Microwave Downconverter and Upconverter Update

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The Proceedings of Microwave Update 1995 paper "The Next Generation of No-Tune Transverters" provides an available-technology overview for designers of amateur microwave transverters. The following is a more detailed discussion of a few of the advances and digressions made at KK7B since then. One change that has occurred since 1995 is the adoption of new spectral purity requirements, which take effect in 2002. These are of great benefit to microwave amateurs, as they spell out for the first time realistic spectral purity requirements for amateur microwave transmitters. In general, standard-practice amateur microwave techniques below the 1 watt output level will comply with the new regulations, but higher powered transmitters will need additional filtering and shielding ("Unwanted Emissions Comments" June '98 QST pp 61 and 62). For virtually all amateur microwave work, the new regulations may be summarized very simply: all spurious outputs must be less than 50 microwatts (-13 dBm).

Amplifiers and commercial filters continue to improve, and MMIC mixers are finally becoming attractive for amateur microwave transverter designs. Choice of transmitter and receiver mixers must be approached with caution, since the constraints that apply in the cellular handheld industry (3 volt operation at the lowest possible current) do not generally hold for higher-performance amateur systems. Several MMICs in the TriQuint catalog will be discussed, in comparison with the conventional diode ring and microstrip-diode mixers in the present generation of transverters. Finally, a discussion of appropriate IF radios for microwave weak-signal work is presented.

Downconverters

Starting with receiver applications, a bench-mark is a standard-level minimum-loss packaged diode mixer from the extensive Mini-Circuits offerings, with a MAR-2 driving the LO port and a low-pass filter and MAR-6 on the IF port. This combination will have conversion gain of about 10 dB, noise figure of about 9 dB, input third-order intercept of about 14 dBm, and require about -5 dBm LO drive. As used in a typical no-tune transverter with 12 volt supply, the total current drain will be about 40mA, and total parts cost will be about $10. In comparison, the TriQuint 5M31 has conversion gain of about 3 dB, a noise figure about 9 dB and an input intercept of 10 dBm, with -5 dBm LO drive. Total parts cost should be less than $2. Performance is comparable. The three major advantages of the 5M31 are size, cost, and power. The 5M31 contains the mixer, LO driver amplifier and IF amplifier in a SOT-23-6 package. This is the tiny BFR-96 type package, but with 6 leads--use a magnifying glass. It requires a few non-critical additional components, about the same number as the diode mixer solution. The required PC board area is much smaller, and the power requirement is only 5mA at 2.8 volts.

The obvious advantages of the 5M31 are very attractive to designers of cell phones for mass production, but less so to an amateur building a single high-performance station. A more subtle advantage is that a receiver using a 5M31 will likely be easier to package and far less susceptible to the familiar "system oscillation when the box is closed" problem. Here's why: both the MAR-2 LO driver and MAR-6 IF amplifier in the diode mixer receiver front-end are wideband amplifiers, with outputs radiating into the enclosure. Oscillations can occur on any enclosure resonant frequency where the amplifiers have gain. In contrast, the 5M31 has a narrow-band LO driver and a narrow-band IF amplifier, both tuned by chip inductors. Furthermore, the high-level LO output-to-mixer connection and sensitive IF input are both on-chip, so they do not significantly couple into the enclosure.

Another advantage is that the 5M31 requires less than a milliwatt of LO drive, so the LO port may be connected directly to the output of a passive diode doubler. The opportunity to eliminate gain at the final frequency of the LO multiplier chain is significant for both amateur and consumer engineers. A preliminary data sheet for the 5M31 is included at the end of this paper.

Upconverters

For a transmitter, a similar bench-mark is a packaged Mini-Circuits mixer with a MAR-2 on the LO port and a second MAR-2 on the RF port--preferably after the first filter. This combination will require -5 dBm LO drive, have about 6 dB conversion gain (minus filter loss), and an output 1 dB compression of about +5 dBm (again, minus filter loss). As used in the present no-tune transverters, current drain will be about 50 mA at 12 volts. Cost will be about $10.

The equivalent circuit using a TriQuint 3601 balanced upconverter will have a conversion gain of about 13 dB, output 1 dB compression point of about 0 dBm and require -4 dBm LO drive. Cost should be less than $2. Power supply requirements are 2.8 volts at 18 mA, although in amateur applications it is perfectly safe to crank the supply up to 5 volts and obtain 3 dB more output power. Once again, performance is similar, with many of the obvious MMIC upconverter advantages being primarily of interest to cellular phone designers.

There are also subtle advantages to replacing a diode transmit mixer with a TQ3601. Since the 1 dB compressed output of the MMIC is about 0 dBm, the transmit frequency amplifier chain needs less overall gain to reach the final output power. Gain may be cheap, but stability is expensive. A transmitter with a standard-level diode mixer requires almost 40 dB gain just to reach the 1 watt level. This much microwave gain in one enclosure requires careful engineering. Increasing the output power of the basic upconverter stage may allow the designer to eliminate a separate enclosure for the PA or driver amplifier. Another advantage is that the 3601 LO port may be directly driven with the output of a simple passive diode frequency doubler.

