Short Circuits

Designing a wideband VHF to HF Converter

INTRODUCTION. This converter was put together quickly in response to a challenge and proved more complex than initially thought. I thought it would make a good subject for this column as the design processes, particularly the calculation of mixer spurious responses and the resulting filter requirements, are typical of many amateur projects.

VHF beacons on 40, 50, 60 and 70MHz at GB3RAL were described in April 2008 *RadCom*. The beacon keeper recently commented that there is a lack of reports on the 60MHz signal. After a bit of research, he soon realised that most modern amateur rigs do not cover that frequency, whereas many of them do cover 40 and 50MHz. So he suggested a dual band converter could be designed to cover 60 and 70MHz, to let HF operators have a go at receiving 70MHz as well. Of course, a certain writer couldn't ignore that challenge! So here are the design notes and thoughts that lead to a not-quite-perfect-but-adequate breadboard converter.

INITIAL ASSUMPTIONS. In order to scope the design I needed to make some initial assumptions. These were:

1) Full HF receive coverage is available, so we can choose a conversion with a single local oscillator (LO), then listen on two intermediate frequencies (IF) separated by 10MHz.
2) The LO is usually the most complicated part of a converter and it would help if an off-the-shelf packaged module could be used.
3) The beacons are high stability phase locked units, so the option of being able to use an LO locked to a master 10MHz reference should be possible. Ideally the LO should be a multiple of 10MHz.

Using a 50MHz LO, we get IFs of 10 and 20MHz for the two beacon frequencies. Ready-made TTL oscillator modules are easily available at low cost **[1]** and are usually more than adequate as LO sources even into the UHF region. Unfortunately, they are not usually frequency adjustable, so some calibration error and drift will have to be accepted. However, they can be surprisingly stable at a constant temperature. For more precise frequency setting, a 10MHz master reference can be used with an x5 multiplier to provide the LO instead, but for now we will keep with the simple solution.

Next, we have to consider what interfering frequencies and image problems there are. This will let us choose the best type of filtering to remove them. The first image will fall in the frequency band 30 – 40MHz (LO – RF = 10 to 20MHz) and we are fortunate that there is not too much activity in this part of the spectrum. Low power cordless phones exist at 36 and 39MHz, as do some radio controlled toys and other low powered devices. These should not be too much of a problem and almost certainly won't need excessive filtering to reject them: 30 to 40dB should be adequate. But, there is a far more serious interference issue to consider – that of direct breakthrough from HF leaking past our mixer and being picked up on wiring. We will be tuning the range from 10 to 20MHz. Broadcast signals in the 10MHz region can be massive, especially at sun spot maxima. On a typical HF antenna, several broadcast carriers of -40dBm each are not unknown. A typical balanced mixer will provide 20 to 40dB of isolation against direct leak-through, but will still result in signals that will are many tens of dB up on the weak ones we want to hear. So how do we calculate the filter attenuation necessary?

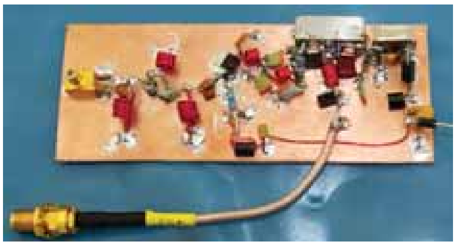

PHOTO 1: With only a little effort it's possible to make a converter to receive the 60MHz and 70MHz beacons.

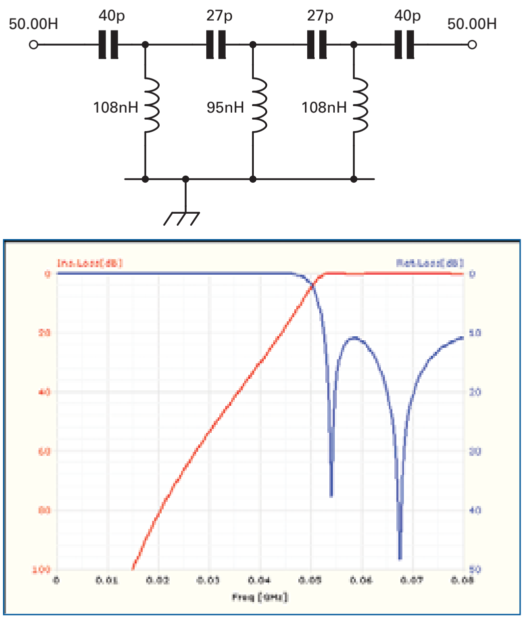

FIGURE 1: The 7th order Chebyshev filter and its modelled frequency response.

