RADCOM TECHNICAL FEATURE

An S band to 70cm receive converter for P3D

David Bowman, G0MRF*

A RECENT SURVEY of satellite users world-wide revealed that only 3% were active on mode S. With the re-entry of Oscar 13, we have now sadly seen the end of a mode S transponder that has given years of reliable service and to one of the most appreciated and successful experiments to be carried on an amateur satellite. For those 3%, operating mode S meant working at the cutting edge of satellite communications. On Oscar 13 the 2400MHz transmitter was usually run at a power of less than 1 watt into its small eight-turn helix. When working mode S on the satellite a typical receive station could consist of a 0.6 metre dish but needed a high performance receive converter having a noise figure of around 0.6dB. With this system it was very easy to receive the satellite's signals over distances of 35,000km.

With Phase 3D, the S band transmitter will operate at powers in excess of 40 watts and have an antenna gain at least 6dB or four times greater than Oscar 13. The receive converter described here, together with a small helix antenna 0.5m long, will give excellent results with the new satellite.

**31 Benson Close, Hounslow, Middlesex TW3 3QX*

This circuit was originally outlined at the 1996 AMSAT UK Colloquium and published in *Oscar News* October 1996.

DESIGN OBJECTIVES

THIS PROJECT HAS been designed for home construction, with performance only one of several considerations. These include:

1) System Noise figure of less than 2.0dB
2) Conversion gain of > 20dB
3) Low cost consistent with ease of construction
4) One PCB with low component count
5) Robust and easy to reproduce
6) Easy to align. ie, No complicated test equipment and less than 15 minutes!

The final result of this process has been to produce a receive converter which I believe meets the design criteria. Testing of a prototype on a Hewlett Packard 8970A Noise Figure meter showed a System noise figure of 1.85dB with a conversion gain of 32dB.

MODERN MICROWAVE COMPONENTS

THE LAST FEW YEARS have seen a rapid growth in UHF and microwave telecommunications. The expansion of this industry, which is rightly seen as a threat to our amateur allocations, has also led to the development and mass production of some very useful RF devices. The trend in current microwave design is to use components that are internally impedance matched to 50Ω. Our circuit maximises the use of these easy to use and reliable 'building blocks' - Gain is provided by Monolithic Microwave Integrated Circuits (MMIC). The mixer used has schottky diodes and matching transformers mounted inside its ceramic case and the filter has four connections: Input, output and two to ground. A degree in plumbing is definitely not required!

The first amplifier used at the antenna input largely determines the overall sensitivity of a receiver. The Low Noise Amplifier (LNA) used here was introduced by Hewlett Packard in 1996. The MGA86563 is a high gain LNA usable within the 500MHz to 6GHz frequency range. It is a 3 stage GaAs FET MMIC con-

