A VHF SSB-CW TRANSCEIVER WITH VXO

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Twenty years ago ICOM introduced one of the truly classic 2 m SSB-CW rigs--the ICOM 202. With 3 watts PEP output, no FM capability, only 4 200 kHz wide tuning ranges and a narrow-band front-end, it had limited appeal to the ham who wanted to try a little of everything. As a special-purpose radio however, it offered some real performance advantages. First of all, the narrow-band front-end resists intermod interference from out-of-band signals and even local 2 m repeaters. With no provision for FM, there is no need to use a wide bandwidth "roofing filter" after the mixer--the first IF filter has SSB bandwidth, and the close-in dynamic range is quite good. The superb noise blanker has its own separate wide-band IF. The transceiver only draws 60 mA on receive--perfect for operation from the internal batteries. The 3 watt power output is ideal for driving a ceramic tetrode amplifier to a few hundred watts output.

But the technical spec of the ICOM 202 that is unequaled to this day is the phase noise of the local oscillator. The tuning knob on the front panel of the ICOM 202 drives a variable capacitor in series with a crystal operating at about 14 MHz. The crystal oscillator output is multiplied by 9. It is exceptionally hard to improve on the phase noise performance of a good crystal oscillator followed by a frequency multiplier.

For a few years the ICOM 202 was a favorite of serious DXers, but it fell from grace as larger radios with more bells and whistles began to improve in performance. Then it was embraced by the satellite crowd, who appreciated its low cost and dedicated SSB-CW performance. By the time "grid-squares"caught on in the United States, the newer Yaesu portables were the darlings of the rovers. ICOM 202s began to gather dust in closets, and for a while, one could find them at hamfests for $100.

Then microwaves caught on and everyone needed an IF rig. Avid microwavers would converge on Dayton each year, buying up all of the Frequency West brick oscillators and ICOM 202s they saw. WA5VJB was reportedly spotted with five of them. I once created a distraction for WA8NLC so that I could snatch one that he hadn't spied yet at Dayton. He got even with me by finding one brand-new-in-the-box at half price a few months later.

The "ICOM 202 well" has been dry for a few years now, and my notebook pages have had random sketches of ICOM 202 replacement microwave IFs for even longer than that. This paper describes one of my sketches that made it all the way to production form.

A few years ago I described the R1, R2 and T2 high performance direct conversion receiver and exciter boards in QST. I also described their use as microwave IFs in a later article. The R1, R2 and T2 were designed with advanced experimenters in mind--people who were already fluent in VFO, preamp and switching circuitry and could come up with the necessary support circuitry to build a rig. After my fifth or sixth R2-T2 rig, I began to entertain thoughts like "wouldn't it be nice to have a little motherboard with all of the support circuitry on it, so I could just connect up the R1 or R2, the T2 and the no-tune transverter board and have a complete microwave transceiver?" It usually takes me a few years from concept to circuit board, so it was a year ago before the first "little motherboard" LM1 was built. It worked fine, and is built into a cute little 1296 receiver, but it was about twice as big as it needed to be, so it went back to the drawing board. I have worked on the LM2 off and on for the past year.

Meanwhile, the miniR2 was designed and put in production. The miniR2 uses circuitry I described in the Proceedings of Microwave Update 1993. The miniR2 is half the size of the R2 (it is the same size as the T2 and R1), has simpler diplexers so that no hand-selected parts are needed, and has a headphone-only output stage. Two-tone third-order dynamic range is about 95 dB, and audio distortion with headphones is very low. The noise figure with no preamp (only audio gain) is about 11 dB, and TUF series Mini-Circuits mixers are used so that the basic board will work from 150 kHz to 1500 MHz, with the appropriate choice of mixer. The only adjustment on the miniR2 board is the audio amplitude balance trimpot used to null the opposite sideband.

RF frequency dependent components were deliberately left off the R1, R2, T2 and miniR2 boards to make them useful to experimenters at all frequency ranges. The T2 board needs only a microphone, key, LO and LO splitter-phase-shifter to provide +3 dBm output. The miniR2 needs an LO, LO splitter-phase-shifter, volume control and headphones to build an 11dB noise figure receiver. At VHF, a single stage preamp is recommended to improve the noise figure.