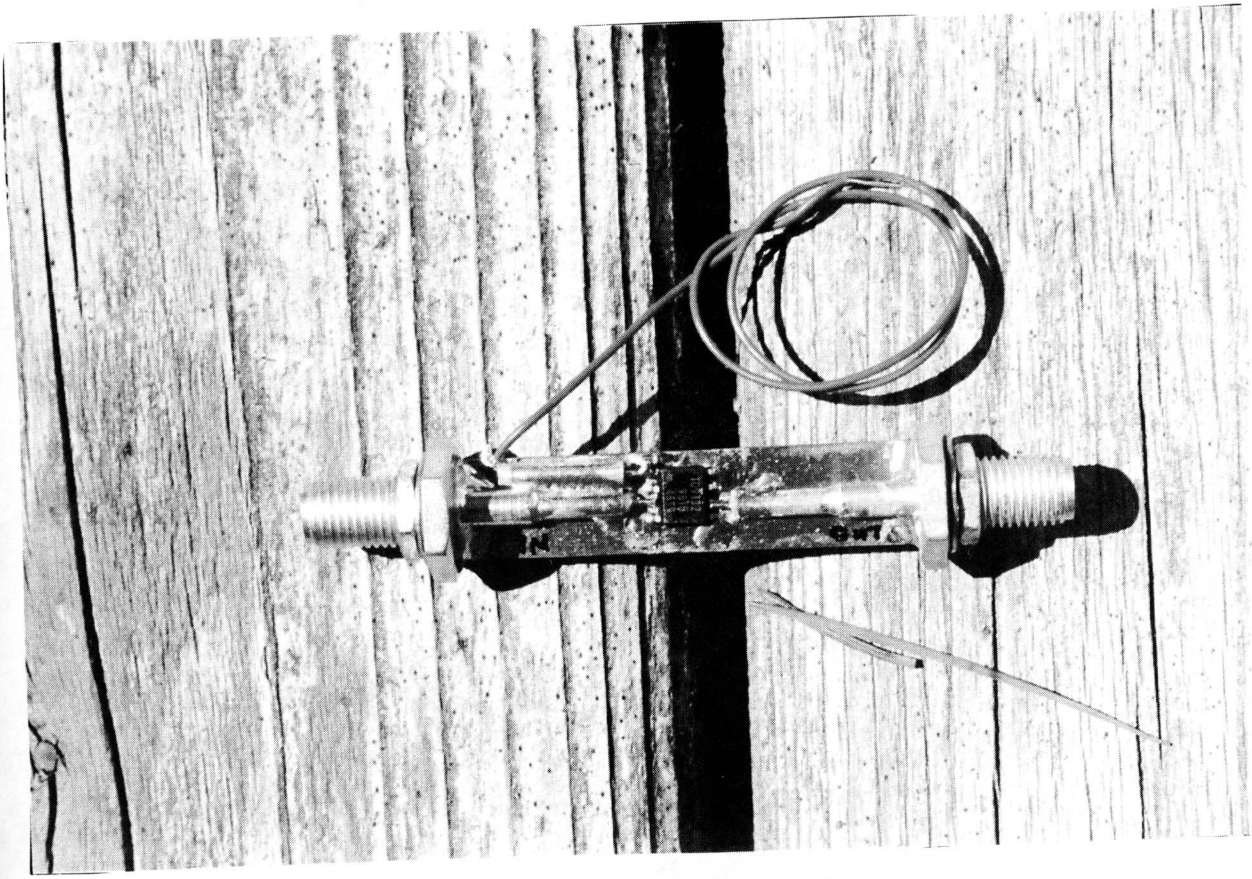
For both transmitters and receivers, the bottom line is that the only externally measurable performance advantage in replacing diode mixers with new MMICs is a reduction in operating voltage and current. This may be important for low-power amateur microwave systems that must be carried to the top of a mountain on the back of the operator, but is probably insignificant for the usual home and vehicle-portable stations. For new designs, however, there may be a significant cost and packaging advantage in replacing a pair of packaged diode mixers and four MMICs with a pair of tiny SOT-23-6 packages.

Regardless of the choice of mixer, high-performance amateur microwave systems--those that drive power amplifiers to more than 1 watt output and operate on hilltops in the presence of strong microwave interference--should use modular construction with the transmit and receive mixers and low-level stages built in separate boxes with SMA connectors. The open-board techniques commonly used a decade ago will no longer provide acceptable performance on hilltops shared with multiple 800, 900, 1800 and 2400 MHz transmitters.

Filters

One advantage of sharing amateur bands with other services is that inexpensive filters are available. It is more cost effective for a new 903 MHz transverter design to use inexpensive 900 MHz packaged filters than to devote the required PC board area to printed hairpin filters. At present, there are no high-volume users sharing the top end of the 1300 MHz amateur band, so printed hairpins are still useful. There are probably attractive filters for 2300 MHz and 2160 MHz on the horizon, and they will certainly out-perform printed hairpins on 0.063 FR-4 circuit board material. The performance advantage of using small three-resonator ceramic filters is significant: a typical cell-phone upconverter with a TQ3601 and PCS band filter provides 0 dBm output at 1 dB compression with all spurious outputs more than 50 dB down--all in less than 1 cm^2 circuit board area.