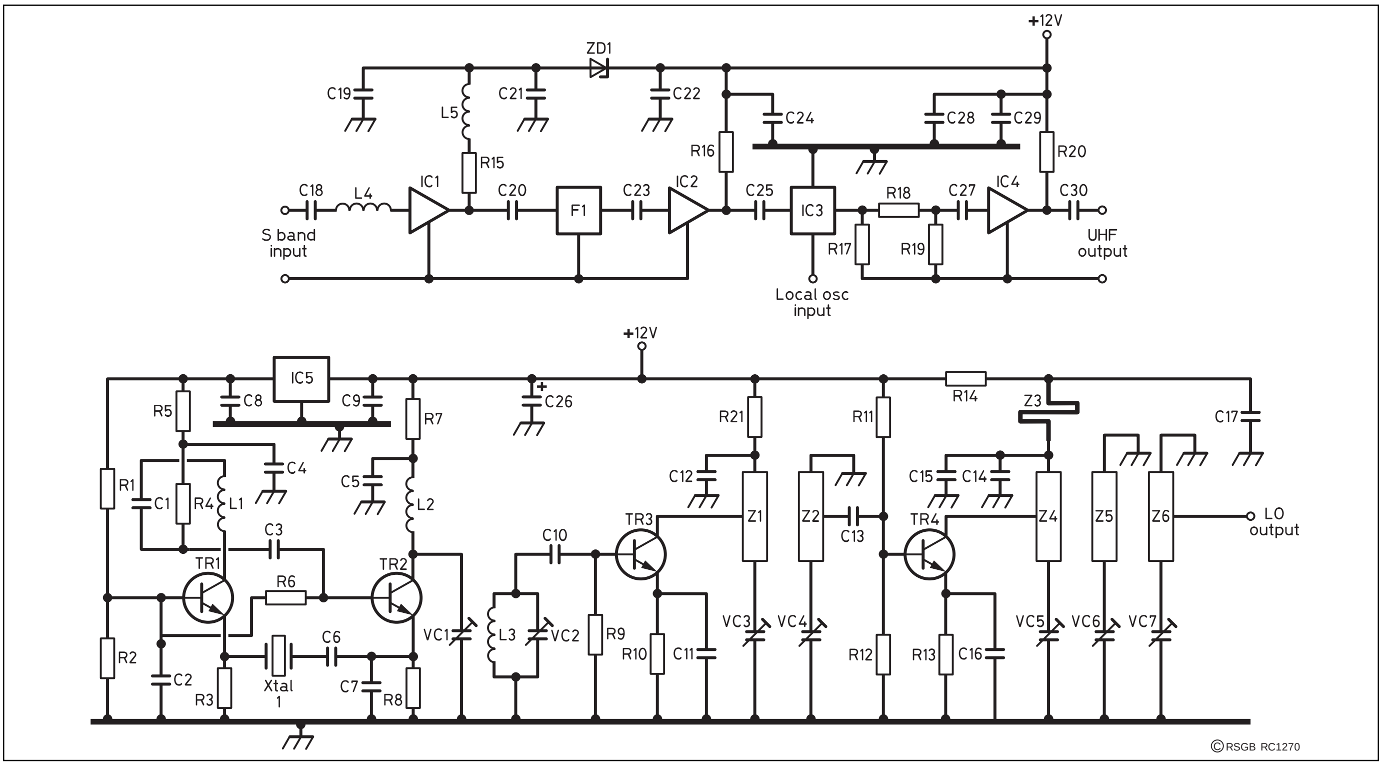

Fig 1: S band converter, circuit diagram.

structed using 'State of the Art PHEMT technology'. The device requires a nominal 5 Volt supply at 14mA, but unlike other similar products, can operate from higher voltages thanks to an internal bias regulator.

The converter is constructed on a standard 62mil (1.58mm) double sided FR4 fibreglass PCB. While this material is not the best choice for use at this frequency, it is more robust and easier to handle than boards using very thin PTFE substrates.

I also decided early on in the project to use surface mount components. I realise that this may discourage some potential constructors but there are two indisputable reasons for doing so. Firstly, I found that the local oscillator section could be built using four transistors using surface mount devices (SMD) but needed an extra stage if I used conventional components. Secondly, there are many opportunities for leaded components to be incorrectly inserted into a PCB. Long wires usually equal a non-functioning circuit at S band. With a surface mount component, if it's in the right place and soldered correctly, then it'll work. As a compromise, I've used the largest variety of SMD for ease of handling.

CIRCUIT DESCRIPTION

THE LOCAL OSCILLATOR is based on an excellent design by Sam Jewell, G4DDK. Sam's original circuit has been adapted in this application for surface mount construction and optimised for a frequency range of approximately 1700 to 2000MHz. The circuit diagram is shown in **Fig 1**.

Crystal X1 is a 5th overtone unit with a frequency of 109.333MHz. Transistors TR1 and TR2 form a Butler oscillator with L1/C1 tuned to the crystal frequency. The output at the collector of limiting amplifier TR2 contains a high level of harmonics and tuned circuits L2/VC1 and L3/VC2 select the third harmonic at 328MHz. TR1 and the base of TR2 operate from a 9V supply produced by 100mA voltage regulator IC5. TR3 is a frequency multiplier which triples the frequency from 328 to 984MHz. The input is coupled to the base of TR3 by C10. The value of C10 is only 4.7pF which allows enough signal through to drive TR3, but is small enough in value not to degrade the Q factor of L3/VC2, and to provide some rejection of any residual 109MHz. R9 provides a constant load for the drive and sets the bias point for TR3 ensuring the generation of harmonics.

The output of TR3 is a two-stage bandpass filter constructed using microstrip techniques. Z1 and Z2 are inductively coupled, shortened quarter wavelength lines, etched onto the printed circuit board. Each line is tuned by a variable capacitor (the high impedance end) and is AC coupled to ground at the other (low impedance) end. The transistor is impedance matched into the filter simply by tapping onto Z1 at the appropriate point.