The LM2 board contains a VXO, frequency multiplier, two splitters, an LO phase-shifter, a narrow-band receive preamp, a TR relay, CW semi-break-in and CW RIT-offset circuit. The VXO is an adaptation of a circuit published by Joe Reisert as a high-stability reference oscillator. It can be very stable, depending on the quality of the VXO tuning components and the thermal environment of the crystal.

Figure 1 shows the interconnections to build a low power SSB-CW IF transceiver using the LM2 board. The receiver board may be an R1, R2 or miniR2. If an R2 or miniR2 and a T2 board are used, an additional LO splitter-phase-shifter must be used. It is convenient to use a small "piggy-back" board on top of the T2 mixers. The VXO has a CW RIT-offset trimpot on the board. This control may be replaced by a panel mounted pot.

Figure 2 is a block diagram of the LM2 board, and figures 3 and 4 are the schematics of the various sections. The numbered components are listed in the parts list and Tables 1 and 2.

The RF circuitry is built using surface mount components wherever possible. This is not only for small size, but to reduce radiation coupling between the various parts of the circuit. For the same reason, a small ferrite toroid RF choke is used to bias the MSA1104 instead of the more common solenoid. Remember--the size of a Z-144 RF choke in wavelengths is about as big as a Hustler 160 m mobile whip.

VXO performance depends on the quality of the tuning capacitor, the value of the series inductor, and the thermal environment of the crystal. Use the best available tuning capacitor (dual ball-bearings and a Jackson Brothers reduction drive are nice), recognize that increasing the VXO range with a series inductor degrades stability, and wrap the crystal in packing foam. The LM2 board was specifically designed to place the crystal far away from heat sources (primarily the MSA1104 and its bias resistor). With a little care, the stability of the VXO will be much better than the stability of a 96 MHz 5th overtone Butler oscillator. With no series inductor, 50 kHz tuning range is typically available at 2 m. With the proper choice of inductance, the range may be increased to over 200 kHz.

Component values for the LM2 schematic are given for the amateur bands from 18 MHz to 222 MHz. The LM2 can be built for other frequencies between about 18 and 230 MHz by redesigning the filters using ARRL Compact or PSPICE. The low frequency limit is set by the TOKO splitters and 7 mm RF inductors. The upper frequency is limited by the 74AC04 CMOS multiplier. All of the odd harmonics (X3 X5 X7 X9 etc.) are present at the output of the 74AC04. The LO filtering selects the desired harmonic. An 18 MHz rig may be built using a 6 MHz crystal (X3), and a 222 MHz rig may be built using a 24.68 MHz crystal (X9). The VXO has enough output to drive a diode balanced doubler, as described in Solid State Design for the Radio Amateur and also available as a packaged component from Mini-Circuits. With a balanced doubler between the VXO and CMOS odd-multiplier, multiplications of X6, X10, X14 and X18 are possible.

A two-board CW transceiver may be made by connecting a jumper between the LO output and the T port of the relay. The LO multiplier-amplifier may then be keyed for transmit.

Despite the fact that almost all of the circuitry is contained on three small circuit boards, this is by no means a beginner project. First of all, there are about a hundred parts on each board. Secondly, the LM2 board uses lots of chip capacitors with different values--a mistake is exceptionally difficult to troubleshoot. Third, the analog signal processing used to eliminate the opposite sideband on transmit and receive is outside the experience of most amateurs, which means that if it doesn't work, what you think is wrong is probably not the problem. I have been very careful not to make mistakes and each one I built has worked right off. Then later when I screwed things up I at least knew that it used to work!