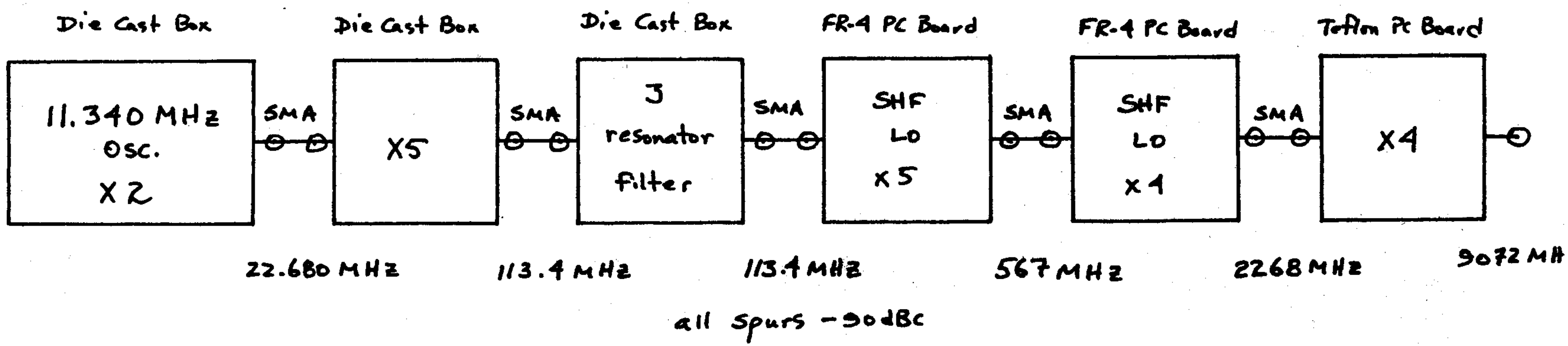
Amplifiers Amplifier technology is being pushed by the commercial microwave industry. It is prudent for the amateur system designer to enclose the basic transverter in a shielded enclosure with SMA connectors providing no more than +10 dBm transmit output and about 3 dB receive noise figures. This will permit real station performance upgrades (transmitter power, receive noise figure, spurious immunity and dynamic range) to be implemented as the technology improves and the surplus market coughs up new treasures. Amplifiers continue to improve. The TQ9132 is an example of how easy it is to obtain gain on the 900 to 2400 MHz bands. Even the input and output capacitors are included on chip, so gain blocks can be assembled by running semi-rigid coax right up to the pins. The construction method is shown in the photograph below. Note the use of a short piece of 085 semi-rigid and a chip cap to build a microwave feedthru for DC bias.



TQ9132 Amplifier

Local Oscillators Some real progress has been made in this area. The KK7B 10368 MHz transverter now has an entirely homebrew LO that draws 300 mA at 12 volts and drifts less than 4 kHz from a cold-start turn on--most of that in the first second. The block diagram of the LO system is shown in figure 1. The key to stability is a good, thermally shielded fundamental crystal oscillator running around 10 MHz. Multiplying up from 10 MHz to10 GHz is non-trivial. Any phase-noise or spurs at the input to the multiplier chain will be 60 dB stronger at the output. A good plan is to multiply up to about 100 MHz, pass the signal through a very good filter, and then use a phase-locked-oscillator brick to multiply up the rest of the way. A homebrew phase-locked oscillator may be built, but it needs either a machined cavity resonator or dielectric resonator. A phase-locked-loop multiplier using a commercial packaged VCO or (worse) an integrated PLL-VCO IC will most likely be too noisy for amateur SSB work above 2.4 GHz. There is a good reason that phase-locked oscillator "bricks" use machined cavities.

It is widely quoted that "phase locked loops can clean up phase noise." This is true, with one significant requirement: the free-running microwave oscillator must have lower phase noise than the desired Nth harmonic of the reference. This is achieved in "brick" oscillators, by using a precision machined cavity or dielectric resonator. Since the long-term stability of the cavity or dielectric resonator is generally not good enough for



KK7B 10368 Transverter LO

for 1296 IF

RLC 9/3/98

Figure 1

amateur SSB work, it is phase locked to the harmonic of a crystal oscillator, using a very narrow loop bandwidth. Inside the loop bandwidth, the phase noise is close to that of the reference, multiplied by N. Outside the loop bandwidth, the phase noise is primarily determined by the cavity or dielectric resonator. If the phase noise of the microwave oscillator is worse than the phase noise of the reference oscillator times N, the best that can be done is to use a wide loop bandwidth and achieve almost as good performance as a straight multiplier.

In practice, this means that the amateur has two choices for LO multipliers for the higher microwave bands:

1. A conventional oscillator-multiplier, as used in all of the amateur transverter kits.

2. A very seriously designed cavity or dielectric resonator phase-locked oscillator, widely available as surplus.

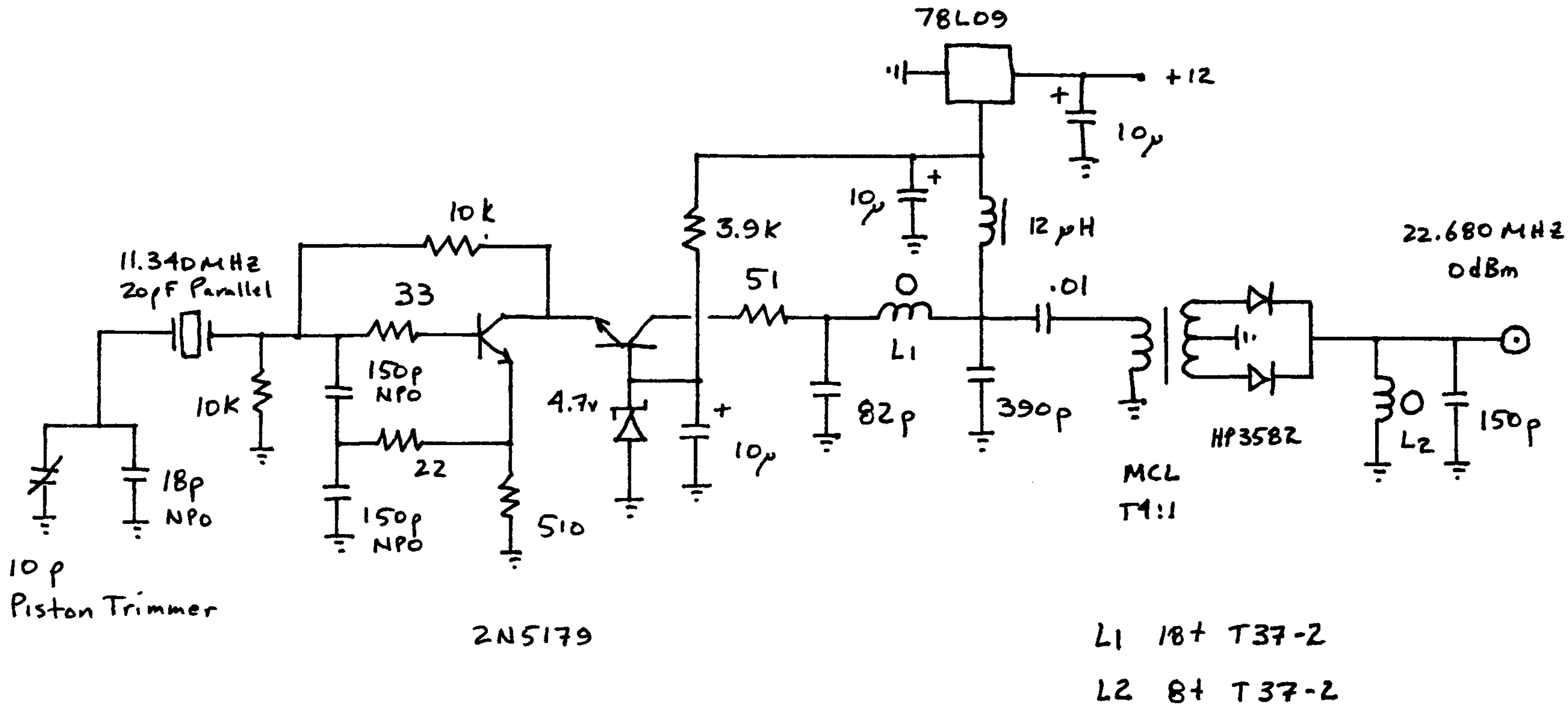
The conventional oscillator-multiplier will have slightly better close-in phase noise, and the phase-locked oscillator will have better spectral purity far from the desired output, all else being equal.

