Build Your Own Receiver

The **advantages** of making your own Receiver, or other equipment.

eg. Aerials[1], test equipment, auxilleries, synthesisers, etc.

1. The satisfaction of doing it yourself, see what others[2] have done.
2. You get exactly the features you choose.
3. You can change your mind.
   You know what is there, and can add or change at any time.
4. You can gradually add bands & features, according to time, money & understanding.
5. You can get very high performance.
6. You needn't spend a large amount of money.
7. You may need to spend a large amount of time (learning), share this with others.
8. You will gain from this a great deal of knowledge & expertise.
9. You can build separate single band, single mode receivers, as continuous band monitors.
10. You can make it a transceiver if you wish.
11. You can be creative, try your own ways of doing things, as you learn how.
12. You can use a great deal of second hand parts.
13. You can use the classical superhetrodyne[3], or a Software Defined Radio[4] approach.
14. You can choose to use one aerial connector, or group bands between several connectors.
15. You can build your own dial, or use a computer to produce dial like features.
16. You can learn to develop your own computer control programs, lots are doing this.
17. Because of computer simulation, this process is getting simpler, almost no "trial & error".
18. Power supply can be from dry batteries, 12 or 24v DC, mains, internal or external.

Are there any reasons above why you should have a go at rolling your own?

The **disadvantages** of making your own Receiver, or other equipment.

1. I don't know enough to decide what to do.
   Join up with at least one other, and share the learning by discussion.
   A first class reason to join an amateur radio club, in person or via the internet.
2. I don't have enough construction experience. Start with a simple project.
   This will never come by talking without having a go. There are many experienced people ready to help & encourage.
3. I don't have any test equipment.
   There will be people about, or clubs, that do have, can help, in many ways.
4. I don't have enough time.
   Ahh! Then you aren't really interested, go buy something second rate.
   But you can still read and learn, until such time as you re-arrange your priorities to give you some construction time.

Desirable **Features** for a receiver.

1c. Selectivity is the ability to restrict what you hear to a particular range of frequencies, and not hear a strong signal a little off frequency, say on an adjacent channel, being FM, AM, SSB, CW, or a digital mode. With a superhet, often achieved by the use of a crystal filter of the required bandwidth, in the above cases, usually separate filters switched in according to the mode. With an SDR, defined by software thay you can download or write yourself.

2c. Stability is the ability to be able to set the frequency of the desired signal, and know that a short or long time later it will still be precisely on that frequency. SSB requires tuning to stay within about 20Hz, whereas FM may be within about 200Hz. There should be no noticeable frequency shift with temperature, power supply voltage, or mechanical vibration.

3c. Phase noise[5] is the local oscillator noise sidebands that can contribute to interfering noise on weak signals, when a strong adjacent signal is mixed with it. Some lower cost rigs have this design flaw, so are very bad in this respect. Especially 2 metre rigs interfered with by pager systems. The interfering transmitter might also have poor phase noise, which you can't control.

4c. Spurious signal response is the embarrassing ability some receivers have, to pick up signals that they are not intentionally tuned to, and is a design flaw that many lower cost, and older rigs exhibit. Two of the most obvious of these are the image freq (see 7c below) and the harmonics of the oscillator frequency. A poorly chosen oscillator can also produce various spurious frequencies, such as a DDS[6], Direct Digital Synthesiser, if there is truncation of the digital word length.

5c. Third order intermodulation distortion[7] (IP3) is often talked about, but is very difficult to measure on the test bench, but is another feature that can seriously limit the ability of a receiver to hear weak signals when strong signals are on adjacent channels. When choosing circuits, a transistor mixer might have an IP3 figure of -12dbm, whereas a diode ring mixer might be +35dbm or more, ie. 47db better. A very large difference. IP3 is actually the generation of in band spurious signals from an out of band signal, by the non-linearity (intermodulation distortion) of an amplifier or mixer, so it can't be filtered out.

6c. Noise figure[8] is a measure of how much noise the actual receiver produces, which competes with the signals you want to hear, and the smaller the noise figure the better. Where ever possible, the noise coming in from the aerial, with the signal, should be the limiting factor, not the noise generated within the receiver itself.

