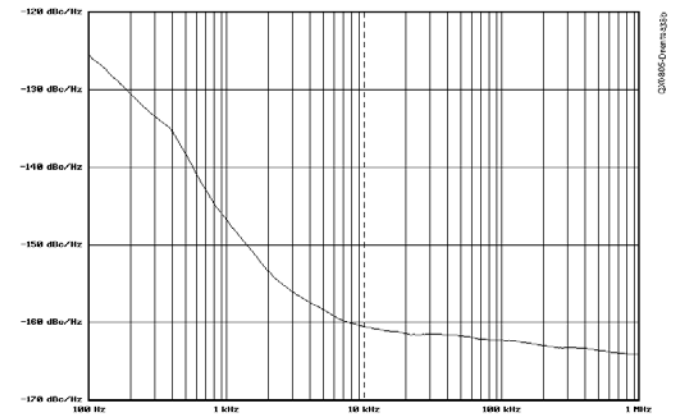
donated by Ulrich Rohde, N1UL.

The FSYNTH phase noise performance was further tested at several frequencies, 78.7 MHz (3.7 MHz), 82.1 MHz (7.1 MHz), 89.2 MHz (14.2 MHz), 96.2 MHz (21.2 MHz) and 103.4 MHz (28.4 MHz).

A final integrated phase noise plot of the FSYNTH from 10 Hz to 1 MHz offset was obtained using a PLL measuring system. The test was performed by KG6NK in his laboratory. A Bliley OCXO reference and its calibration plot against the Wentzel OCXO master was provided by John Miles, KE5FX. The FSYNTH frequency in this test was 100 MHz or 25 MHz receiver/transmitter frequency. See Figure 38B. A –138 dBc/Hz SSB phase noise was verified through this final test.

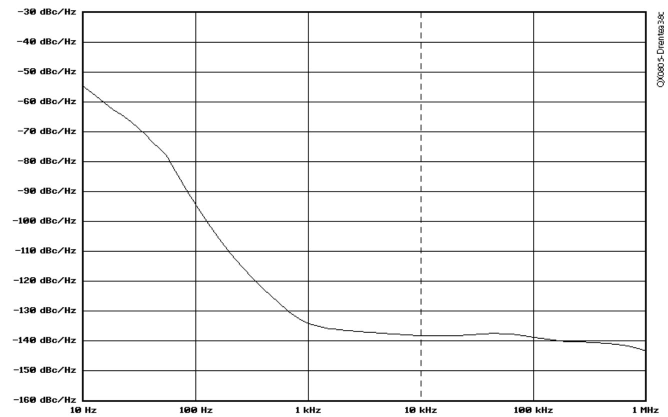
Transmitter two-tone intermodulation distortion tests were performed at 14.2 MHz with and without audio compression. The third order products were 32 dB down without compression and slightly worse with the audio compressor switched in. This is shown in Figure 38, Parts D and E. The harmonic rejection performance has been documented in detail in references 1, 2 and 3 from Part 2 of the article.

Transmitter SSB audio response measurements were performed in the upper and lower sidebands with full power (100 W) output by using an Amber 3501 audio distortion measuring system, a Bird-43 RF wattmeter and a dummy load. Although the theoretical transmitted audio frequency response was calculated to be from 300 Hz to 2700 Hz, the actual audio response under full transmit-



Trace	Carrier Hz	Carrier dBm	dBc/Hz at 10000 Hz	RF Atten dB	Instrument
Bliley NV26R891 #0017 vs Wenzel Sprinter	100 000 000	-7.20	-160.5	10	HP8566B

Figure 38 B — This plot shows the phase noise performance of the 100 MHz Bliley OCXO reference source used in these tests. It was calibrated against a very high quality Wentzel frequency standard. The plot shows the integrated single sideband phase noise plot from 100 Hz to 1 MHz. This calibration and plot are courtesy of John Miles, KE5FX.



Trace	Carrier Hz	Carrier dBm	dBc/Hz at 10000 Hz	RF Atten dB	Instrument
FSYNTH/BLILEY REF 100 MHZ	0	0.00	-138.2	0	HP3585A/B

Figure 38 C — This plot shows the Integrated single sideband phase noise plot of an improved *Star-10* FSYNTH assembly from 10 Hz to 1 MHz. The performance is better than –138 dBc/Hz at 10 kHz offset. The test was performed by KG6NK in his laboratory and was obtained using a professional PLL measuring system, a Bliley OCXO reference source calibrated against a Wentzel frequency standard, and the HP-3585A spectrum analyzer. "Tool Kit PN " software was provided by John Miles, KE5FX and was implemented together with a Prologix interface, which was used to control the instrument, integrate the results, and display them. The FSYNTH frequency in this test was 100 MHz or 25 MHz receiver/transmitter frequency.