Other options will simulate rain-scatter on clear air paths.

Whatever the choice for LO multiplier chain, it is now clearly desirable to replace the old 100 MHz 5th overtone oscillator with a good fundamental oscillator followed by a clean multiplier and serious 100 MHz triple-tuned filter. This will provide hands-off SSB operation on 10 GHz and a dial that reads correctly to the nearest kHz. Note--you **must** use a piston trimmer in series with the crystal--1 kHz of frequency trimming at 10 MHz is more than a MHz at 10 GHz. It is impossible to set the frequency with a stiff half-turn air variable and screwdriver.

The oscillator-multiplier circuit used at KK7B is shown in figure 2. It is best to put the oscillator in a die-cast box and the X5 multiplier in a second die-cast box. PC board may be used for the multiplier, but it is better to build the oscillator "ugly style" on a piece of unetched copper-clad board firmly fastened to the die-cast box lid. The oscillator circuit was published by Joe Reisert as a frequency standard in his classic Ham Radio series on VHF. The spurious outputs from the multiplier chain are only about 45 dB down. This is not good enough. Multiplying from 100 MHz to 10 GHz will bring the spurs up 40 dB. The three-resonator filter in the third die-cast box was described by Wes Hayward in Mar/Apr '98 QEX. After the filter, the spurs are 90 dB down, which is acceptable.

In the KK7B version of the filter, the air-wound coils have a blob of clear silicon rubber across the turns to dampen mechanical vibration. Mechanical vibration phase modulates the carrier, and is quite audible after multiplying the signal up to the final frequency.



Stable Oscillator

X2 Multiplier

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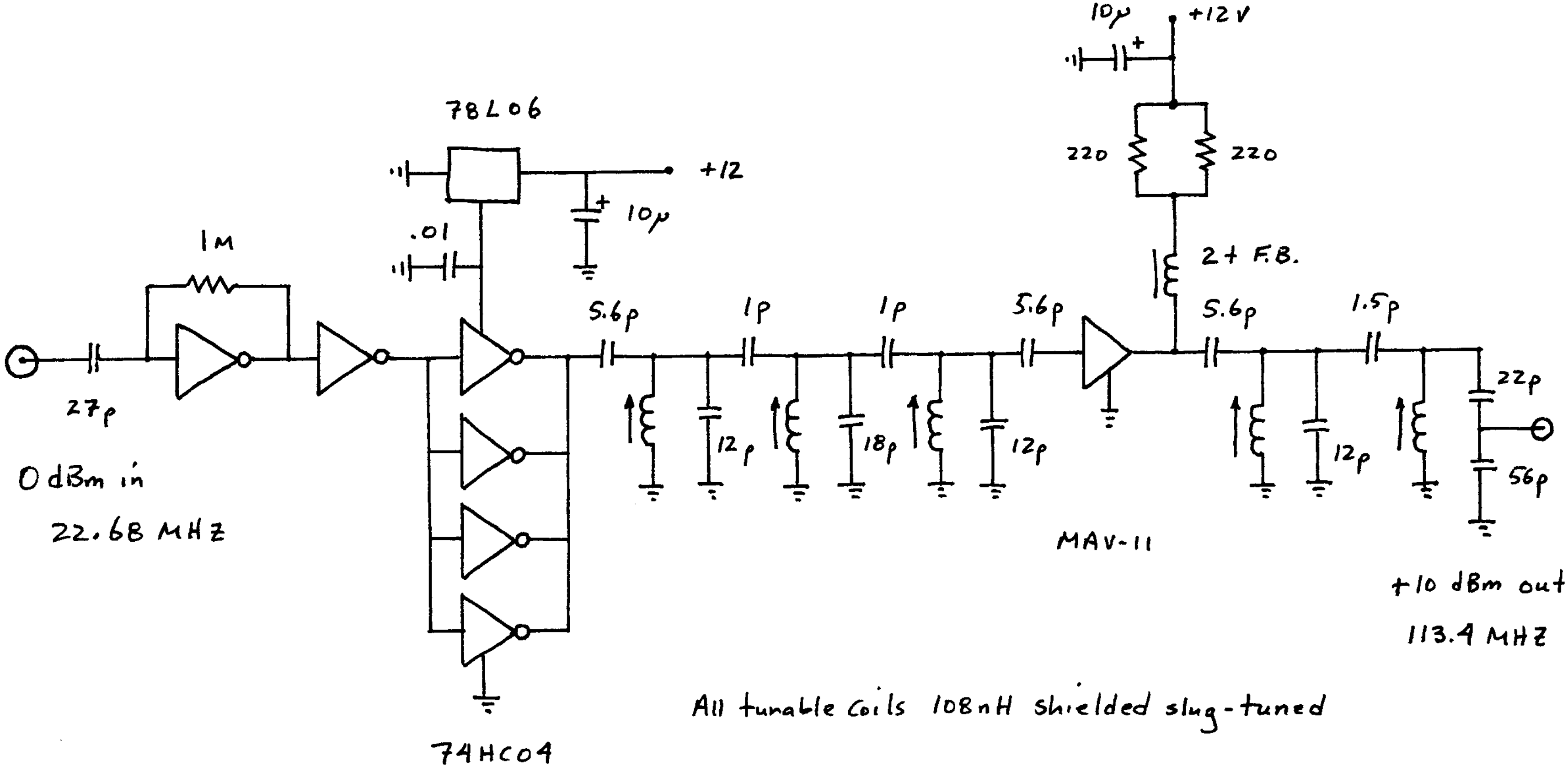
Figure 2a