The final stage in the Local Oscillator is a frequency doubler, from 984 to the output frequency of 1968MHz. The input is coupled to the base of TR4 by C13. The transistor is biased to class B by applying approximately 0.6 Volts to the base produced by potential

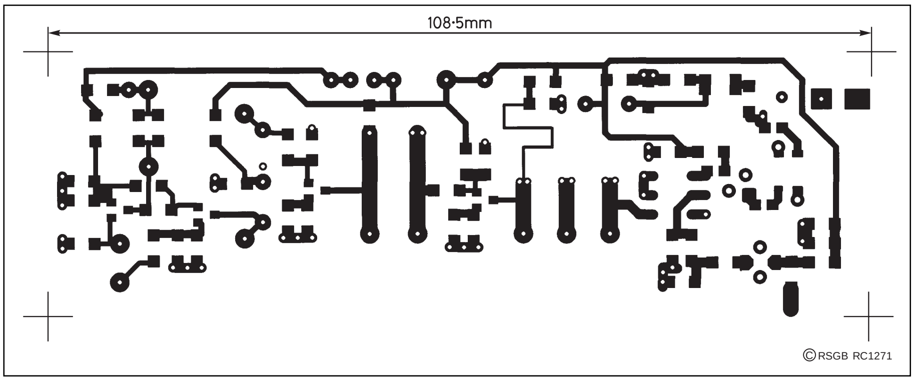

Fig 2: PCB trackside (underside) layout.

divider R11, R12. The collector supply is fed to the transistor via stripline Z4 with RF decoupling performed by C14 and C15. During development I found that the standard 1nF chip capacitors were not very effective at decoupling frequencies above 1GHz. The addition of the porcelain American Technical Ceramics capacitor C14 increased power output by 50%. A further increase was achieved by including the quarterwave high impedance transmission line Z3.

The output at 1968MHz is taken from the collector and applied to another microstrip bandpass filter. A three section filter was selected to allow effective filtering of the local oscillator. Any spurious signals will cause unwanted products to appear at the output of the converter. The filter, Z4 Z5 and Z6, provides a clean output of 5mW with unwanted products suppressed by at least 42dB. Each stripline is tuned by a variable capacitor as in the previous stage, but here the type of trimmer chosen is important. The green SKY trimmers, see Note [1], specified have a maximum value of 5pF, but more importantly, have a minimum capacitance of only 0.5pF. Any substitute should have a minimum capacitance of not greater than 0.75pF. This will limit the choice to foil or ceramic types which are physically small, or to trimmers of the piston variety.

THE RF SECTION

THE ENTIRE RF section is constructed from modern 50Ω block components. The amplifiers, filter and mixer are all internally matched to 50Ω and consequently there are no adjustments to be made. The broadband characteristics of the devices used mean that this converter receives all frequencies from 2400 to 2500MHz and converts them to 432 to 532MHz

The input at 2400MHz is passed via a low loss ATC capacitor C18 and matching inductor L4 to the LNA IC1. Supplying voltage to the LNA requires some care as it is only conditionally stable at some frequencies. My final solution was to use RF choke L5 with a series resistor R15 to reduce the Q and ensure stability. Zener diode ZD1 drops the 12 Volt supply to 6.4 Volts which is within the limits of IC1. The LNA output feeds bandpass filter F1. This filter has a bandwidth of 100MHz and is manufactured from the same type of ceramics technology found in dielectric resonant oscillators. The centre frequency is 2450MHz providing an ideal response for S band satellite operation. The manufacturer's data sheet shows a mid-band insertion loss of 1.16 dB with a LO rejection of -35dB. Image frequency rejection is off the graph supplied by Toko but in reality is likely to be limited by coupling between PCB tracks. IC2 is a standard MAR6 MMIC which has a gain of 10dB and a noise figure of 4dB. This feeds a Mini Circuits RMS30 double balanced mixer. The RMS30 is specified to 3GHz and has internal matching on all ports. The output is taken from the IF port to a -3dB resistive attenuator. This was included because the input of the 432MHz amplifier IC3 may not be 50Ω at all frequencies emerging from the mixer.