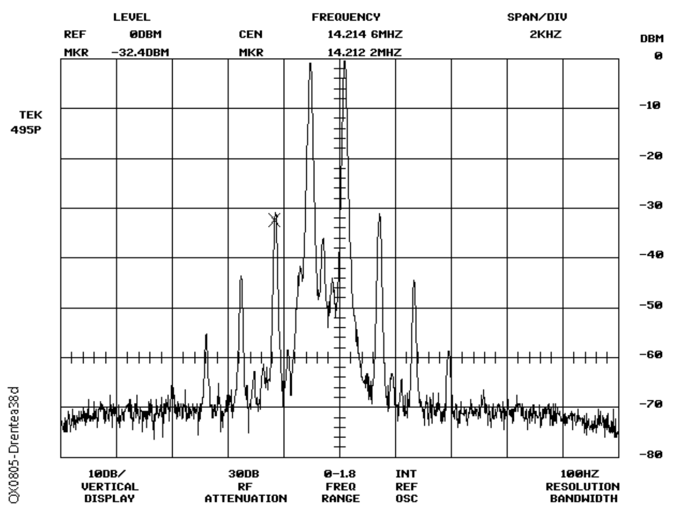


Figure 38 D — Here are the two tone transmitter test results, without compression. Third order products are 32 dB down. The tests show a clean noise floor, which is due to the FSYNTH performance.

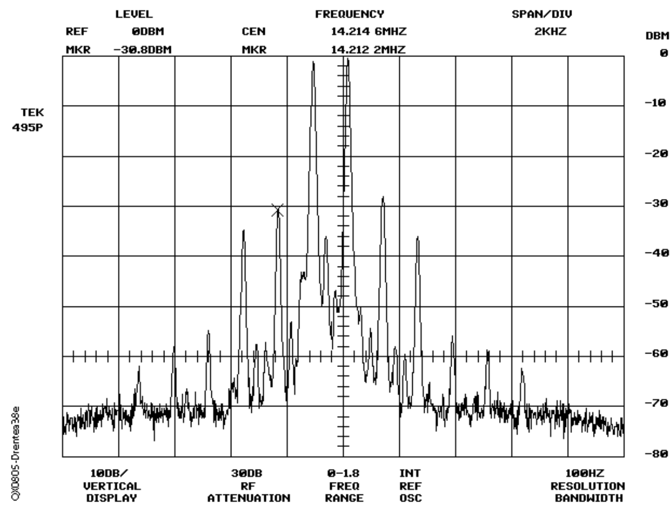


Figure 38 E — The two tone transmitter test with 2:1 audio compression turned ON is shown here.

ter output was found to be from 270 Hz to 2800 Hz at the 6 dB points. The output falls greatly before and after these points due to the 16 poles of transmit IF filtering. No splatter was ever reported from the *Star-10* during on-the-air tests. Harmonic rejection and image rejection tests have been previously performed as a function of the front-end half-octave filter banks and have not been repeated this time.

Lessons Learned

As with any new piece of equipment of this magnitude, a certain number of problems are usually expected. Because of the intense breadboarding and design verification before its final implementation, these problems have been kept to a minimum in the final version. In retrospect, most problems in the execution of *Star-10* have been mainly cold contacts in the interface control wires, connectors and relays. Some of the old relay contacts corroded and caused heating of the low pass filter banks in transmit. This situation was immediately corrected. Because of the tight *Star-10* package, access to some of these connectors has sometimes been difficult. Some problems also occurred in the SMT circuits.

After getting rid of most bugs, *Star-10* has performed reliably. Especially trouble free has been the DFCB command and control assembly and its associated software, which performed as designed after intense and careful analysis of the mathematics governing the system and operator interface. Numerous software upgrades were implemented and tested before the current trouble-free version. This combined with careful breadboarding, troubleshooting and testing the DFCB in the early phases made for an almost perfect software design. Also, the IF9TX, IF9RX and IF75BC and power linear amplifier have operated flawlessly from the start. Other assemblies required some tweaking, but have proved equally reliable after the initial hurdle.

