1665 MHz
Radio Astronomy
Receiver
2006

Part 1

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During early July 2006, Robin Holdsworth member of Hamilton Astronomy Society asked me to work on engineering a new receiver for the 1665 MHz band.

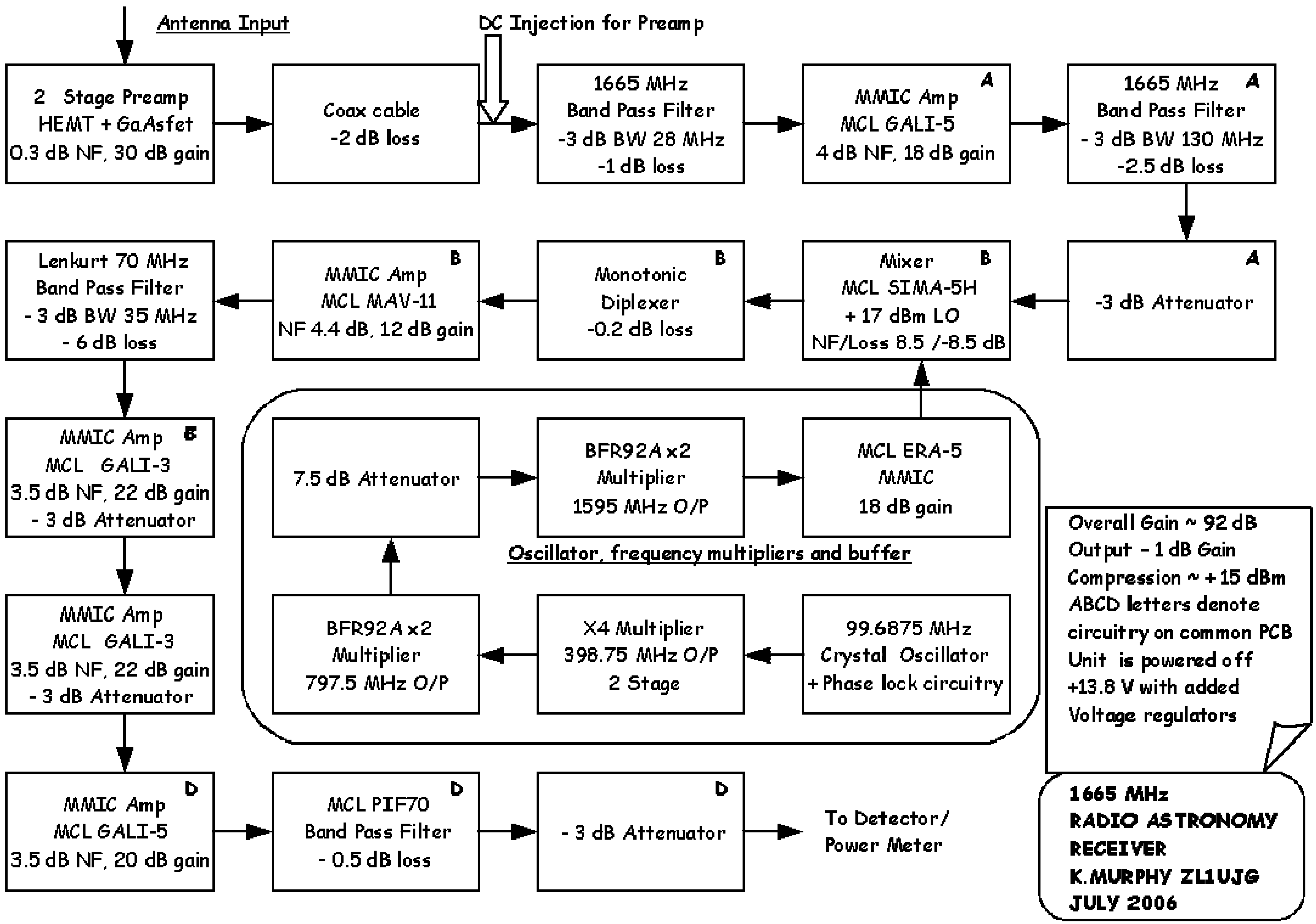
The 1420 MHz receiver, that I worked on during 2004, was previously built, I think by University students so I used the modules as much as I could to complete the unit. However there were some issues. The IF amp has a low compression point and there is no gain after the IF filter, so adjacent channel performance is determined by the RF selectivity and gain predominantly.

I had some items that Robin had given me previously, which could be used for new receivers.
There was 2 Lenkurt 70 MHz IF filters BW ~ 35 MHz. These are discrete units (L & C). One of these has been cut down so that it 2/3rd the length. Also some discrete PCB mixers, however these are dimensioned for 1420 MHz. There was some useful enclosures.

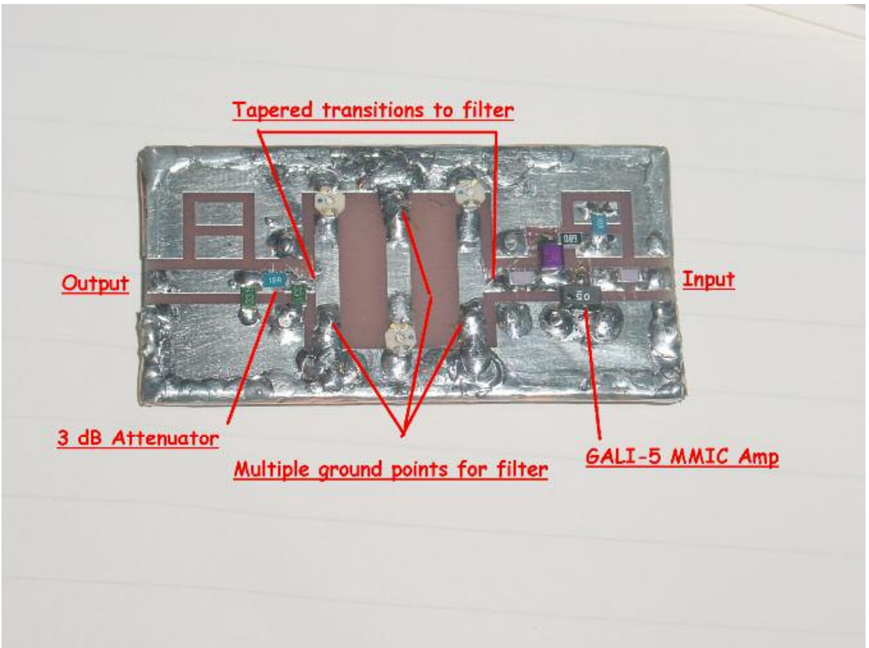
For this new project I have compiled a block diagram giving notes on individual stages. See following page.
The gains / losses and noise figures are approximate values only and may change depending on how the modules perform.