CONSTRUCTION AND TESTING

THE PCB IS DOUBLE sided, with the topside used as a groundplane for all earth connections. Some components are mounted on the GP side and these are identified in the parts list. The trackside layout with its component overlay is shown in **Fig 2** and **Fig 3** respectively. If you plan to mount the PCB into one of the popular tin plate boxes, see Note [1], trim it to size before you fit the components. Any flex-

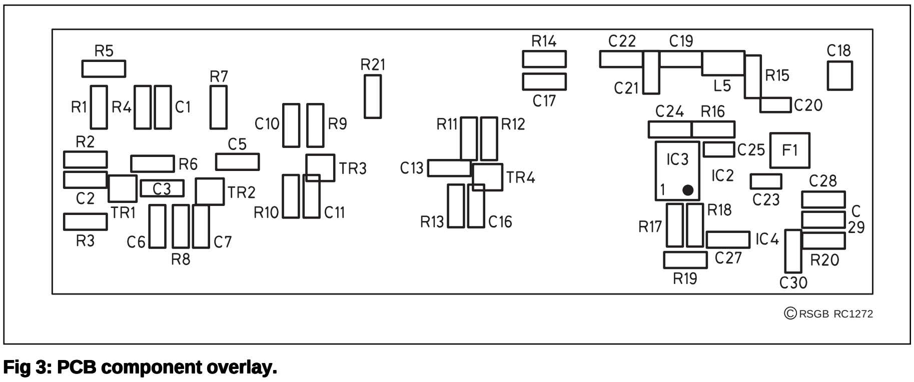

Fig 3: PCB component overlay.

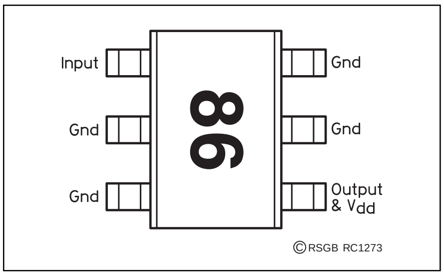

Fig 4: MGA86563 GaAs FET amplifier, SOT-363 pin connections.

ing of the PCB after assembly may crack the surface mount devices.

Start the assembly process by identifying and soldering all the through board earth connections. These can be formed by cutting short lengths of 24SWG tinned copper wire and then bending 2 -3mm at 90°. These are inserted into the groundplane side and soldered. Then, turn the board over, solder the links on the track side and cut off the excess wire. The components can be fitted in any order, but leave the LNA and L4 until last. The best results are obtained using a minimum quantity of solder; if you use too much, the excess can be removed with desolder braid.

The LNA is only manufactured in a miniature SM package, see **Fig 4**. I found that it can be soldered successfully if you hold it in the correct position and then solder one of its ground connections. With the device in place, look very carefully at its position. If it's not correct then reheat the joint and move the device. When you are totally satisfied that the LNA is in the right place, solder the remaining five leads. It is almost impossible to reposition the device once all six leads have been soldered.

The alignment process is in two stages. You will need an analogue multimeter, a 70cm receiver and a 2.4GHz signal source - more on this later.

Start by pre-setting the variable components as follows. Adjust the core of L1 to be level with the top of the former and then turn the core into the former by another 2 full turns. Set VC1/2 to be 40% meshed VC3/4 to 15% meshed and VC5, 6 and 7 to be 5% meshed. Support the board off the work surface so that the microstrip lines are not detuned and connect 12 Volts. The current should be 60-70mA before tuning and about 130mA when alignment is complete. First, check that the crystal is oscillating by listening for the fourth harmonic near 438MHz on the 70cm receiver. If no signal can be heard, then adjust L1. With the oscillator running we can now align the three multiplier stages. Set the meter to read 1 Volt full scale and place the probe on the emitter of TR3. With no drive, the voltage will be zero. Using a trim tool, adjust VC1 and VC2. As you tune the circuits to 328MHz, TR3 will begin to conduct. Just tune for maximum emitter voltage - it's as simple as that! Next, move the meter probe to the emitter of TR4. The voltage should be around 100mV due to the bias resistors on the base. Repeat the tuning process, this time adjusting VC3 and VC4 to give maximum emitter voltage. When correctly tuned, the voltage should increase to over 750mV. One word of caution is necessary here. TR3 is designed as a frequency tripler from 328 to 984MHz. However, it is possible to tune the striplines to 656MHz by mistake. Fortunately, this is fairly obvious as the trimmers will be 50% meshed at that frequency. The alignment process for the final doubler is a little different, as we have now run out of emitters! To adjust the last stage, connect an antenna to the converters input and your 70cm rig to the IF output. At this point, you'll need to generate a weak test signal on 2400MHz. The Amsat UK signal source, see Note [2], is ideal but your S band converter is very sensitive and will easily pick up a harmonic from a VHF / UHF source. Failing that, a few hundred milliwatts of 28MHz applied to a signal diode and series 50Ω resistor will suffice. Place the test source 6ft away, switch on the receiver and select SSB. As you apply 12V to the converter the noise level from the receiver will increase. Locate the test signal and note the S meter reading. The final three trimmers will all resonate close to minimum capacitance. Adjust each one for maximum S meter reading. This indicates minimum conversion loss in the mixer and completes the alignment.