7c. Image response is one of the worst of the spurious signal responses mentioned in 4c above. The superhet receiver has an input signal frequency, say 53Mhz, and may have an Intermediate Frequency of 10.7Mhz, with an oscillator frequency of 53 – 10.7 = 42.3 Mhz which may be derived from a crystal oscillator at a lower frequency, say 21.5Mhz. Now that osc freq and IF freq will also respond to a signal frequency of 42.3 Mhz – 10.7 Mhz = 31.6 Mhz. Which is twice the IF freq (21.4 Mhz) below the desired freq. Filters should reduce the response at the image freq by about 90db or more.

8c. Dynamic range[9], is a measure of a radio's ability to deal with the very weakest to the very strongest signals without ill effects such as distortion. This term includes 3c, 5c, and 6c above.

Find a **starting point.**

Every receiver has to select a frequency or band of frequencies to listen to.
Lets assume that you have a surplus FM two way radio from a taxi or ambulance etc.
To make this listen on 10, 6, or 2 metres, with a better performance than the original, a new “front end” can be made. This process is exactly the same as if you are making the whole receiver from scratch, a multi-band receiver, or a transceiver. However in this case the choice of the IF frequency has already been made for us, its 10.7 Mhz. Another choice I have deliberately taken is to have the input and output impedance of the filters, RF amplifier and mixer set to 50ohms, to simplify testing each module separately.

Signal Filters

Older receivers had 3 gang tuning capacitors (even older ones had separate tuning knobs for each of three or more tuning capacitors), one gang tuned the oscillator, to set the received frequency (sum or difference between the signal and intermediate frequency), and the other two tuned to the incoming signal, but the ability to deal with Feature 4c above was poor.

We will look at using filters designed for the band required, and using 8 tuned circuits to get very good spurious signal rejection. Looking around the various parts suppliers, we find that shielded variable inductors are more than a dollar each, so 3 filters for the 3 FM bands suggested would cost around $35 just for the inductors. So lets try hand wound inductors, with or without trimming capacitors, as ELSIE enables us to calculate size of wound inductors.

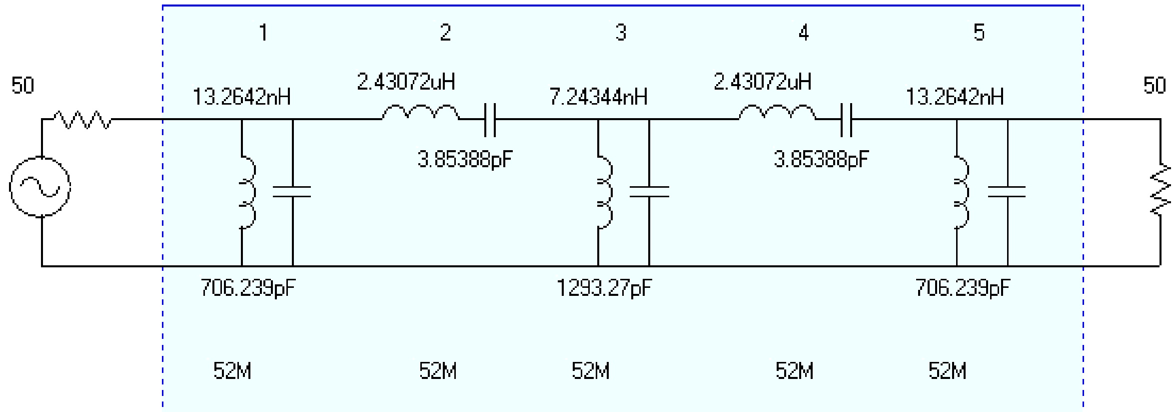
Good news is that Hy-Q[10] has small trimming capacitors in quantities of 100 are only 23c (Aus) each, a more attractive approach, especially for a group construction project. Other suppliers, such as Mouser have similar items. Lets now do some computer calculations and see what can be achieved.

There are a number of different types of filters that can be used as signal filters, and the decision which one to use, varies according to the bandwidth, available components, ease of construction, and cost. Commercial manufacturers usually use a number of tuned circuits, inductively coupled, or else coupled with small coupling capacitors. It is tedious to set inductive coupling up, because there will need be an adjustment of the spacing between the coils. Capacitive coupling can result in very small values of capacitance, and less “high side” attenuation.