X5 Multiplier

Figure 2b

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These three die-cast boxes are certainly a more ambitious approach to a microwave oscillator than the traditional 5th overtone variety, but the benefits are worthwhile, especially above 2.4 GHz. This approach is particularly attractive for battery-powered portable work. The quick warm-up allows the equipment to be left off until a few minutes before it is needed. Since the only frequency determining element is the fundamental crystal oscillator (which draws a few mA) the rest of the circuitry may be turned off when not actually transmitting or receiving. As a fringe benefit, the amateur passion for setting the transverter oscillator so that the IF rig digital display reads correctly may be exercised (until the threads on the piston trimmer fail). To zero the display to the last decimal point, it will be necessary to have a "fine" frequency control in addition to the piston trimmer. This may be implemented by using an LM-317 voltage regulator with a ten-turn pot to fine-tune the oscillator voltage.

A final recommendation for high-performance amateur microwave LO systems is to have each frequency multiplier in a separate box, with connection to the next stage using SMA connectors and semi-rigid cable. This facilitates testing and troubleshooting, and makes it easy to add filtering to the LO system as needed. There is no need to completely redesign well established "no-tune" circuitry--just cut up the large transverter board into smaller functional blocks.

Packaging

Geographic location has a profound influence on packaging of microwave systems. In some parts of the world, the best portable microwave sites are accessible by car. In others, there is no need to operate portable at all because trees are rare and the horizon is distant. In still others, "hilltopping" involves the use of an ice axe, and every ounce needs to be counted. Packaging is where the most creativity is required in assembling an amateur microwave system, because everyone has different needs. A few general guidelines are all that can be provided.

1. Use interconnecting BNC cables below 1 GHz and SMA cables above, so that individual sections (IF, LO etc.) may be tested in the field with simple equipment.

2. Standardize DC connectors, and for those with the luxury of entirely homebrew systems, microphone and headphone connectors.

3. Allow the system to evolve. Don't build a complete 9 band microwave station before ever getting on the air--every operating experience will change the way you think about how things should be done.

4. For portable systems, use lots of double-sided-tape, duct tape, velcro, cardboard, bailing wire etc. This encourages evolution, keeps weight under control, and makes field repairs possible. From personal experience, the nicer portable equipment looks, the less it gets used.

IF

Two decades ago, the standard amateur microwave SSB-CW station included an ICOM-202 and a transverter. While available transverter performance has steadily improved, IF rigs have gone down hill. Prices have skyrocketed while performance has suffered. In place of real performance improvements, manufacturers have added a series of clever but useless whistles and bells. Since the ICOM 202, 2 meter transceivers have added all-modes (sacrificing close-in dynamic range), synthesizers (sacrificing noise floor on both transmit and receive), extended receiver tuning range (sacrificing sensitivity and overall dynamic range, and making hilltop operation impossible without the use of an external cavity filter), additional VHF and UHF bands (sacrificing operational simplicity and price) and finally HF bands. The ICOM706 and its competitors have created a real boost in VHF band occupancy, and have provided thousands of hams with their first taste of weak-signal VHF DX. A multiband-multimode is not the best choice as a microwave IF, however. It is a Pentium II with uninstalled Paint Shop Pro and hardware compatibility problems, when a pencil and paper is needed.

Amateur microwave operators don't (intentionally) stray very far from the calling frequency. They use USB and CW, and need to switch back and forth without retuning. The ideal microwave IF has a big tuning knob, a volume control, a microphone jack, a headphone jack and a key jack. Real radio performance--output power, receiver noise figure and antenna gain--are determined by the rest of the station, not the IF. The new low-cost single-band VHF boxes appear to be ideal--but they make performance compromises to achieve low cost. A strong microwave transverter connected to a weak IF radio makes a very weak microwave station. What is needed is the combination of simplicity and high performance--a Ferrari, not a Yugo.