FILTERING. Assuming -40dBm of interfering RF with 30dB of mixer rejection, we start out with -70dBm of unwanted signal to remove. At low VHF we are usually dominated by external noise, even in rural areas. Experience has shown that the antenna background is equivalent to a noise figure in the region of 10 to 15dB at 70MHz in quiet areas, so let's stay with this value for 60MHz as well. For aural CW reception of a tone, most listeners accept an effective noise bandwidth of around 100Hz is about right. A 10dB signal to noise ratio in this bandwidth is about the lowest that can be heard reliably by the average set of ears. So, taking all these values into account, we now calculate the Minimum Discernible Signal (MDS) we will be able to hear and the filtering necessary to get the HF leakage down to an acceptable level that won't cause annoying interference.

Thermal noise (dBm) =
–174 + noise figure (dB)
+ 10 x log (bandwidth in Hz).

For the values given, this equals -144dBm, so a 10dB S/N ratio requires an MDS of -134dBm. To attenuate our -70dBm interferer to this level means we need 64dB of filtering rejection in the band below 20MHz. So, a filter providing a few tens of dB in the 30 – 40MHz region and probably 70dB or more below 20MHz immediately suggests a high pass filter with a cutoff around 55MHz to allow for component tolerances. Using AADE Filter Designer **[2]** or the filter tool in Ansoft Designer **[3]**, we can play with candidate designs until we come up with a suitable one and **Figure 1** shows the filter I selected. A 7th order, 0.2dB ripple Chebyshev design provides, potentially, over 80dB of rejection at 20MHz – and a lot more than we need at 10MHz, but at least it is simple and surprisingly immune to component tolerances.

HIGHER FREQUENCIES. Now, what about problems with responses above 70MHz? Mixers respond to images resulting from harmonics of the LO. Odd-order harmonics are most serious, but we cannot ignore even ones. So we need to attenuate 3 x 50MHz ±20MHz = 130 to 170MHz, where not too many strong signals should be present. To a lesser extent we also need to attenuate 2 x 50MHz ±20MHz = 80 – 120MHz. This latter includes the 88 to 108MHz broadcast band, which could be very bad news if you're located close to a broadcast transmitter! Fortunately, we are helped by the fact that response to even-order LO harmonics is typically 30 – 40dB less than that of odd order ones. A fifth order filter with a cut off of 75MHz is used to protect against these unwanted responses.

CIRCUIT ELEMENTS. Now what about the rest of the hardware? We need a balanced mixer and, unless there is a good reason to use something different, it is difficult to beat the old favourite SRA-1 or SBL-1 diode ring mixers. These provide an insertion loss of around 7dB and the filters contribute about 3dB loss between them. To ensure we don't lose too much sensitivity we need to provide a gain of some 6 – 8dB more than the losses – in other words we need about 16 – 18dB gain. As mentioned earlier, atmospheric noise dominates at low VHF, so a good noise figure is not essential and a single MAR-6 modamp with its 19dB gain and 3dB noise figure fits the bill perfectly. And that's it!

Figure 2 shows the complete circuit diagram of the finished converter. The high pass filter is placed before the gain stage to prevent amplifying HF signals. The modamp has well defined 50Ω port impedances which nicely terminates one end of each of the filters. A 3dB 50Ω attenuator is inserted between the low pass filter and mixer to improve the match for both. This makes our gain distribution a bit marginal, but the noise figure still remains at an acceptable level. To complete the unit, a 25MHz LPF is added at the mixer output to clean up any mixer harmonics leaking out. This is not really necessary as any subsequent receiver input circuitry will do the job far better, but having one is just good practice.

DECOUPLING. Good decoupling, particularly of power supply wiring, is absolutely essential. HF or VHF broadcast signals can easily be picked up on external wiring and carried into the signal path if they are not completely bypassed. Internal decoupling must cover all frequency bands as the MAR-6 has significant gain up to over 1GHz and stray feedback must be prevented.

Photo 1 shows the finished unit constructed dead-bug-breadboard style. All inductors were air wound for simplicity, their sizes being determined from Wheeler's equation (see sidebar). The inductance can be fine-tuned by stretching the turns. As the inductors only make up half of each filter's components and relatively accurate capacitors form the other, their values in practice are usually not too critical. In fact, it can be quite revealing just how good a measured response can be with lumped element filters such as these, even when components are more than 20% away from their correct values – provided the tolerances are all in different, random, directions.

RESULTS. This lashed-together breadboard ended up with a net overall gain of 5dB and, after a bit of inductor squeezing and bending, a response that rolled off rapidly below 59MHz. Frequency response was even better than expected, achieving an attenuation of around 85dB at 20MHz. At 90MHz (2 x LO – 10MHz IF), close to BBC Radio 2 or 3, attenuation was measured as only 60dB, which means it would be very audible at the appropriate IF. Fortunately, the R2 or R3 frequencies in this part of the world do not place a spur close to 10MHz. If this situation does arise, the most realistic scenario would be to change the LO frequency slightly, to 48MHz for example, then tuning 12 – 22MHz. The alternative is to build a higher order low pass filter.