If you don't already have the filter design programme, ELSIE, then download the free student version from LINKS 9.4, and start with the two parts of the 6 metre filter. I have chosen a filter with the following :

topology	shunt input bandpass			
family	Chebyshev			
bandwidth	4.5Mhz	(a little wider than the 6m band)		
order	3	and then	5	(number of tuned circuits)
input term	50 ohms	(impedance)		
passband ripple	.05	(keeps VSWR below 1.2:1)		
centre frequency	52Mhz	(centre of 6m band)		

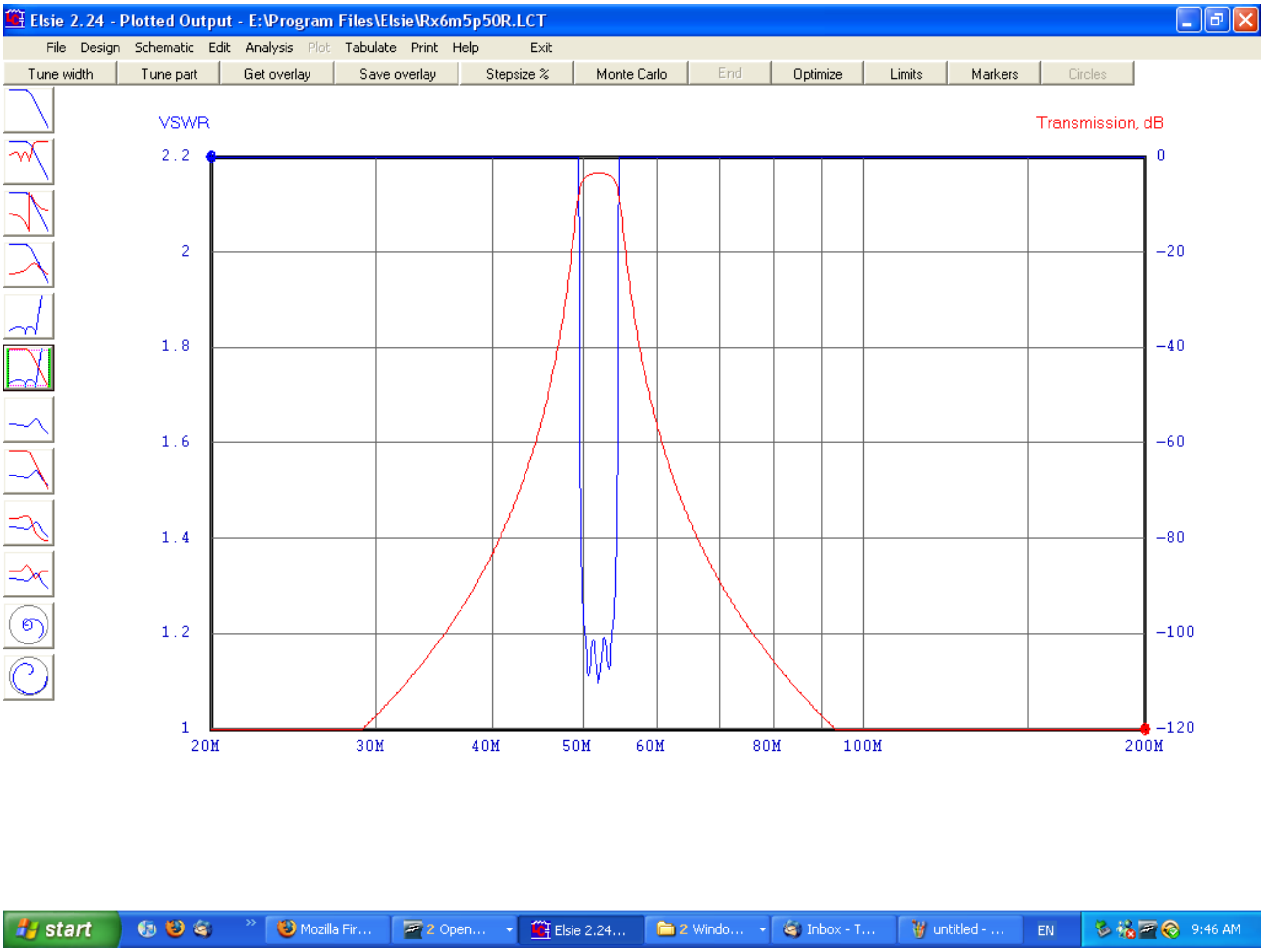
To use ELSIE, you click on Design to enter the data, or open the stored file, then you can click on the schematic to see the component values on the circuit.