I am using Waikato VHF Group PCB's and will attempt to put multiple stages on each board. I will document each board as it is built both in design notes and performance. The boards are not built in any particular order. I intend to use MMIC's, as much as I can to give high stage gain, and 50 Ω in/out impedances. Other prepackaged units , such as mixers, and filters will also be used at the appropriate points

The oscillator EME65 from Minikits, will be used in this unit, as I had used it in the 1420 MHz unit, with good success. I have done some further refinements on this board, which should enhance its performance.


Antenna Input
DC Injection for Preamp
2 Stage Preamp HEMT + GaAsfet 0.3 dB NF, 30 dB gain
Coax cable -2 dB loss
1665 MHz Band Pass Filter -3 dB BW 28 MHz -1 dB loss
A MMIC Amp MCL GALI-5 4 dB NF, 18 dB gain
A 1665 MHz Band Pass Filter - 3 dB BW 130 MHz -2.5 dB loss
A -3 dB Attenuator
B Mixer MCL SIMA-5H + 17 dBm LO NF/Loss 8.5 /-8.5 dB
B Monotonic Diplexer -0.2 dB loss
B MMIC Amp MCL MAV-11 NF 4.4 dB, 12 dB gain
Lenkurt 70 MHz Band Pass Filter - 3 dB BW 35 MHz - 6 dB loss
B MMIC Amp MCL GALI-3 3.5 dB NF, 22 dB gain - 3 dB Attenuator
MMIC Amp MCL GALI-3 3.5 dB NF, 22 dB gain - 3 dB Attenuator
7.5 dB Attenuator
BFR92A x2 Multiplier 1595 MHz O/P
MCL ERA-5 MMIC 18 dB gain
Oscillator, frequency multipliers and buffer
BFR92A x2 Multiplier 797.5 MHz O/P
X4 Multiplier 398.75 MHz O/P 2 Stage
99.6875 MHz Crystal Oscillator + Phase lock circuitry
Overall Gain ~ 92 dB
Output - 1 dB Gain
Compression ~ + 15 dBm
ABCD letters denote
circuitry on common PCB
Unit is powered off
+13.8 V with added
Voltage regulators
D MMIC Amp MCL GALI-5 3.5 dB NF, 20 dB gain
D MCL PIF70 Band Pass Filter - 0.5 dB loss
D - 3 dB Attenuator
To Detector/ Power Meter
1665 MHz
RADIO ASTRONOMY
RECEIVER
K.MURPHY ZL1UJG
JULY 2006

2nd stage RF Amp, 2nd filter and attenuator



The image above shows the aforementioned unit. The filter was built first, then the 3 dB pad and then the GALI-5 amp. I built the filter initially using Voltronic ptfe trimmers of 0.6 to 2 pF capacitance. The frequency response indicated an unusual response, with low roll-off attenuation at low frequencies, with a high side notch and also high loss of about 4 dB. The cold ends are shorted via veropins to the opposite earthplane and copper tape wrapped around the edges and soldered

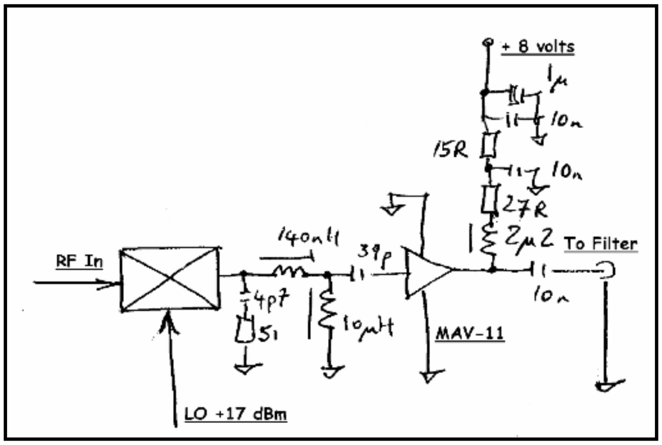
We tried putting 8 veropins through in the vicinity of the trimmers and this had no apparent change. We used these ceramic trimmers, in case the original ones showed an unusual performance. The original trimmers were layed out in a single ended configuration, however we thought that there may have been interaction and were changed for the middle opposing configuration. I managed to get ~ 3.5 dB loss, and so left it at that, but wasn't too satisfied.

At this point I added the 3 dB attenuator and the total loss measured about 8 dB! I had put one 330Ω resistor on the oposite side of the middle track, and suspected that gave a problem. I reworked it so that it was near the other 330 Ω and the total loss came down to about 7.0 dB. I also cut the RF tracks entering the filter at a diagonal so the filter would be tapped nearer ground. (see image) I tried shorting the earthy (cold) end of one of the stripline inductors to the adjacent earthplane, with a screwdriver and that gave an about 0.4 dB improvement. I then added copper tape so that the cold ends were grounded to the adjacent earthplane. The loss measured around 5.7 dB and the response improved with around 50 dB rejection at 2 GHz. The low sided roll-off wasn't as good, but appeared satisfactory.

Return loss (RL) measured around 15 dB inband from the input end of the PCB, while the output end gave 25 to 30 dB RL inband. O/P RL Out of band was 6 dB from LF to 3.2 GHz where it deteriorated probably due to the 1206 size resistors used.
The rejection at 1525 MHz (RX Image 1665- 140 MHz) was about 10 to 12 dB. Not brilliant, the rejection here will worsen the PCB noise figure by ~ 0.4 dB , whereas no rejection would add 3 dB. It shouldn't be a problem as the rejection by the 1st filter will give adequate image rejection overall and the amplifiers should overide any deterioation of this NF. The 3 dB bandwidth measured about 130 MHz, quite large,

The GALI-5 MMIC and associated circuitry was built on the PCB at this point.
Series capacitors were 47pF SMD 1206 and inductor was 120 nH SMD. I cut the PCB to add extra lands for the device and inductor. I powered the stage up and saw about 100 mA !
I had calculated the wrong total resistance
Device voltage.= 4.4 volts and current 65 mA. Supply volts 8 volts. Therefore R = 3.6/ 0.065 = 55Ω. I had used 2 times 68 ohms in parallel and a 10 ohm (where I should have a 20 ohm)
I adjusted the supply down to ~ 7.5 volts to counteract this.
The gain after adjustment of filter was + 12.87 dB, with the filter and attenuator added it +18.67 dB.
Compression occurrs at ~ +11.87 o/p (+17.67 dBm o/p)