One of the most important lessons learned from this design is that no matter how careful one is in selecting components, by the time the design is implemented, they become obsolete. Of course there is always a better way of doing things, in retrospect. This is not a new thing, however. Engineers everywhere face this kind of problem in an ever-changing industry.

A second lesson learned which goes hand in hand with the first one is to know when to stop designing circuits and not run the risk of breadboarding forever. This was hard. It required discipline and a firm gut feel about when to freeze the design.

Another good lesson learned is that no matter how careful one is in a design, things suspected to work well, don't, and things suspected to have problems might sometimes work just perfectly. This is also known as Murphy's Law.

An interesting conclusion after performing complex testing and operating the *Star-10* in rough contests is that, contrary to popular belief, roofing filters are not as important in improving dynamic range as once thought, if good front end performance is provided in the first place. As explained in Part 2, roofing filters with a 3 dB bandwidth of 10 kHz or less, that withstand the high signal levels required for ultra high dynamic range needed at this point in a system, are extremely demanding to manufacture from an IMD point of view. If the front end has the kind of performance realized in the *Star-10*, the roofing filters can be more forgiving. That is not to preclude that narrow roofing filters can greatly help overall performance of radios with lesser front-end dynamic range performance.

A final lesson learned is that no matter how good the design is; better AGCs and better noise blankers are always needed. *Star -10* makes no exception to this rule.

In operating the radio, a 500 Ω dynamic microphone with a flat response has been used. Some compression has been found useful, but not necessary, as the audio response is very crisp and distinct. Initial tests driving a full legal power linear amplifier revealed some RF feedback getting into the microphone circuits because my 20-meter beam is located right above the radio room. As any notorious RF feedback problem goes, this problem wasn't cured just with little ferrite beads and bypass capacitors as is usually found in transceiver microphone circuits. An investigation of the literature revealed not much information on RFI microphone filters.

A third order Butterworth audio low-pass filter with a 2.7 kHz cut-off frequency was designed and implemented at the transceiver microphone input, and the problem went away for good. This design was done using the AADE Filter software and is shown in Figure 39.

The *Star-10* transceiver has been in reliable operation, 24 hours a day, seven days a week for more than a year. Although three other transceivers are available here, using