Next click on Analysis and set Start Frequency say 20Mhz, Stop Frequency 100Mhz, Loss Bottom db -120, and the defaults should be ok for the rest. It is most important that you use the upper case “M” after any frequency, otherwise you get really strange results. Then you can click on Plot, to see a range of things, I generally click on the 6th down from the top of the 12 choices on the left. You then get the frequency response in red and the VSWR in blue, see page 4.

You will find that the narrower the bandwidth as a percentage of the centre frequency, the higher will be the loss, or attenuation, for the signals you want to pass. You have some control over this by adjusting the pass band ripple figure, the order (number of tuned circuits or poles[11]) and the Q of the inductors. The figures shown are a reasonable compromise. All engineering like this is a matter of choosing the best compromises.

The idea is to have the 3 pole filter, with the lower loss ahead of the RF amplifier, so as to not degrade the noise factor by more than 1.5db, and the 5 pole filter after the RF amplifier, but overall attenuation at the image frequency adds up to be well over 100db, a very good figure, even if the shielding is not perfect. In actual fact, two 3 pole filters would probably be adequate (about 110db), but I've decided to "over design" a little, where it doesn't degrade something else. After all, the VHF band is filled up with TV, FM, two way radio, navigation beacons etc. none of which we want to hear.



The component values for the series circuits are sensible for the 50 ohm filter, but the shunt elements of 620pF and 15nH are not. At this frequency of 52Mhz, these components have a reactance of 5 ohms, and this is so low as to be hard to make and very lossy. So what to do? I tried multiplying the impedance by different factors of voltage or turns ratio, the impedance ratio being the square on this, and came up with voltage or turns ratio of 7, so impedance ratio of 49.

What this means is we multiply the inductors by 49, and divide the capacitors by 49, and then put a 7:1 tap to connect to our 50 ohm filter. Running ELSIE again, but changing the impedance to 2450 ohms gives the same figures for the shunt elements only. The tap can be in the inductors or capacitors. This worked out well for the 10 metre case as well.

Using ELSIE to calculate coil sises is very simple, and it enables the 7:1 turns ratio to be readily maintained. For instance for a 650nH coil, choose 1cm long and 14 turns, so diameter 66.1mm. This allows a 2 turn tap to be the 50ohm point, or else a two turn link for balanced feed to the mixer (single channel version).

With filters having such a high attenuation “out of band”, it will be necessary to construct it with very careful shielding, in fact double shielding of the actual filters. If multi-banding, even more care will be needed to get the full benefit of the filters. The use of double sided printed circuit boards, with one side an earth plane, is important in the shielding process, and there are several ways they can be made, but my preference is to use Olimex[12] in Bulgaria, for good quality and reasonable cost.

Looking at the curve shown above, you see the VSWR figure in blue, is always less than 1.2:1 over the pass band, which is very good. Note the “ripple” in the passband, as determined by the entered figure of 0.05. The in and out of band figures can be read from the curve by using the mouse to put the cursor on the curve, and pressing the the right mouse button.

		order 5		order 3	
See	-3.5db	53Mhz		-1.5db	centre
	-5db	50Mhz	54Mhz	-1.8db	pass bandwidth
	-60db	44	61	-27db	stop band
	-80db	40	66	-37db	
	-100db	35	76	-50db	
	-120db	28	93	-61db	