Mixer, Diplexer and IF Preamp



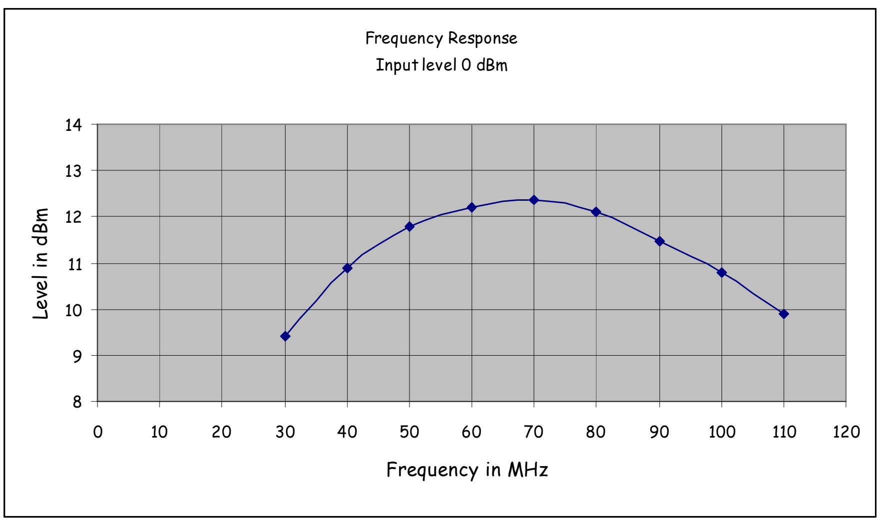
The IF Preamp was built first. The input to the MAV-11 MMIC is a simple series tuned circuit, comprising of the 140 nH and 39 pF. This is operating at low operating Q, to minimise losses and provide wide IF bandwidth. At high frequencies (~ 1600 MHz) the series tuned is highly reactive (High Z). The termination is provided by the 5 pF and 51 Ω. At 70 MHz this has virtually has no effect. The mixer has a DC return provided by the 10 uH choke. This is at the junction of the 140 nH and 39 pf as its stray capacitance is not across the mixer output.

The first mixer I installed was no good. It is possible that it was damaged on the PCB it was removed from, as extensive burn marks were evident. I have a number of spares so it wasn't an issue.

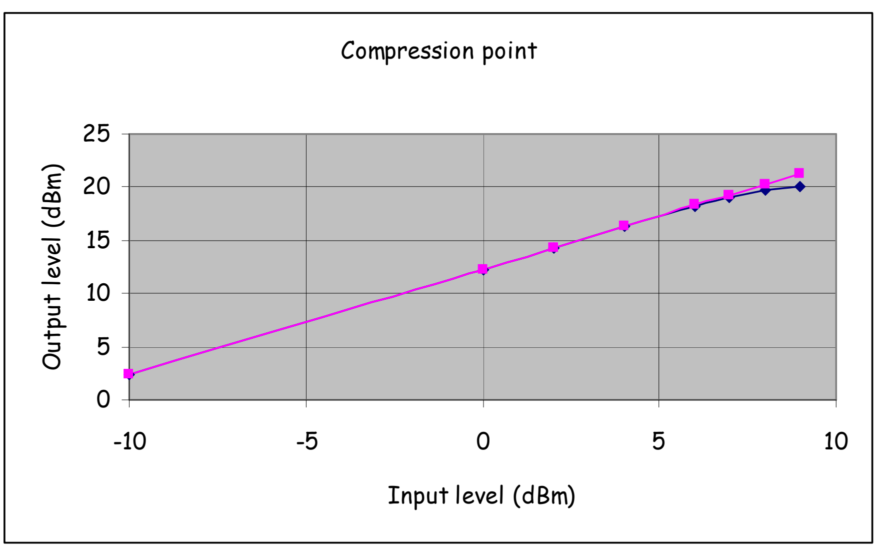
The gain of the MMIC is purposely kept low in this application due to the high level of LO oscillator that may appear at the mixer output. There would be significant attenuation by the series tuned circuit however.

1 dB bandwidth is ~ 45 to 92 MHz (47 MHz) and 3 dB bandwidth ~ 30 to 114 MHz (84 MHz)

3 dB bandwidth is calculated to be ~82 MHz (2 xPIxFxL)/50



The gain of the MMIC is very close to the specifications. Data sheets indicate about + 12.5 dB gain and a similar value is measured. The measured compression point of the MAV-11 appears to be around + 20 dBm @ 70 MHz and manufacturer data indicates around +18.5 dBm. However no frequency is quoted for this. The DC current was measured around 65 mA.



The noise figure of the IF preamp was not measured, but the manufacturers data indicates ~ 4.4 dB, however no frequency is quoted. Note there are 3 types of MAV-11. One a SMD type and the 2 others are leaded. The earlier device is a MAV-11, with NF of ~ 3.5 dB and -1 dB compression power of + 17.5 dBm (A on Package) The more recent device MAV-11B, has a NF of 4.4 dB and – 1 dB compression power of + 18.5 dBm (11 on package)

The Minicircuits (MCL) SIMA-5H mixer was fitted, and then replaced, since the first one showed a short on a insulated pin. I had initially thought it was a IF pin, but it was unused, according to MCL data. The replacement mixer appeared o/c on that pin.
Since the mixer is only rated to 1.5 GHz, 2 readings where taken, so that a comparison could be made with from MCL data at 1500 MHz and experimental data on 1500 MHz and 1665 MHz.

Mixer loss **SEE FURTHER NOTES OVER PAGE**
0 dBm RF into mixer at 1500 MHz, + 17 dBm LO at 1430 MHz, Output from MAV-11B was + 4.5 dBm, so loss of mixer = Gain overall – IF preamp gain = 4.5 – 12.4 = -7.9 dB

0 dBm RF into mixer at 1665 MHz, + 17 dBm LO at 1595 MHz, Output from MAV-11B was + 4.0 dBm, so loss of mixer is Gain overall – IF preamp gain = 4.0 – 12.4 = -8.4 dB

The 8.4 dB loss of the mixer at 1665 MHz is quite acceptable and ~ 0.5 dB above 1500 MHz. MCL data indicates that loss at 1500 MHz could be as high as 8.5 dB anyway. Note this includes a cable loss of ~ 100mm double screened teflon coax.