How does an LM2-miniR2-T2 rig stack up against an ICOM 202 as a microwave IF? First of all, the ICOM 202 has a number of features missing from these three boards: an S meter, RIT on both SSB and CW, AGC, noise blanker, 4 tuning ranges and speaker output. The LM2-mR2-T2 set has a few features missing on the ICOM 202: CW semi-break-in, CW sidetone and easy transverter connections. Since packaging is left up to the builder, the LM2 rig may be built much smaller than an ICOM 202, or in a rack panel box with an Eddystone dial. All three boards will fit nicely on the back of a no-tune 903 transverter board for a compact transceiver. In terms of performance, there is little difference. Selectivity and opposite sideband suppression are about the same. The dynamic range and audio fidelity of the LM2 rig are measurably better. I find the ICOM 202 AGC annoying while digging for weak signals, and it can't be turned off. The biggest advantage of the LM2 rig is that the unpackaged boards are available, and that may encourage the construction of dedicated, packaged transceivers for 2304 and up. If it is easy to operate the 2304 rig, that will encourage activity on the band.

Even more important than the comparison with the old ICOM 202 is a comparison with currently available radios. There is little point in building a homebrew 144 MHz radio for everyday use on the 2 m band. The limited tuning range of the LM2 is a severe handicap, and by the time all of the prices, including a modular brick amplifier and a nice case are added in, the homebrew rig would probably cost more than a used TS700. On the other hand, an experienced radio craftsman can build a weak-signal microwave IF around the T2, R2 or miniR2 and LM2 boards that outperforms any commercial radio in terms of dynamic range, spectral purity, and clean audio for digging out weak signals.

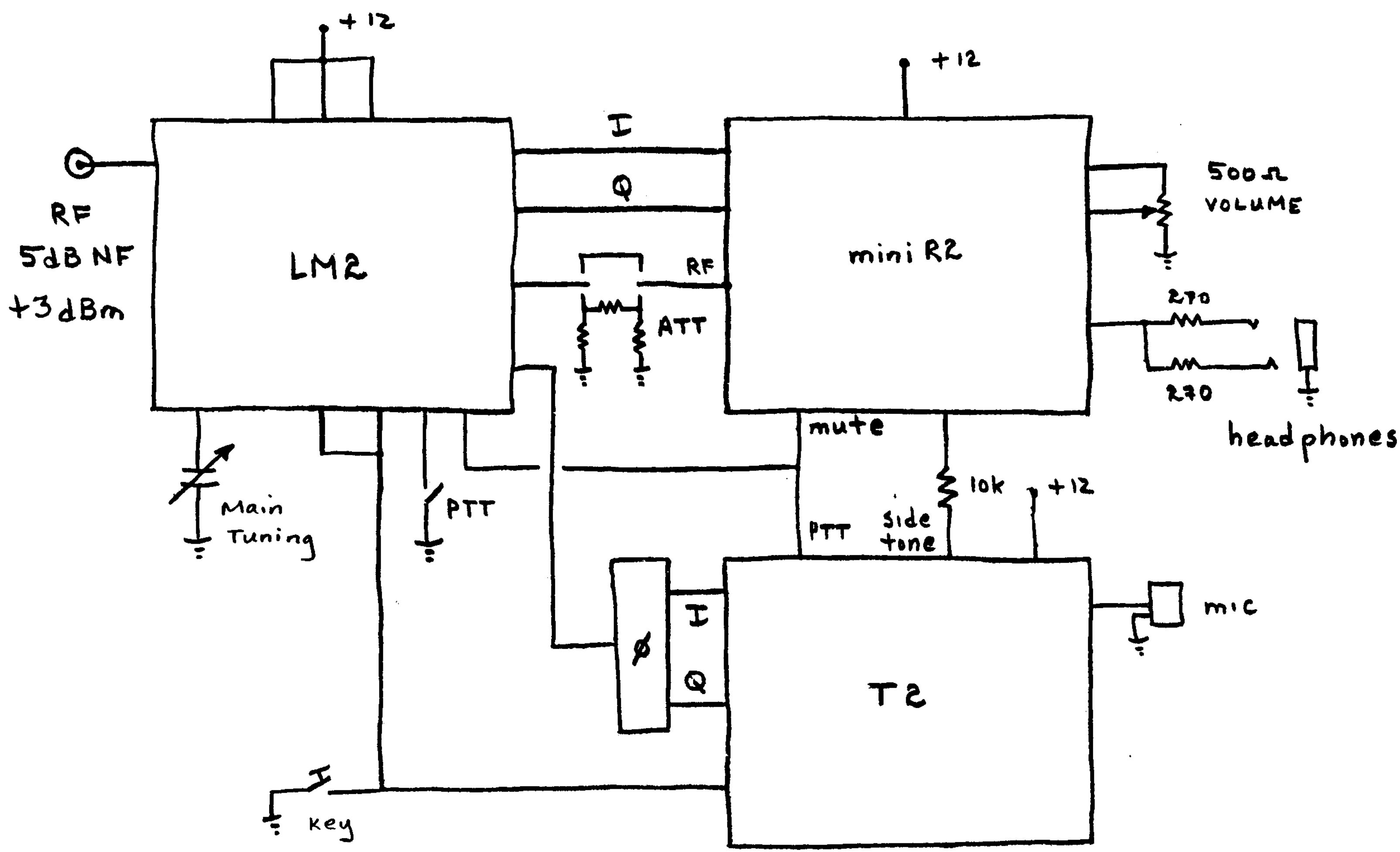
If there is any question about the need for high dynamic range in a radio used as a microwave IF, just remember that the 2nd and 3rd harmonics of the 1152 MHz LO in the 1296 converter are usually received at about 60 dB over S-9 at 2304.0 and 3456.0. Any internally generated signals in the transverter or IF rig will mix with these strong LO harmonics in a low dynamic range IF receiver and generate a large number of birdies in the tuning range of the receiver. These birdies are a serious inconvenience when tuning for weak signals in the noise. None of the four microwave radios built at KK7B using the T2, R2 etc. boards have any spurious responses in the receive tuning range.