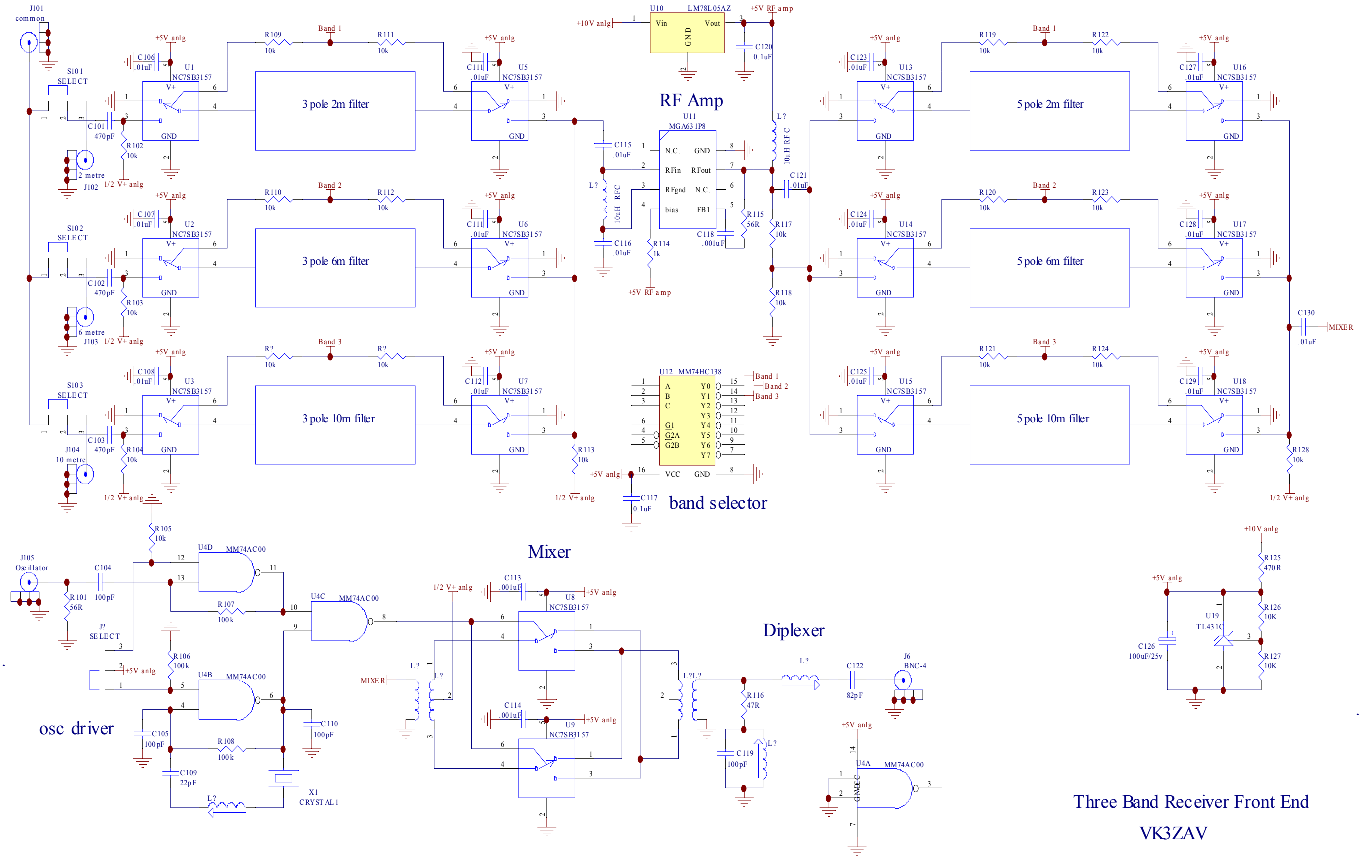
This is a very good performance, and will contribute to a seriously good receiver, without too much cost and complexity. For comparison I have shown the attenuation figures for the 3 pole filter also. Note the attenuation at the Aus. TV Channel 2 (63 to 70Mhz) with 100 kw transmitters, is 70db and 43db for the two filters.

Adjusting these filters requires some thought too, so I will start with the shunt tuned circuits installed on the PCB first, and adjusted independently. Next the series circuits will be installed, and each end bridged to ground, and also adjusted. For the higher bands, choosing 5% surface mount capacitors and adjusting turns spacing to get resonance at the centre frequency as shown on the ELSIE schematic.

RF Amplifier.

There is a common misconception that the noise figure of the RF amplifier for HF receivers does not need to be less than about 10db, but this is not correct. The overall noise figure of the receiver probably does not need to be less than 10db, but if the RF amplifier noise figure is, say 1db, and the input IP3 figure is 20dbm, then you can afford to have another 9db attenuation ahead of the RF amp, yielding an IP3 figure of 29dbm.

For this reason I have chosen a to use an Avago MGA631P8[13] for the RF amp (Mouser[14] $4.68), and expect a noise figure of 0.6db, and an output IP3 of about 39dbm, with a supply of 5v @ 80mA, gain is 16db, so input IP3 = 23dbm. This chip has setable gain and current.
An alternate from Mini Circuits is the GAL-74, with a noise figure of 2.7dbm, output IP3 +38dbm. Fixed gain 25db, too high, so input IP3 = 13dbm, price much the same.



Choosing a Mixer.

The classic approach is to use a packaged mixer, such as a low cost diode ring mixer, with a loss of about 6db, and input IP3 of about 14dbm. In the around $25 class mixers with IP3 of up to 35dbm are available, either diode ring or passive FET. Compare these examples of Mini Circuits[15] LAVI-2VH+, HJK-3H & ADE-1.