Local oscillator rejection measured on output of MAV-11B
@1500 MHz   - 15 dBm (Y level)
@1665 MHz   -12 dBm
MAV-11B gain at these frequencies is ~ 9 dB and LO level is ~ + 17 dBm, and manufacturer states that LO to IF rejection at 1500 MHz is a nominal 27 dB. (MCL states the minimum LO-1F isolation could be as low as 13 dB however !!)
LO level – LO-IF rejection – MAV11 gain = X level. The difference between this X level and Y level above is due to diplexer roll-off.

At 1500 MHz 17- 27 + 9 = -1 dBm. So ~ 14 dB extra loss added due to Diplexer. (possibly)

At 1665 MHz, since this is out of band, the LO to IF rejection is probably worse. The MCL data, shows considerable slope on the graphs. The measured degradation of a further 3 dB, is acceptable.
However the low rejection overall may possibly be a problem. (This may possibly be due to the temporary bench setup) Leakage of the LO through the IF filter may cause problems. Another topology of a IF diplexer could be used, such as a T type L-C-L instead of the series tuned circuit, if this presents a problem, in service.

Gain Compression
With 0 dBm RF at 1665 MHz into the mixer, the output level from the MAV-11B was + 4 dBm. I increased the RF level to + 10 dBm and + 14 dBm appeared. The MCL data indicates that + 10 dBm RF was the -1 dB compression of the mixer. There wasn't any apparent gain compression, so was pleasantly surprised, so the termination of the IF port apparently works.
The RF port of the mixer will be terminated by a 3 dB attenuator PAD and the LO port will have a MAV-11, so this should maintain a similar result.

Image above shows Mixer/IF preamp PCB, with original coil, and missing vias !!

FURTHER NOTES

I suspected that low LO rejection was due to the 1595 MHz bypassing the variable inductor, due to its construction. The input winding and the output winding, (coming down the side of coil) passed each other.

I decided to use a 120 nH SMD 1008 inductor and this was resonated with a 47 pF, and this improved the LO rejection from -12 dBm to -28 dBm. About 25 dB due to the diplexer. (LO input was +15 dBm)

I measured overall gain as 3.3 dB, (at RF/LO 1665/1595 MHz) however the SMD coil has low Q, only 30 to 40.

I decided to try an airwound inductor. I replaced the capacitor with the 39 pF again. I disconnected the mixer and measured the gain as 12.5 dB at 70 MHz. After reconnecting the mixer, I remeasured the gain at RF/LO = 1500/1430 MHz, then also RF/LO = 1665/1595MHz.

The gain was 3.45 dB and 2.2 dB. I found that placing my finger near the 10 nF bypass capacitors that I was able to increase the gain to 3 dB + at the higher frequency. I noticed that I hadnt put any vias through the PCB, near the mixer and around the coil and bypass capacitors. There also appeared to be also some shift in the IF centre frequency between having the mixer attached and disconnected.

I think that I misread the original gains (see mixer losses on previous page) and the gains were +3.5 and +3.0 dB, (not +4.5 and +4.0 dB) now making the mixer loss -8.9 and -9.4 dB. The mixer losses could be higher than expected due to low LO level and also a 100mm length of teflon double screened coax, and also the current PCB earthing. I will add vias and retest.

RETEST

After adding numerous double vias (U links) I remeasured the gain, with 0 dBm RF and +15.5 dBm LO
With 1500/1430 MHz RF/LO frequencies gain is 4.1 dB. Mixer loss is -8.4 dB
With 1665/1595 MHz RF/LO frequencies gain is 3.7 dB. Mixer loss is -8.8 dB

0.5 dB Bandwidth measured by adjusting RF frequency is ~1650 to 1690 MHz (70 MHz +/- 20)
1.0 dB Bandwidth measured by adjusting RF frequency is ~1640 to 1707 MHz (70 MHz +32/- 25)

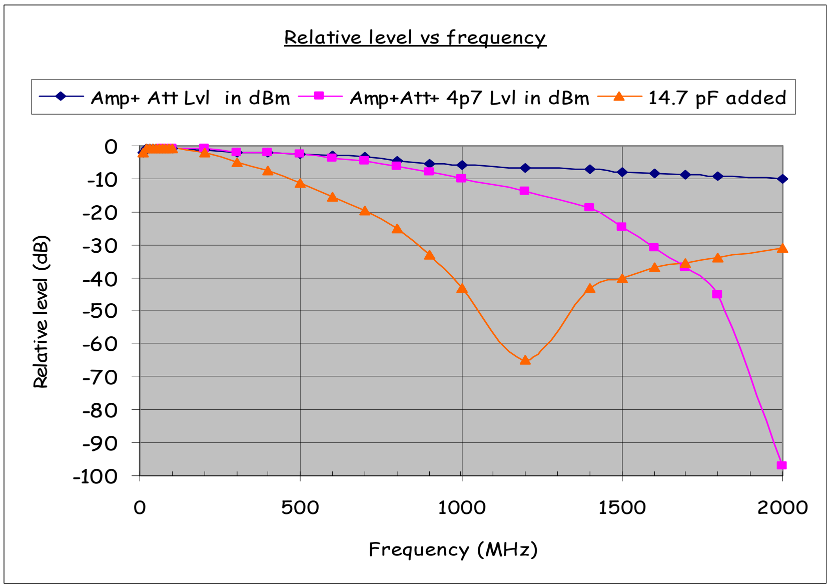
At + 15.5 dBm LO is -24.5 dBm at IF output
At 0.0 dBm RF is -27.5 dBm at IF output

0 dBm RF in gives +3.7 dBm IF
+10 dBm RF in gives +13.7 dbm IF

Note that the LO was only +15.5 dBm at signal generator, probably ~ +14 dBm at mixer, so gain should increase a few 10 th's of a dB. The interaction on the PCB as mentioned previously is gone, and the combined mixer loss and IF preamp gain, has improved significantly due to the improved earthing