Bare boards and kits for the boards mentioned in this article are available from Bill Kelsey, N8ET at Kanga US [1]. The price for the complete set is about the same as the price of a new ICOM 202 twenty years ago.

Building a complete microwave station from scratch is not a weekend project, but dedicated 5760 operators usually have time on their hands between contacts. This is especially true since the new rover rule eliminated microwave activity in remote grid squares.

[1] Boards and kits are available from:

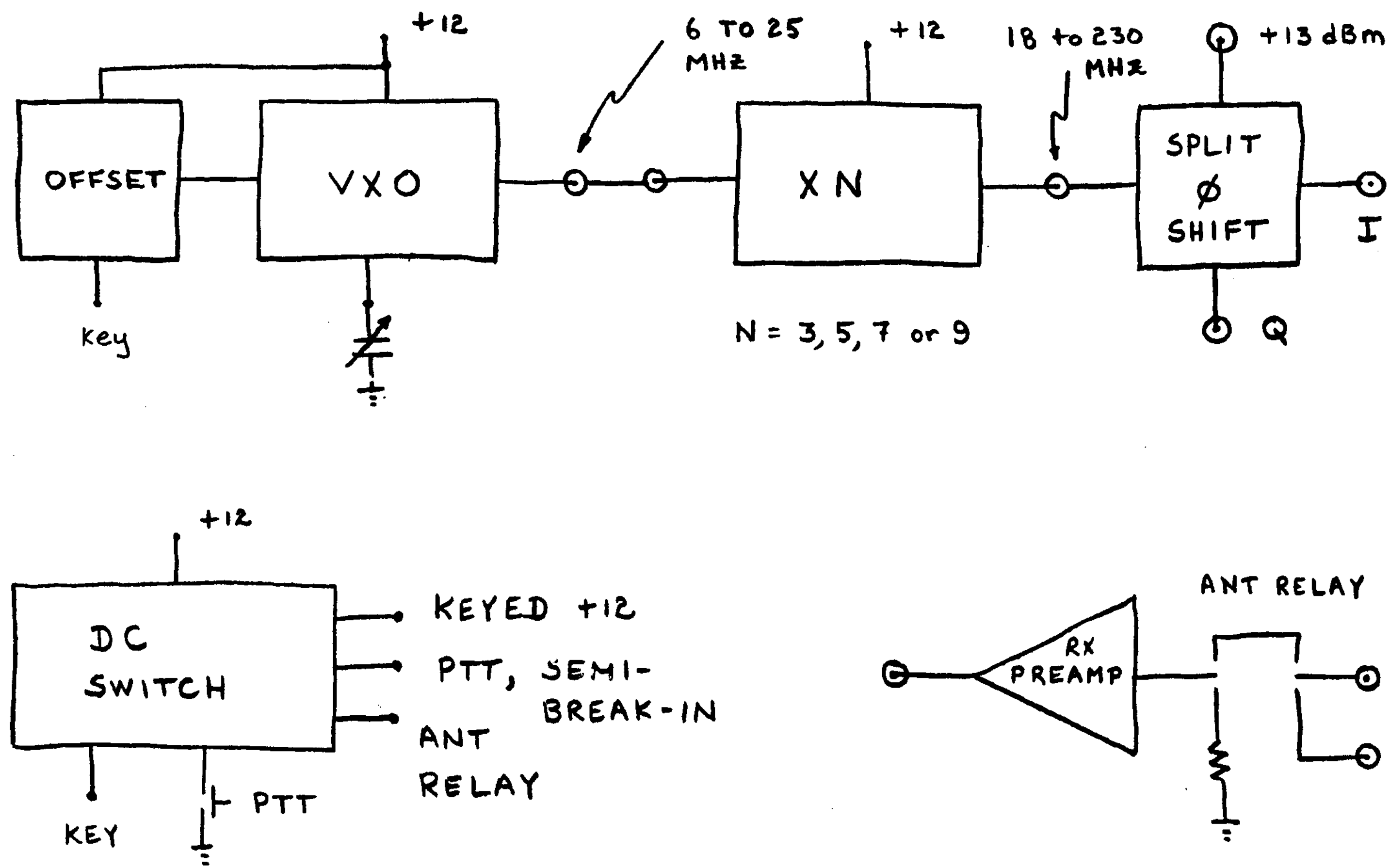
Kanga Products
Bill Kelsey N8ET
3521 Spring Lake Drive
Findlay, OH 45840
419 423-4604
email: kanga@bright.net