I will try a much lower cost approach, that should perform well, using a pair of logic circuits, Fairchild NC7SB3157P6X[16]. This is a CMOS SPDT switch, and can be driven from a logic level signal from a synthesiser acting as local oscillator. Price from Mouser[17] site is $0.30 each. This mixer is yet to be tested here, but should work well for either superhet or SDR receivers. The speed of operation may not be fast enough for 2 metre use, but certainly should be ok for 6 metres.

Another thought is to use 3rd harmonic mixing for 2 metre operation, ie. use the oscillator (square wave) at 1/3 of the frequency. This also reminds us that when using this mixer, the signal filters should have a large attenuation to prevent the mixing of input signals with the oscillator 3rd harmonic.

The IF Filter.

For this example of the FM receiver upgrade, the filter is provided, but if you want to start from scratch, then building your own filter is very much less costly than buying one. There is a low cost source of crystals available in Australia, with a frequency of 11.0592Mhz from X-ON for 36c each, which it seems could make a set of lattice or ladder filters for differing bandwidths. A rough check suggests that a CW ladder filter with bandwidth of 500Hz would use capacitors of about 300pF, an SSB filter with bandwidth of 2.5Khz would use capacitors of about 100pF, and an FM or AM filter with bandwidth of 7.5Khz would use capacitors of about 30pF. I suspect that around 6 to 8 crystals per filter will be needed.

Proper design would require the purchase and measurement of a batch of crystals, and then accurate calculation of capacitors for the bandwidths required. A search of “crystal ladder filter design” using “dogpile.com” (a multi search engine, much better than Google on its own) will find several ways to calculate this, some better than others. The actual IF frequency chosen is not important, unless it leads to a spurious response somewhere. With a digital synthesiser for tuning, it is quite acceptable to use a different IF frequency for each bandwidth, with the control software correcting the tuned frequency.

Multi band operation.

It is possible to switch different front end signal frequency filters to allow one receiver (or transceiver) to operate on different bands, but care is needed, because we have filters with stop band attenuation in excess of 120db, then the switching system will need to have an “off” attenuation of at least this much, quite a tall order. The commonly used method of switching is to use PIN diodes or relays, but meeting the -120db will be quite difficult.

A suggested approach would be to use the same logic switch that I suggested for the mixer, with a separate chip for each end of each band filter, as shown above. This low cost (30c) chip allows the use of a single RF amplifier chip, as its a $5 item, rather than one for each band. The drawback with this chip is that each switch has an on resistance of 6 ohms, so will introduce about 1db of loss, which adds up, but it is still needs a careful look. In this case, the switch is used so as to short circuit the unwanted signal path and get an additional attenuation in the “off” position.

General coverage version.

A variation of the multi-band approach would use a set of filters that each overlap by a small amount, so that computer controlled tuning would select the correct filter for the frequency tuned. This means that each filter would have a bandwidth much greater than a ham bands only receiver, and this might not be as good at rejecting unwanted out of band signals. Have a look at a set of ten filters using a bandwidth of 1.65 : 1, but they might need to be 5 pole and 7 pole.

Lower	centre	upper	bandwidth	
360	470	600	236	Khz
600	770	990	390	
990Khz	1.27Mhz	1.63Mhz	644	
1.63	2.10	2.70	1.062	Mhz
2.70	3.46	4.45	1.752	
4.45	5.70	7.34	2.891	
7.34	9.41	12.11	4.771	
12.11	15.53	19.98	7.872	
19.98	25.62	32.97	12.99	
32.97	42.28	54.40	21.43	

A revolutionary idea is to use a mixture of general coverage and Ham bands only.

Band Switching

There are several approaches to this, from the hand operated mechanical switch of the 1950's, to computer controlled switches of various types. The SDR1000[18] used relays, directly connected to 5 volt logic chips, but this approach can't be recommended for several reasons. I have already mentioned using logic switches, but if we are to produce a design that can be expanded, we have to start with that capability.

Relays seem to be a simple solution, as they are readily obtained and understood. There is an elegant solution to driving then, by using an older logic chip the 74SL145. This is a decoder with 10 open collector outputs that can switch up to 15v at 80mA. This would allow 12v relays, with reverse diodes across the coils, and can be borne in mind for transmitter or remote aerial matching use. However size, weight, and cost don't favour this option.