Wheelers Equation

Wheeler's Equation is a classic formula for calculating the inductance of a single-layer coil. The equation is:

$$L\,(nH) = \frac{(N \times D)^2}{(0.46 \times D + M)}$$

where

D – Coil mean diameter in mm
M – Coil length in mm
N – Number of turns
L – Inductance in nanohenries

Approximate Inductor Dimensions:

55MHz HPF

107nH	6 turns, 6mm long, 5mm overall dia, 0.8mm wire
98nH	5 turns, 4mm long, 5mm overall dia, 0.8mm wire

75MHz LPF

84nH	6 turns, 3.6mm long, 3.5mm overall dia, 0.5mm wire

25MHz LPF

180nH	10 turns, 5mm long, 3.5mm overall dia, 0.5mm wire

Software for coil design can be found at www.g4jnt.com/wound.zip

CONCLUSIONS. A bit more gain would be desirable, although with the high atmospheric noise levels these days, does not present a problem. Filtering at VHF Band 2 Broadcast really ought to be improved, especially if the converter is to be used outside the target 60 and 70MHz input regions. However, as a breadboard project it works very well.

REFERENCES

[1] http://uk.farnell.com/ order code 951-0176 for example
[2] AADE Filter Designer: www.aade.com
[3] Ansoft Designer: www.ansoft.com/ansoftdesignersv/

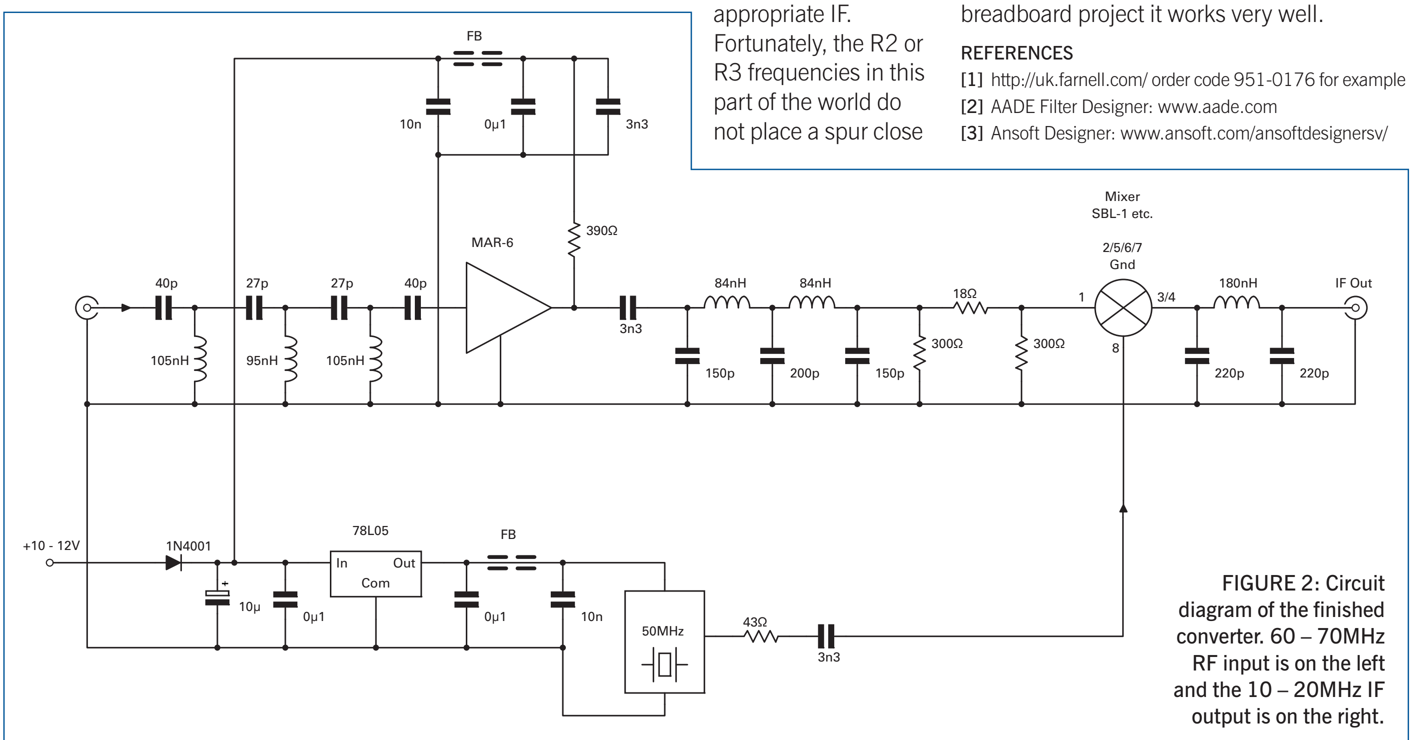

FIGURE 2: Circuit diagram of the finished converter. 60 – 70MHz RF input is on the left and the 10 – 20MHz IF output is on the right.