VXO SSB-CW TRANSCEIVER

RLC 4/12/95

FIGURE 1



LM2 BLOCK DIAGRAM

FIGURE 2

RLC 4/12/95

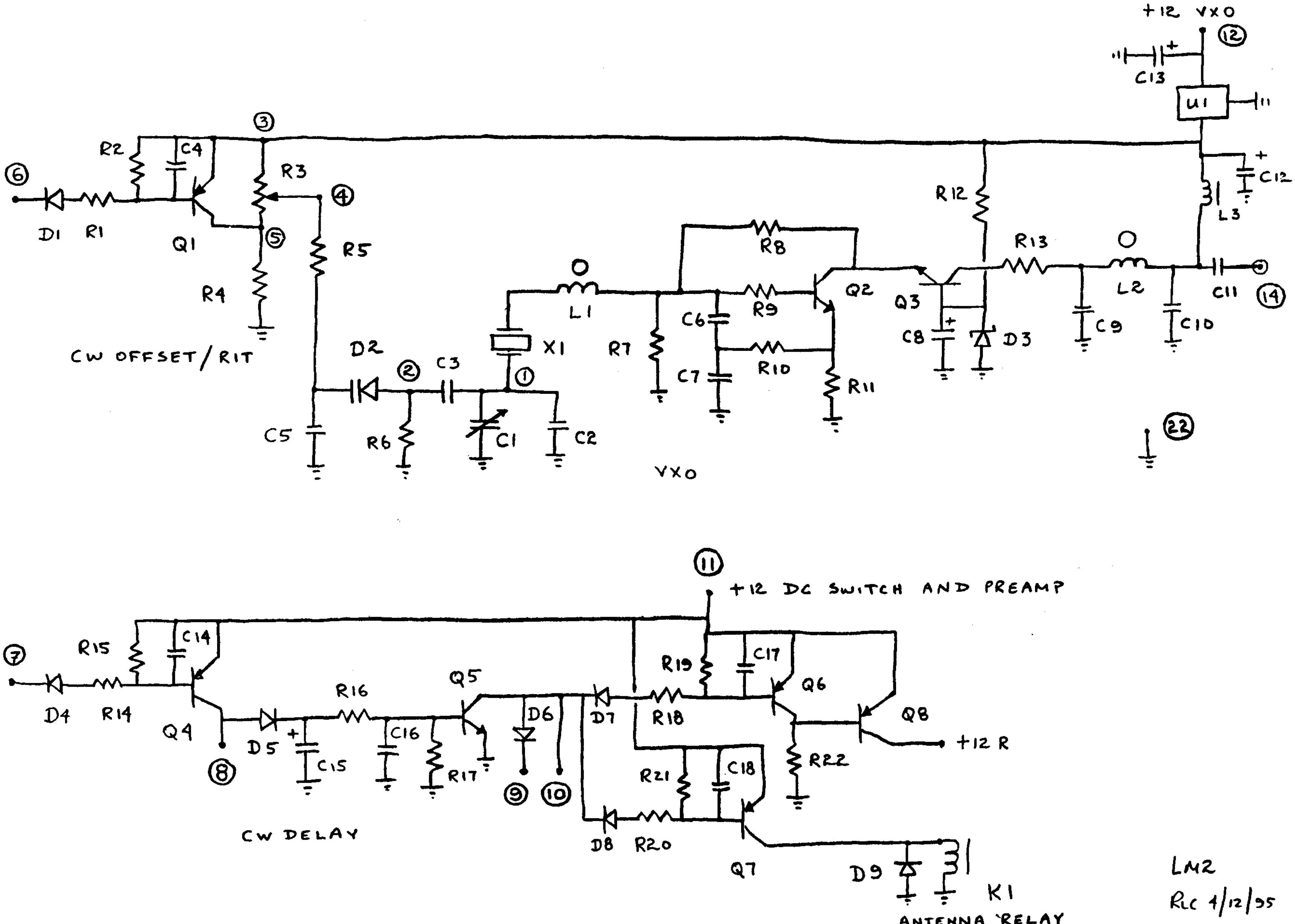

+12 VXO
C13
U1
C12
L3
R12
R13
R8
R9
R10
R11
Q2
Q3
C8
D3
L2
C9
C10
C11
X1
L1
R7
C6
C7
D2
C3
C1
C2
C5
R6
R5
R3
R4
R2
C4
D1
R1
Q1
CW OFFSET/RIT
VXO
+12 DC SWITCH AND PREAMP
R15
C14
D4
R14
Q4
D5
C15
R16
C16
R17
Q5
D6
D7
R18
R19
C17
Q6
Q8
+12 R
R22
R21
C18
D8
R20
Q7
D9
K1
ANTENNA RELAY
CW DELAY
LM2
RLC 4/12/95