A few amateur microwave enthusiasts have discovered the no-compromise world of entirely homebrew IF systems. The KK7B home station microwave IF includes the following:

1. Eddystone dial readable to within 1 kHz
2. 3 bandwidths (3.1 kHz 2.4 kHz and 0.7 kHz)
3. Automatic mode switching (semi-break-in CW if I touch the key, USB if I pick up the mike--without retuning)
4. RF gain control with calibrated 6 dB steps from 0 to 72 dB
5. Output signal-to-noise floor meter
6. Better phase noise than a Ten-Tec Omni VI
7. Low-distortion product detector and audio power amplifier
8. Front-panel switching of transverters from 222 MHz through 10 GHz
9. 2 dB noise figure
10. 0 dBm output power
11. All spurious transmit outputs and receiver responses more than 70 dB down
12. 96 dB two-tone third-order dynamic range
13. 62 dB audio output dynamic range (not as good as CD, but better than FM stereo)

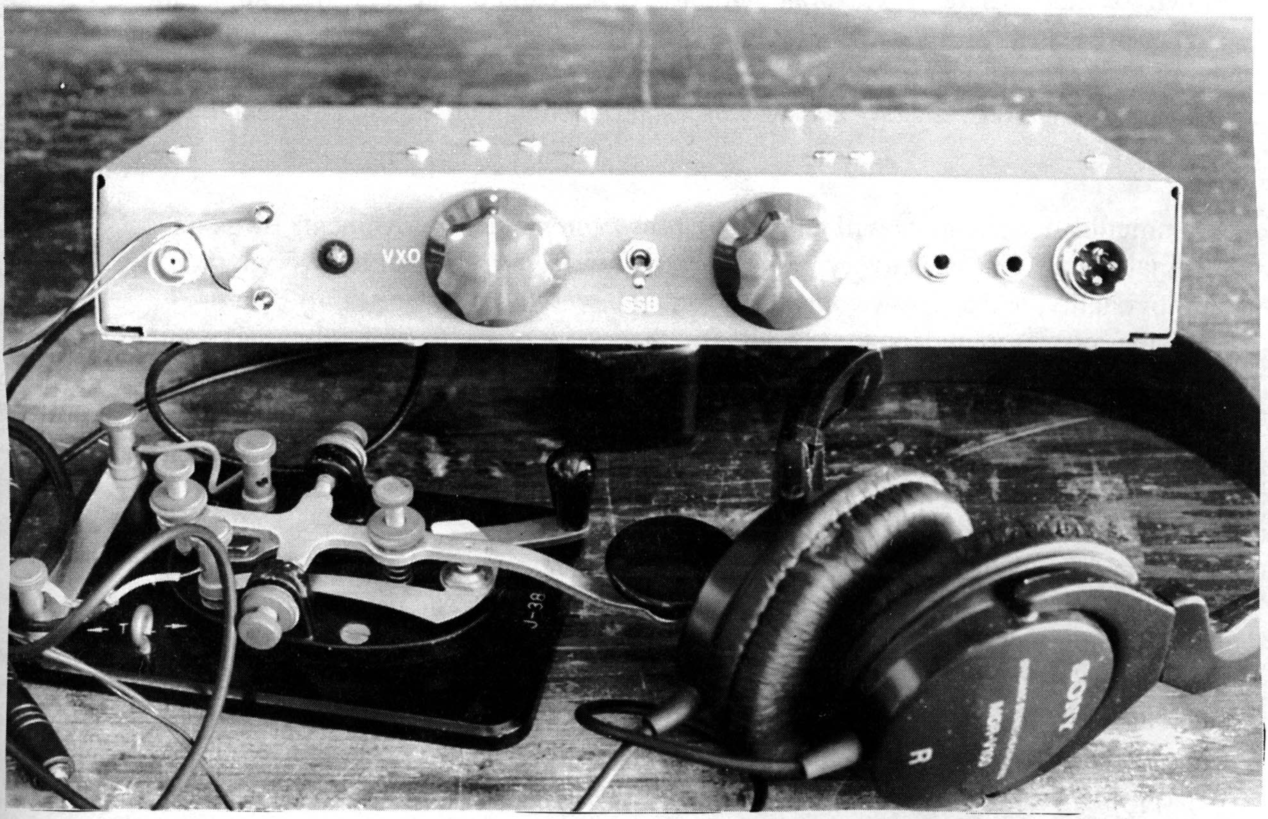
KK7B Home Station UHF IF

No plans, descriptions or schematics are provided--the basic circuitry has been published in QST, and preferences, junkbox, tools and skills are very personal. This is not a weekend project--it is approximately the radio equivalent of designing and building a boat.

For portable use, there are two 144 MHz VXO rigs, identical except for packaging and built exactly as described in CSVHF Proceedings 1995 using the three board set available from Kanga US.

When the latest generation of wide-band receivers was introduced (the ICOM PCR-100 is a good example) visions of a set of companion transmitters and receive converters to build a truly tiny portable system for 50 MHz through 10 GHz came dancing. The first test reports threw a wet blanket on the project, however, revealing the deadly combination of poor sensitivity and abominable dynamic range. Sensitivity can be improved by adding a preamp, and dynamic range can be helped by adding an attenuator. Since KK7B is line-of-sight to the broadcast towers serving Portland and no grid-expeditions to remote valleys are planned, neither option is acceptable.

As the microwave bands become more and more crowded with strong non-amateur signals, microwave operation from good locations will require a more serious approach to receivers. Rumor has it that at least one well-known microwave EME operator is now using a 75A4. (A classic Ferrari is fine, if you have the skills keep it running.)



144 MHz VXO IF Rig

Other Modes

CW and SSB are old. Amateur SSB operation is almost as old as the average ham. In a world where a 14 year-old kid with a 486 is the laughing-stock of his Pentium MMX buddies, the use of such antiquated modes by the cream of the amateur crowd is clear evidence that amateur radio must be a dying art.

There is a serious flaw in this argument. SSB and CW are still around because they work. They are the modulation equivalent of cars with 4 wheels and bicycles with 2. It takes a little skill to ride a bike, but you can get farther with less energy than just about any other form of transportation. Cars have four wheels because that is the right number, and SSB and CW are useful because they are efficient.