AND FINALLY . . .

A TINPLATE BOX is available for the converter and is recommended as it has a removable lid and base, giving excellent access. Being tinplate, the PCB can be soldered to the sides of the box along with the RF and power connectors. An alternative solution is to fit the PCB into a diecast aluminium enclosure. This will be much easier to waterproof but do keep the box as small as practical.

The finished converter should be installed as close to the antenna as possible, as coaxial cables have very high losses at 2.4GHz. The IF output at 70cms can, however, be run back to the shack via long lengths of cable without problem. Because the gain of the converter is 32dB, the coaxial cable can lose up to 10dB without noticeably affecting overall performance. Finally, as most units will be mounted outdoors, local oscillator stability should be mentioned. The LO frequency can be measured at all times by listening to the crystal's 4th harmonic on 438MHz. In most cases any drift in the LO will be minimal compared to the Doppler shift from the satellite. However, a small 12V clip on crystal heater is available, see Note [3], and will hold the frequency to better than 1 KHz during cold weather.

NOTES

[1] Tinplate boxes model 7754 and 5pF SKY trimmers are distributed in the UK by Piper Communications, 4 Severn Road, Chilton, Didcot, Oxfordshire, OX11 0PW. Tel: 01235 834328.

[2] A Low cost signal source for 2.4GHz. Amsat UK. Oscar News No 112.

[3] Crystal heaters / Sky trimmers. - RSGB Microwave Component Service, c/o Ms P Suckling, 314a Newton Road, Rushden, Northants, NN10 0SY. ♦

COMPONENT LIST

Components marked * are located on groundplane side of PCB.

Resistors (1206)	
R1, 3, 6	1k0
R11	22k
R2	820R
R10, 13, 15	47R
R4, 5, 8	470R
R16	680R
R7, 14, 21	10R
R17, 19	330R
R9, 12	2k2
R18	18R
R20	220R
Capacitors	
C1, 6, 7	22pF
C4*, 8*, 9*	4n7 plate ceramic
C2, 5, 11, 12*, 15*, 16, 17, 19, 20, 21, 24, 27, 29, 30	1nF
C22, 28	0.1uF
C3, 23, 25	27pF (0805)
C26*	10uF Tant
C10, 13	4.7pF
VC5*, 6*, 7*	Sky 0.5 - 5pF
C14, 18	12pF Porcelain ATC 0.1 inch
VC1*, 2*, 3*, 4*	10pF film trimmer, 5mm dia. (Philips)
Inductors	
L1*	4.5 turn Toko S18 with Aluminium core
L2*, L3*	3 turns 22SWG tinned copper. 4mm inside diameter. 2.5mm off PCB.
L4*	22 SWG tinned Copper formed into U shape with I.D 4mm. 5mm high.
L5	Toko SM inductor 150nH type 32CS
Semiconductors	
IC1*	MGA86563-H.P.
IC2	MAR6 - Mini Circuits
IC3	RMS30 mixer
IC4	MAR3 - Mini Circuits
IC5*	78L09
TR1, TR2	PMBTH10 - Philips
TR3, TR4	BFR93A - Philips
ZD1*	5V6 400 mW
Miscellaneous	
F1	Toko chip dielectric filter.TDF2A-2450-10
PCB	with etched micro-strip elements. 108 x 36 mm.
Xtal 1	Crystal HC18U 109.3333MHz series resonant

A Kit is available from the author, tel 0181 752 8615 (phone or fax)