FIGURE 3

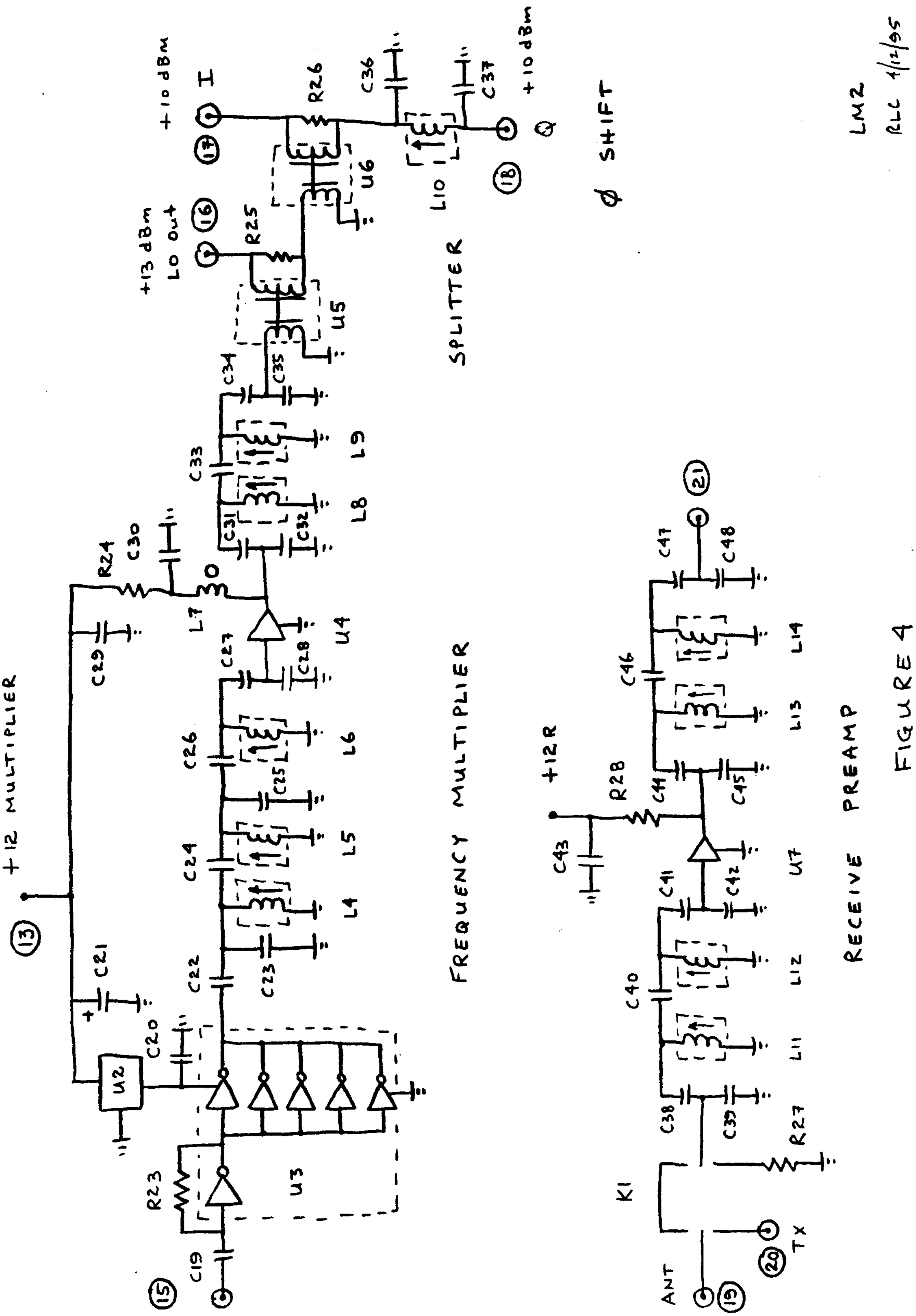

+12 MULTIPLIER
FREQUENCY MULTIPLIER
SPLITTER
+13 dBm
LO out
+10 dBm
I
Q
ϕ SHIFT
+12R
ANT
TX
K1
RECEIVE PREAMP
LM2
RLC 4/12/95