When CW was introduced, it was technically advanced compared with spark. SSB was technically advanced compared with double-sideband AM. SSB and CW are no longer "advanced" modes in any sense of the word. They are basic. A pure sine wave is the easiest signal to separate from noise, for an EME operator listening for weak echoes, or an astronomer looking at the Hydrogen line. This is not marketing hype, it is basic physics. SSB is efficient because the entire received signal is linearly translated from RF down to audio, where the ear-brain neural-network can operate on it with millennia of signal-processing software development specifically directed toward recovering weak human speech from an incredible variety of random and deterministic interfering noises. A computer can't even copy CW as well as a trained human, let alone speech buried in noise.

Communication theorists will tell you that they can make improvements by using "signals designed for recovery." The basic requirement for signal recovery is orthogonality, and a sine wave is orthogonal to everything (hence Fourier theory). Amateur efforts to understand modulation theory are often hampered by marketing hype from the cellular industry. Millions of dollars are spent to convince us that "CDMA is the wave of the future" and "Digital PCS offers better voice quality and improved talk time." Buzzwords like "processing gain" are bantered about--usually by people who can't define them mathematically.

Each modulation technique has advantages and disadvantages, but amateurs operating with weak signals over long paths are much closer to the basic physics than cell-phone systems in urban areas. It has been suggested in the amateur press that the "processing gain" from CDMA will permit EME operation at significantly lower power levels than are currently needed. This is false. EME contacts are made against a background of almost pure white noise, and the information rate is slowed to the point where only the QSB peaks are used for communication. Thus two of the real benefits of a proper CDMA system: suppression of non-random interference; and ability to coherently combine signals received over different paths, are already available to a traditional CW EME operator. There are theoretically correct ways to use a computer to reduce the power requirements on EME, but they don't involve CDMA.

Advanced modulation techniques are an interesting facet of communications, and one that occupies some of the most talented minds in and out of amateur radio. CW is, however, the most basic mode for weak signal VHF work. It makes the most efficient use of transmitter power and ear-brain processing, and it is robust to every kind of natural propagation anomaly encountered to date. Someday we may forget CW. We may also forget that we used to go to the moon.

TriQuint SEMICONDUCTOR

Preliminary
Advance Product Information

WIRELESS COMMUNICATIONS DIVISION

Data subject to change without notification

3V Downconvert Mixer IC — TQ5M31

Selected Electrical Characteristics

Test Conditions: V_{DD} =2.8 V, T_A = 25° C

Parameter	Min	Typ	Max	Units
RF Frequency Range	750	900	2500	MHz
LO Frequency Range	795	1000	2750	MHz
IF Frequency Range	45	110	250	MHz
Conversion Gain	2.5	3.5	4.5	dB
Noise Figure		9.5		dB
Input IP3		10		dBm
Supply Current: Cellular band		4.5		mA
Supply Current: PCS band		5.5		mA
Supply Current: ISM band		6.5		mA

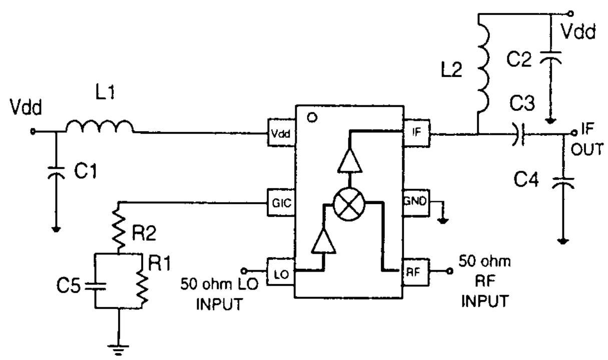
Primary Application(s)

- TDMA / CDMA mobile applications
- AMPS/CDPD
- ISM / general purpose

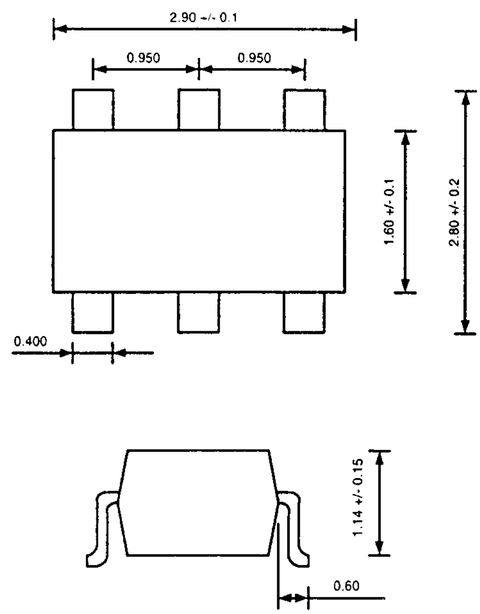
Key Features

- Small size
- Few external components
- Low current
- High IP3 performance

Application Circuit



Package: SOT-23 6



*Package Dimensions in mm

Bill of Materials

Ref Des	Value	Size
C1	1 nF	0402
C2	0.01 µF	0402
C3	10 pF	0402
C4	8.2 pF	0402
C5	Select	0402
R1	Select	0402
R2	Select	0402
L1	12 nH	0402
L2	180 nH	0805

Note: C5, R1, R2 are select components for gain/IP3 adjust

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TriQuint SEMICONDUCTOR

WIRELESS COMMUNICATIONS DIVISION

Preliminary
Advance Product Information

Data subject to change without notification

3V PCS Upconverter IC X3601

Selected Electrical Characteristics

Test Conditions: V_{DD} =2.8 V, T_A = 25° C

Parameter	Min	Typ	Max	Units
RF Frequency Range	1300		2500	MHz
LO Frequency Range	1600		2500	MHz
IF Frequency Range	45		500	MHz
Conversion Gain		15		dB
LO output at RF port[1]		-30		dBm
Output Power		0		dBm
Output IP3		+10		dBm
Mixer LO Return Loss		10		dB
Supply Current		15		mA

[1]LO suppression varies over frequency range. LO output at RF port is typically <-30dBm within 50 MHz of design center.