IF Amplifiers

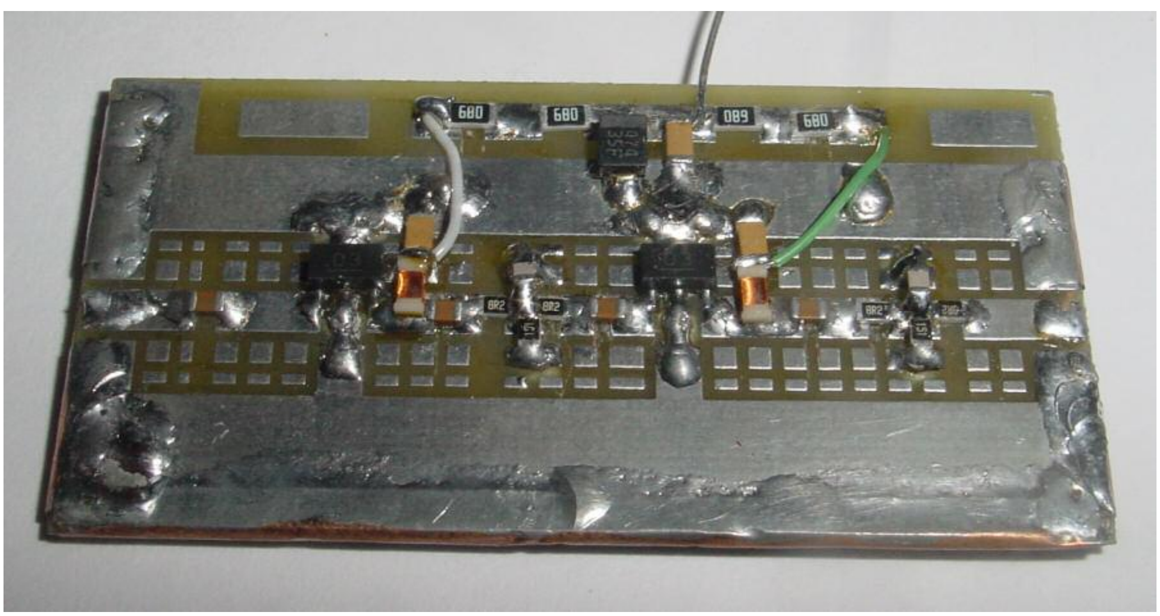
The IF cconsists of a Lenkurt 70 MHz IF filter (bandwidth ~ 35 MHz). This first feeds into 2 IF Amplifier stages, using MCL GALI-3 MMIC's. Each stage is followed by a 3 dB attenuator. The attenuator is of T type with a capacitor across the middle resistor element, so that the frequency response is reduced. This is on a single PCB. The gain of these 2 stages, including the attenuators is 39 dB. This is very close to the MMIC gains and attenuators combined. The chart below shows the relative level before any capacitor was added, and the response falls by about 10 dB at 2 GHz. The addition of a 4p7 capacitor across the middle resistor, increases the attenuation near 2 GHz, however the attenuation near 1 GHz is only increased by a few dB. Increasing the capacitor to 14.7 pF (4p7 and 10pF) dramatically increases the attenuation at 1 GHz. The attenuation in the 70 MHz passband is not changed and attenuation increases by ~ 1dB at 200 MHz.



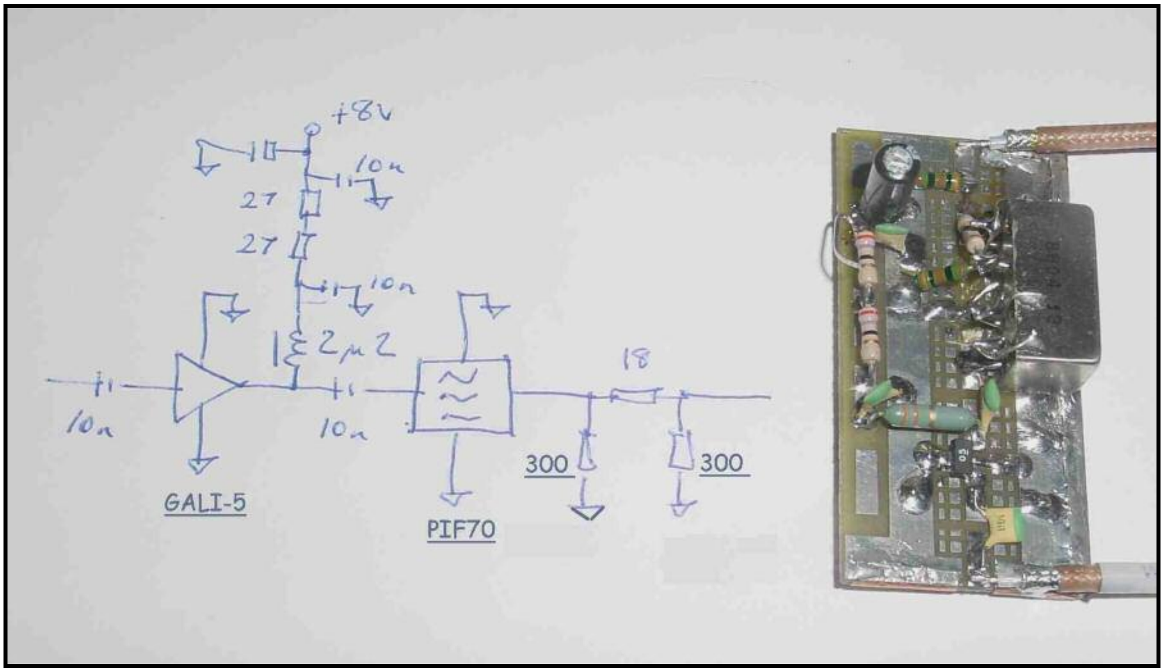
The dip in the passband, is due to the chip capacitor acting as a series resonant circuit, due to its inductance of ~ 1nH

Output compression point is of the order of +10 dBm (+13 dBm – 3 dB)

Due to the high density of components, SMD components are used in its assembly.



The following PCB has a MCL GALI-5 MMIC, used for its high power capability. This then feeds a MCL PIF70 70 MHz filter and a 3 dB attenuator. The PIF70 is a simple filter, that would be used to provide a wideband termination for a double balanced mixer. In this application it is used to reduce the bandwidth of the IF, and hence its noise power. The MMIC's used in the IF are capable of gain certainly in the 10 GHz region. Since Noise Power is proportional to bandwidth, then the bandwidth needs tailoring.