The Fairchild logic switch NC7SB3157 has a switching time of a few nanoseconds, needed for the mixer, and on "on" resistance of about 5 ohms, but the shunt capacitance is 18.5pF when closed and 6.5pF when open. This means that for a 10 band switch, you need to cope with 77pF[19], which might just be possible to incorporate into each of the band filters, but is difficult, and prevents adding additional bands as the urge comes on you.

This brings us back to PIN[20] diodes, and we need to select according to the frequency, the "on" resistance, the "open" capacitance, the power level, and the cost. To assess the lowest frequency that is usable, we need to know the minority carrier lifetime (t), and that reflects on the ham bands as follows:

160m	800nS
80m	400nS
40m	200nS
20m	100nS
10m	50nS
2m	10nS

A search through the Digi-Key and Mouser sites show up some low cost candidates, but not usable for all bands. Looking mainly at receiving power levels here,

Maker	type No.	t nS	C pF	R ohms	voltage	$ approx 100+
Infineon	BA592	120	0.6pF	0.35	30v	0.13
Infineon	BAR64	1550	0.23	2.1	150	0.22
Infineon	BAR67	700	0.35	1.0	150	0.38
NXP	BAT18	120	0.75	0.4	35	0.22
ON	MMBV3700	300	0.7	0.7	200	0.22
ON	MMBV3401		1.0	0.7	35	0.15

Most of the diodes shown above are made by several different manufacturers, and all should be interchangeable.

Now the BA592 looks good as long as you are switching at 20 metres or higher frequency, its able to achieve 0.45 ohms with only 2mA of current, really excellent. The rest of the bands should be ok. with the the BAR64, and its loss will still be under 0.5db I have so far been unable to find the minority carrier lifetime figure for the MMBV3401, a chip developed many years ago by the former Motorola Semiconductors. If you use a PIN diode at a lower frequency than recommended, some rectification will take place, giving distortion and intermodulation, so should be avoided.

The 200 volt rating of the MMBV3700 suggests that this chip could be used safely for switching for power levels of 40 or perhaps 50 watts, for the receive side of a transmit receive switch. For the transmit side, a number of, say, 3 or 4 could be used in parallel, providing that the DC current feed is to each diode separately.

an on going project by Peter Ward, VK3ZAV.

1 I use the English term aerial, whereas some use the biological term antenna, here they are interchangeable.
2 http://yu1lm.qrpradio.com
3 http://en.wikipedia.org/wiki/Superheterodyne_receiver
4 http://en.wikipedia.org/wiki/Software-defined_radio
5 http://www.analog.com/en/technical-library/application-notes/design-center/products/rfif-components/direct-digital-synthesis-dds/resources/index.html get application note AN-741
also http://www.exothink.com/SDR/SDRPN/index.htm
6 http://search.analog.com/search/default.aspx?query=DDS&local=en
see the application notes & data sheets, AN-927
7 http://en.wikipedia.org/wiki/Intermodulation
8 http://www.radio-electronics.com/info/receivers/sensitivity/sensitivity.php
9 http://www.radio-electronics.com/info/receivers/dynamic_range/dynamic_range.php or http://www.radio-electronics.com/info/receivers/dynamic_range/dynamic_range.php
10 See LINKS 6.11
11 Filter poles, in this type of filter same as thr number of tuned circuits, ie, L C pairs.
12 See Links 7.7
13 http://www.avagotech.com/search/results.jsp?src=&siteCriteria=MGA631P8
14 http://www.mouser.com/Search/Refine.aspx?Keyword=mga631&Ns=P_SField
15 See http://www.minicircuits.com
16 http://www.fairchildsemi.com/sitesearch/fsc.jsp?text=NC7SB3157P6X&as=1&render=1&w=&command=text&attr1=&attr2=&t=0&i=sitemap+id&ia=1
17 see http://au.mouser.com/Search/Refine.aspx?Keyword=NC7SB3157P6X&Ns=P_SField
18 http://www.flex-radio.com/About.aspx?topic=history
19 The sum of 18.5 + 9 x 6.5pF for one switch "on" and switches 9 "off", all in parallel.
20 See http://www.rfdesignline.com/howto/209900491
and http://www.qsl.net/n9zia/wireless/pdf/an922.pdf
also http://www.vishay.com/company/press/releases/2002/021206rfdiodes/