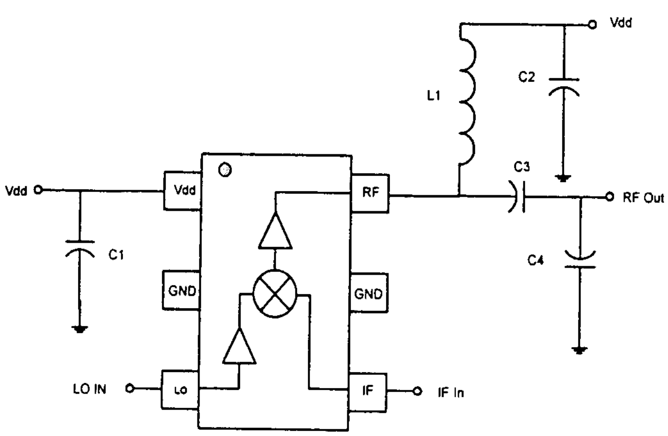
Primary Application(s)

- PCS TDMA/CDMA
- PHS/ISM
- General Purpose

Key Features

- Small size
- Few external components
- Low current
- High IP3 performance
- Balanced Mixer
- 2.7 to 4.5 volt supply

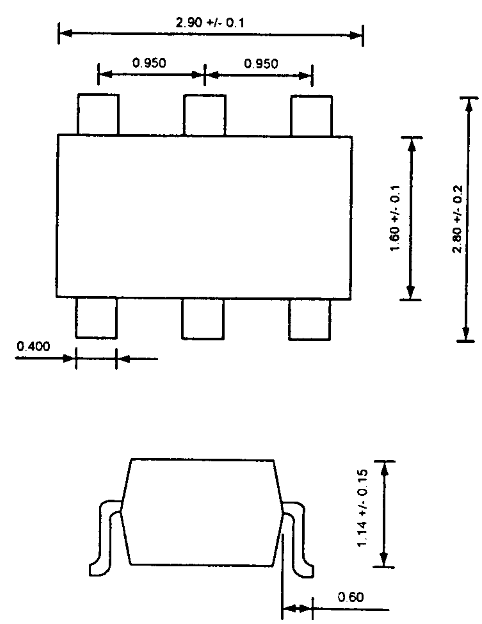
Application Circuit



Bill of Materials

Ref Des	Value	Size
C1	5 pF	0402
C2	5 pF	0402
C3	2.2 pF	0402
C4	3.3 pF	0402
L1	4 nH	0402

Package: SOT-23 6



*Package Dimensions in mm

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7/16/98 REV. C

TriQuint SEMICONDUCTOR

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WIRELESS COMMUNICATIONS DIVISION

Data subject to change without notificaiton

3V Cellular Upconverter IC X3101

Selected Electrical Characteristics

Test Conditions: V_{DD} =2.8 V, T_A = 25° C

Parameter	Min	Typ	Max	Units
RF Frequency Range	500		1500	MHz
LO Frequency Range	800		1500	MHz
IF Frequency Range	45		500	MHz
Conversion Gain		15		dB
LO Output at RF port[1]		-30		dBm
Output IP3		+10		dBm
Mixer LO Return Loss		10		dB
Supply Current		15		mA

[1]LO suppression varies over frequency range. LO output at RF port is typically <-30dBm within 50mhz of design center.

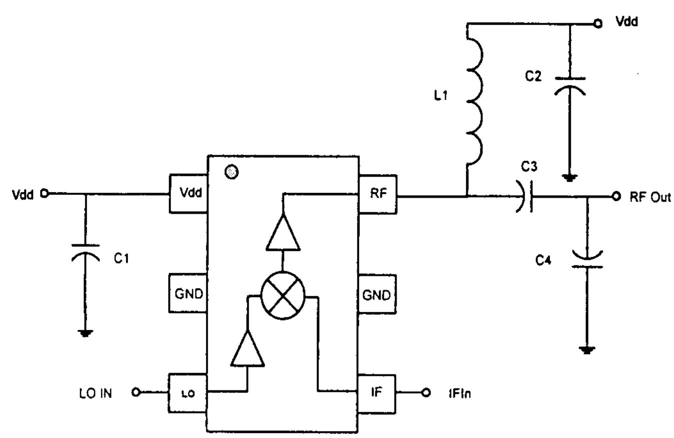
Primary Application(s)

- Cellular TDMA/CDMA
- AMPs/CDPD
- Cordless 900MHz/General purpose

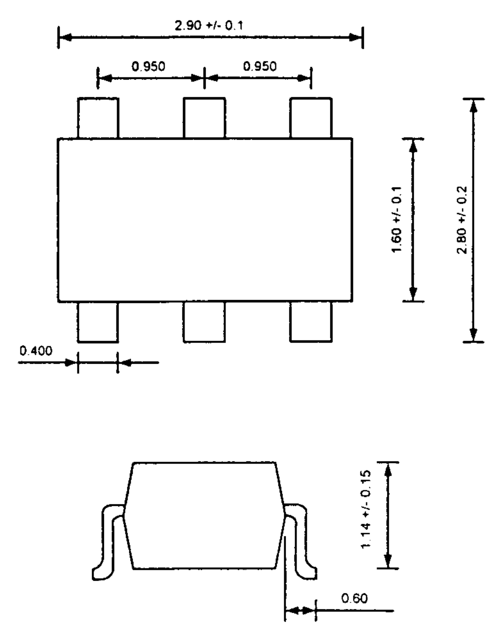
Key Features

- Small size
- Few external components
- Low current
- High IP3 performance
- Balanced Mixer
- 2.7 to 4.5 volt supply

Application Circuit



Package: SOT-23 6



*Package Dimensions in mm

Bill of Materials

Ref Des	Value	Size
C1	10 pF	0402
C2	10 pF	0402
C3	4.7 pF	0402
C4	6.8 pF	0402
L1	10 nH	0402

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