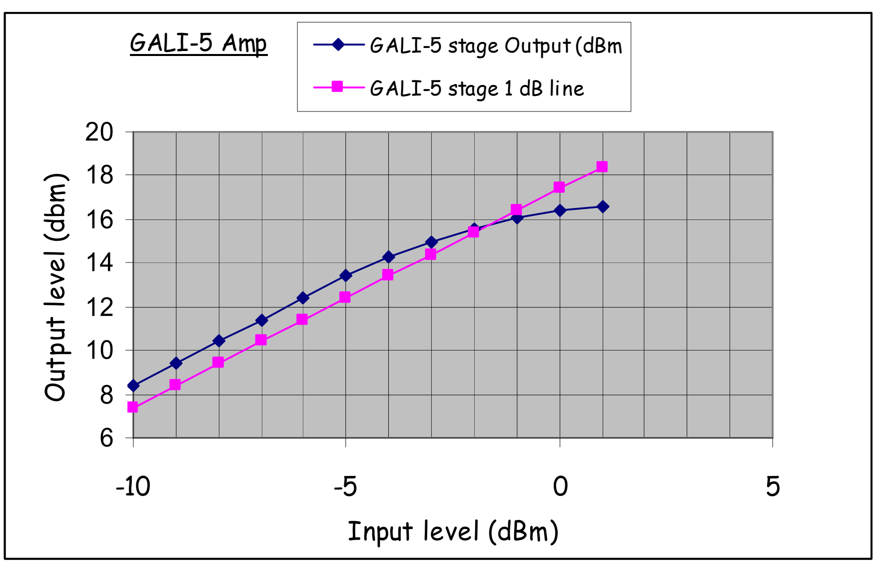
The above image shows the schematic and assembled PCB. At first there was some instability which was fixed, by changing the position of the input capacitor so that it was at horizontal, whereas the capacitor on the output of the MMIC, was vertical. Additional wire vias adjacent to the MMIC, stopped any instability.

The table right shows the PIF70 filtering

Response	F low (MHz)	F high (MHz)
- 1 dB	55	88
- 3 dB	43.6	108.3
- 10 dB	21.6	200

This is very close to that specified by MCL on the data sheet. Care was taken during construction so that ground wire length was minimised. Almost every pin had an individual earth wire.

The MMIC is running at 66 mA and 4.4 volts, close to the 65 mA specified by MCL.



The GALI-5, PIF70 and 3 db attenuator have about 18.4 dB gain in total. The gain of the MMIC then would be in excess of 21.4 dB which is slightly above nominal.

The PCB 1 dB gain compression point occurs at just below +16 dBm output, which equates to the GALI-5 have 1 dB compression in excess of +19 dBm, which is good result.

EME65 Oscillator and Multipliers to 1595 MHz

The EME65 Oscillator has been used for the 1665 MHz oscillator due to its low cost and ease of building.

There are some changes which should enhance its performance.

Use a regulated 8 volt supply (7808 or LM317T) to power PCB and subsequent multipliers. This will enhance stability due to reduction of PSU source variations (DC such as a PSU or battery). Note that stability, encompasses frequency, level and, spurious stability. The 78L08 is removed and a 15Ω fitted to replace it. An additional 10 uF is fitted on, what would have been the regulator output

An active filter as used on the original oscillator is used. This will reduce wideband noise from the regulator output causing unwanted FM. The noise filter action may be seen on the collector of the active filter transistor by using an oscilloscope. The level seen is ~ 60x greater due to the ratios of the 1000Ω and 15Ω.

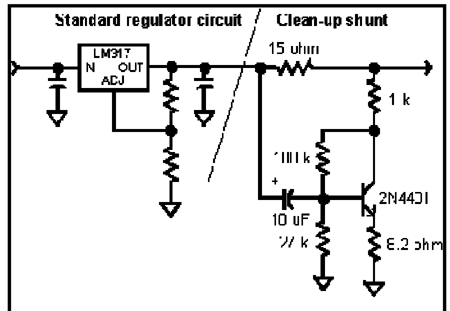


Figure 1: Clean-up circuit for low current loads.

The Collector resistor in the final multiplier on the EME65 may be increased to 100 Ω. This takes the device off saturation, due to over disappation. Even though the regulated voltage is now +8 v, the decrease in power is low. Additionally a 120 nH SMD choke is used between the 100 Ω and the stripline. The output level from the EME65 is increased by ~ 2 dB as the collector load on the final device is increased. Also spurious are reduced as the operating Q is higher.

The collector to base coupling capacitor (27 pF on the EM65 and G4DDK004 and variants) is reduced to 6p8 and the 1^{st} oscillator transistor collector is re-resonated at the crystal frequency. Use $C= 1/(4xPI^2 \times Freq^2 \times L)$

Two 1N4148's are placed across the 1^{st} oscillator transistor collector. This will stop the oscillator devices from switching off during the RF cycle, thereby changing the load that the crystal sees. Note a few pF will need to be subtracted due to diode capacitance. The RF output level doesn't decrease too much as the diodes cause clipping action instead of the oscillator transistors!!

The capacitor between the 2^{nd} and 3^{rd} transistors is reduced from 15 pF to 6p8 to increase collector load on 2^{nd} transistor. This would reduce spurious.

A 50 or 60 degree PTC heater is attached to crystal to elevate crystal above room temerature variations. Attach using low temp heatshrink.

The crystal is kept a few mm above ground and a small wire attached from the side of the crystal to the pcb ground. It stops PTC heater trying to heat the board.

In this unit, the 470Ω across the tuned circuit is now AC coupled to a 47Ω which leads to a MMIC. This is a signal that may be fed to PLL circuitry.

In this unit, a varicap will be lightly coupled to the 22 pF on the 2^{nd} transistor's emitter. This is so that frequency disciplining the the 100 MHz (+/-) oscillator can take place.