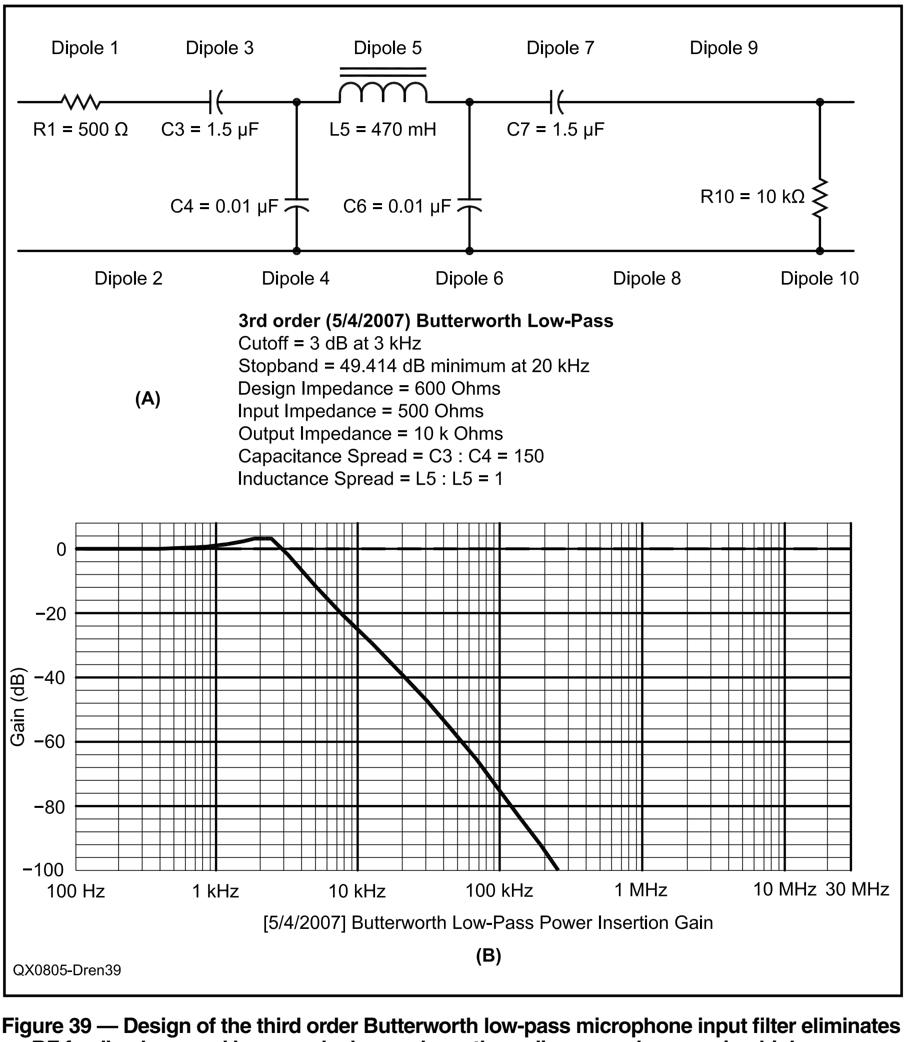


Figure 39 — Design of the third order Butterworth low-pass microphone input filter eliminates RF feedback caused by a nearby beam above the radio room when running high power.

this radio has been the preferred choice, especially when listening to busy bands. Operating this radio has been a joy due to its superior performance and its friendly user interface. *Star-10* stands ready for the upcoming, wildly predicted solar cycle.

Conclusion

The *Star-10* project has been a long and stressful engineering exercise. For the many who wrote in with their positive comments and compliments on the first two parts of the series, thank you.

This article was intended to share information. The *Star-10* transceiver was designed to prove that superior equipment can still be built and high performance combined with professional features can be designed and implemented to compete with any sophisticated transceiver on the market today. Despite this, the *Star-10* is not perfect. Even better transceivers can be built using this experience. I hope this series of articles has been an inspiration to equipment builders everywhere, to RF system designers and engineers, as well as to the armchair radio designers.

As I mentioned at the beginning of this article series, it has always been the dream of the technically inclined radio amateur to build and operate his or her own radio equipment from scratch. With a few exceptions of dedicated home brewers, it appears that operating your own home brewed radio on the bands today is a rarity. In using the *Star-10* on the air and mentioning that it is home brewed elicited some interesting reactions. Much to my surprise, comments like "Is it a kit?" or "Do they still do that?" have been commonplace.

I find this situation sad. Amateur radio used to be at the forefront of technology. Hams were the future engineers and scientists. They were persistent experimenters and innovators that achieved noteworthy technical success. It is my opinion that this trend must continue if ham radio is to remain the technical hobby it deserves to be.

It is a very proud feeling to operate equipment that you have designed and developed regardless of how simple or sophisticated it is.

Cornell Drentea, KW7CD took his first radio receiver apart (and put it back together) at the early age of six. He has been a Ham since 1957. Since then, he's built many radios and transceivers and made his passion for designing "radios" his life long profession. As an Amateur Radio operator, he is known for his extensive RF technology articles in magazines such as Ham Radio, Communications Quarterly, RF Design, *and* QEX. *Professionally, Cornell is an accomplished RF technologist, an engineer and a scientist with over 40 years of hands-on experience in the aerospace, telecommunications and electronics industry. He has been involved in the design and development of complex RF, Radar, guidance and communications systems at frequencies of up to 100 GHz. Cornell has developed several state-of-the-art RF products including ultra wide band high probability of intercept microwave receivers, complex synthesizers, multi-modulation transmitters, Doppler agile space transceivers as well as high power RF linear amplifiers. He received his formal education abroad with continuing studies and experience achieved in the United States. Cornell has presented extensively on RF design topics at technical forums such as IEEE, RF-Expo, Sensors-Expo and has given comprehensive professional postgraduate courses in RF receiver design, synthesizer design, sensors and communications. He has published over 80 professional technical papers and articles in national and international magazines. He is the author of the book,* Radio Communications Receivers, *McGraw Hill, ISBN 0-8306-2393-0 and ISBN 0-8306-1393-5, 1982 and holds five patents. He is currently available for consulting to large and small RF enterprises. You can find out more about Cornell, his consulting and his RF course offering entitled* The Art of RF System Design *on his web site:* **members.aol.com/cdrentea/myhomepage/**

Notes

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