FIGURE 4

LM2 PARTS LIST

R1	4.7k	
R2	10k	
R3	50k Trimpot Panasonic 36C series	
R4	47k	
R5	100k	
R6	1M	
R7	10k	
R8	10k	
R9	33	
R10	22	
R11	510	
R12	3.9k	
R13	51	
R14	4.7k	
R15	10k	
R16	4.7k	
R17	10k	
R18	4.7k	
R19	10k	
R20	4.7k	
R21	10k	
R22	10k	
R23	1M chip	
R24	120 1/2 watt	
R25	100 chip	
R26	100 chip	
R27	51 chip	
R28	510	
C1	Approx. 40 pF variable Main Tuning	See Text
C2	Upper freq. limit or temp. comp.	See Text
C3	RIT range set	See Text
C4	0.1 uF Panasonic V series	
C5	0.01 uF disk ceramic	
C6	See Table 2	
C7	See Table 2	
C8	10 uF electrolytic	
C9	See Table 2	
C10	See Table 2	
C11	0.01 uF disk ceramic	
C12	4.7 uF tantalum	
C13	10 uF electrolytic	
C14	0.1 uF Panasonic V series	
C15	22 uF tantalum	CW semi-break-in delay
C16	0.1 uF Panasonic V series	
C17	0.1 uF Panasonic V series	
C18	0.1 uF Panasonic V series	
C19	22 pF chip	
C20	0.01 uF chip	
C21	10 uF electrolytic	
C22	See Table 1	
C23	See Table 1	
C24	See Table 1	
C25	See Table 1	
C26	See Table 1	
C27	See Table 1	
C28	See Table 1	
C29	0.01 uF chip	
C30	0.01 uF chip	
C31	See Table 1	
C32	See Table 1	

C33	See Table 1	
C34	See Table 1	
C35	See Table 1	
C36	See Table 1	
C37	See Table 1	
C38	See Table 1	
C39	See Table 1	
C40	See Table 1	
C41	See Table 1	
C42	See Table 1	
C43	0.01 uF chip	
C44	See Table 1	
C45	See Table 1	
C46	See Table 1	
C47	See Table 1	
C48	See Table 1	
L1	VXO range inductor 33t T37-2 toroid	See Text
L2	See Table 2	
L3	See Table 2	
L4	See Table 1	
L5	See Table 1	
L6	See Table 1	
L7	6 turns FT 25-43 ferrite toroid	
L8	See Table 1	
L9	See Table 1	
L10	See Table 1	
L11	See Table 1	
L12	See Table 1	
L13	See Table 1	
L14	See Table 1	
D1	1N4148	
D2	MV2107 or similar tuning diode	
D3	4.7 V zener	
D4	1N4148	
D5	1N4148	
D6	1N4148	
D7	1N4148	
D8	1N4148	
D9	1N4148	
Q1	2N3906	
Q2	2N3904 or PN5179	
Q3	2N3904 or PN5179	
Q4	2N3906	
Q5	2N3904	
Q6	2N3906	
Q7	2N3906	
Q8	2N3906	
U1	78L09	
U2	78L06	
U3	74AC04	
U4	MAV-11 or MAR-4 See Text	
U5	Toko splitter	
U6	Toko splitter	
U7	MAR-6	
K1	OMRON 65V-2-H	
X1	Crystal See Text	

Filter and Phase Shift Components

Table 1

Freq. in MHz	18	21	24	28	50	144	222
C_{22}	56	56	39	39	20	3.9	3.9
C_{23}	68	68	47	47	22	5.6	3.9
C24, C26, C33, C40, C46	10	10	10	10	5	1	1
C25	120	120	76	68	39	9.1	6.8
C27, C31, C34, C38, C41, C44, C47	180	180	120	120	56	12	8.2
C28, C32, C35, C39, C42, C45, C48	390	390	270	270	150	47	27
C36, C37	180	150	120	120	68	22	15
L4, L5, L6, L8, L9, L11, L12, L13, L14	422	422	422	350	226	108	53
L10	422	383	350	291	159	53	32

Notes:

1) All chip capacitors values in pF 1206 or 0805 series Panasonic

2) All inductors values in nH MC122 or MC134 series Toko with case

VXO Components

Table 2

Freq. Range MHz		6-8	8-10	10-15	15-20	20-26
C6, C7		220	220	150	100	82
C9		150	120	82	68	56
C10		680	560	390	330	220
L2	T37-2 core	24t	21t	19t	17t	16t
L3	molded iron core	18μH	15μH	12μH	8.2μH	6.8μH

Notes:

1) All C values in pF Panasonic 100v COG, Monolithic Ceramic

2) L2 suggested turns on T37-2 toroid core. Adjust for max. output across 50Ω

3) L3 J.W. Miller Epoxy Conformal Coated Iron core