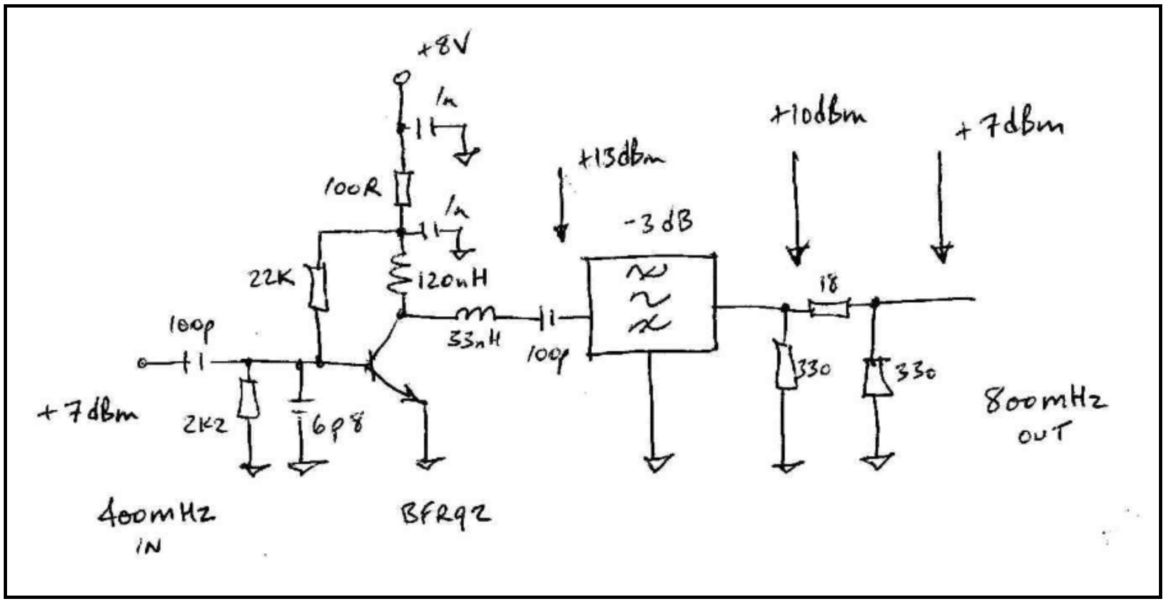
400 to 800 MHz Multiplier

The schematic and image below shows the 400 to 800 MHz multiplier which is fed from the EME65 Oscillator PCB.

The circuit as originally built, did not have the 33 nH inductor in between the collector and the filter. (This value was chosen from previous multiplier experiments as documented in the FUNewsletter at www.qsl.net/zl1ujg). * See note

The inductor was hand wound with 3 turns using a cottonbud tube as a former and was then tinned and placed in circuit and varnished to preserve its shape.

Adding a capacitor to the base give an improvement in output level, as it acts as a path for harmonic currents into the base circuit. 6p8 was chosen as it was what I had with me at the time, and as an educated guess was probably around the right value.



Multiplier driven from a signal generator at 400 MHz @ +7 dBm (5 mW or 0.5v rms) **

Output level

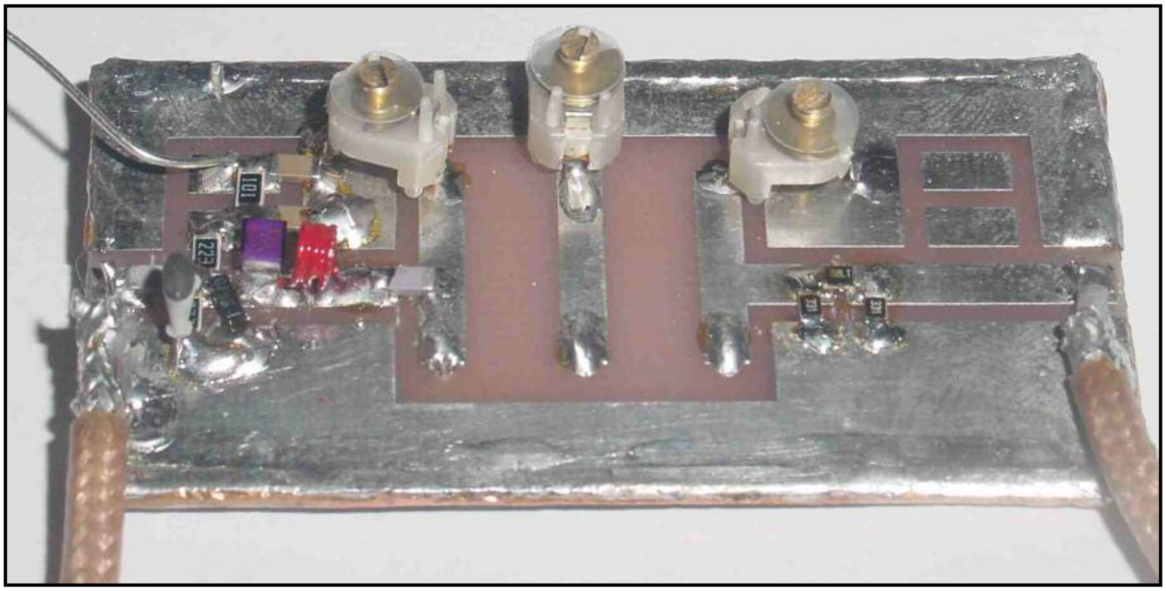
Without 33 nH inductor RF output @ filter output ~ 0 dBm

With   33 nH inductor RF output @ filter output ~ +5 dBm

With 6p8 on base circuit RF output @ filter output ~ +10 dBm

The 3 dB attenuator was fitted after tests, which improves the wideband termination to the following stage and also drops the level to a nominal + 7 dBm (5 mW)

Note:-This attenuator is now changed to 7.5 dB (120Ω for parallel R's and 47Ω for series R). This is because a higher gain device is used for the amplifier between the 1600 MHz multiplier and mixer. The requirement for +7 dBm is reduced to +2 dBm. See notes on 800 to 1600 MHz multiplier for more information.

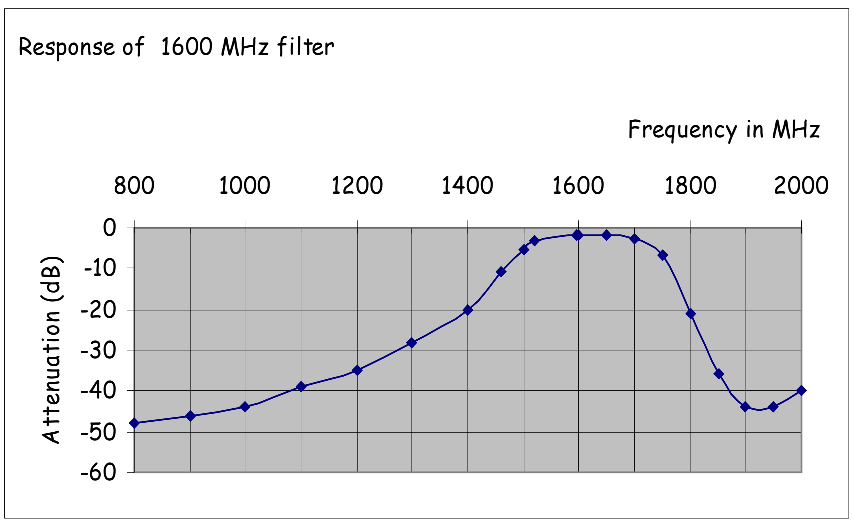


The filter was tuned to maximise output level.
The response was as follows when multiplier was driven as **

Response	F low in MHz	F high in MHz
~ -1 dB	800	840
- 10 dB	782	852
- 20 dB	767	866
- 30 dB	745	883
- 40 dB	713	900 +

The response was very flat from 800 to 840 MHz. The response was wrt output level (which was + 10 dBm as the 3 dB attenuator was not fitted at this time.

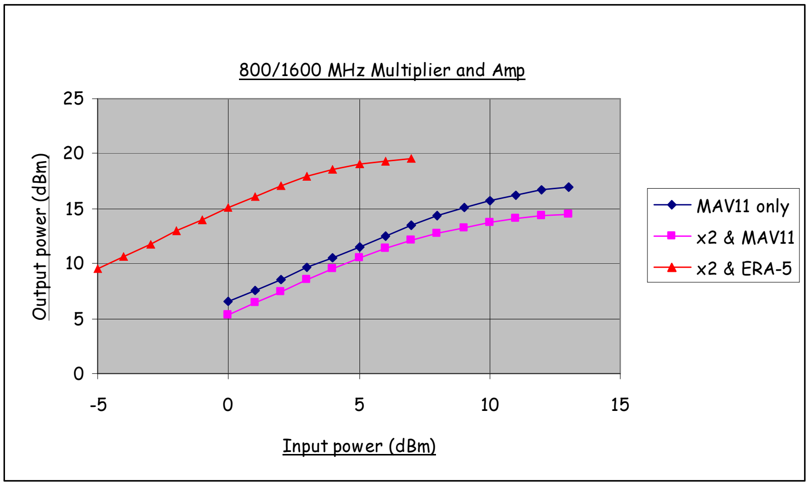
Note The original unit achieved + 12 dBm from a 324 to 648 MHz multiplier. (+ 7 dBm with a 5 dB attenuator fitted) The transistor was a 8 GHz device in a ceramic package with 2 emitter leads. This would have had less inductance and probably more gain overall, so I think the result of + 10 dBm achieved here, is very good.



800 to 1600 MHz Multiplier

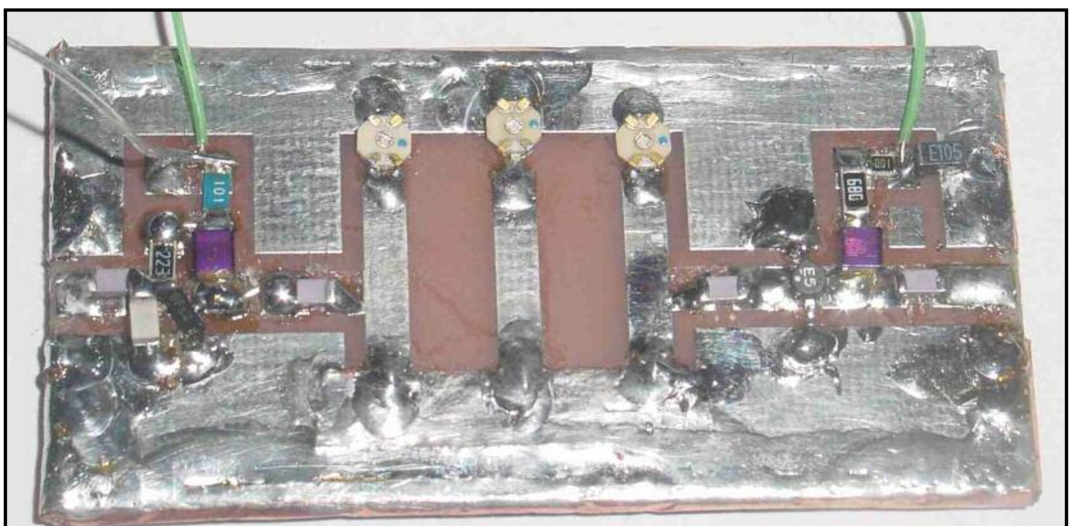
This was built on a VHF Group filter PCB. The filter was built first, with the trimmers at one end of the filter. The other end was grounded using a copper strap. The rejection of unwanted signals was about 20 dB at 800 and 2000 MHz. I then grounded the filter cold ends through the PCB via U links. This improved the rejection significantly.
I initially used a MAV11 as an output amplifier to drive the +17 dBm LO mixer (SIMA-5H).
This device achieved about 8.5 dB gain and ~ +16 dBm at the -1 dB gain compression point. I then added a BFR92a 800 to 1600 MHz multiplier to the first part of the PCB. Unfortunately the overall performance of the unit didn't quite cut the mustard. The level peaked at about +14 dBm, due to lower gain in MAV11 and insufficient output from the multiplier. I will include data in for the MAV11 as it showed the limitations in this application. The alternative part is a ERA-5 and ERA-6. The ERA-6 has about 11 dB gain and +17 dBm

-1 dB compression, while the ERA-5 has about 18 dB gain. The ERA-6 has marginally higher gain than the MAV11 and as the efficiency of the multiplier drops at high input levels, this may have been marginal, so it was decided to use a ERA-5.



The multiplier and ERA-5 is considerably more sensitive (~ 10 dB) at lower levels. The Input level required for ~ +17 dBm out is + 2 dBm, so larger attenuation is needed on the output of the 400 to 800 MHz multiplier. The nominal 800 MHz output (without attenuator) is + 10 dBm. So 8 dB attenuation is required. Using preferred values of PI pad is 120 Ω for the parallel resistors and 47 Ω for the series R which gives 7.5 dB. This will be fitted.

The harmonic output from the 800 to 1600 MHz multiplier is ~ -26dBc for the 2nd harmonic and ~ -42 dBc for 3rd harmonic.
As the gain of the ERA-5 was higher, I thought that ERA-5 Amplifier noise appearing at the Mixer output may degrade the mixer noise figure. I looked at the LO to IF isolation in MCL data, which indicated that the isolation was ~ 62 dB at 70 MHz, which means any amplifier noise is well suppressed.
Another additional point is that the MAV11 was at the limit of its performance at 1600 MHz and the VSWR (return loss) would deteriorate whereas the VSWR of the ERA-5 is good out to many GHz.
The DC requirements of the MAV11 were 5.5v and 60 mA (41.6Ω calculated) and a 44Ω was used.
The DC requirements of the ERA-5 were 4.9v and 65 mA (47.6Ω calculated) and the same 44Ω was used. So current would be ~ 70 mA. It was noticed that the MAV11 current had increased to ~ 65 mA anyway, as compression had changed its operating point.
Some instability was apparent during testing of the ERA-5 unit but was due to ineffective SMA connector termination.



800 - 1600 MHz Multiplier and Amplifier