Optimising the performance of the RSP1A at LF/MW/HF

Introduction
This white paper gives an overview of the operation of the RSP1A at frequencies below 60 MHz. It gives a guide to obtaining the best performance at VLF/LF/MW and SW (HF)

Overview of the RSP1A Tuner architecture
Figure 1 illustrates the architecture of the tuner used to cover bands below 60 MHz on the RSP1

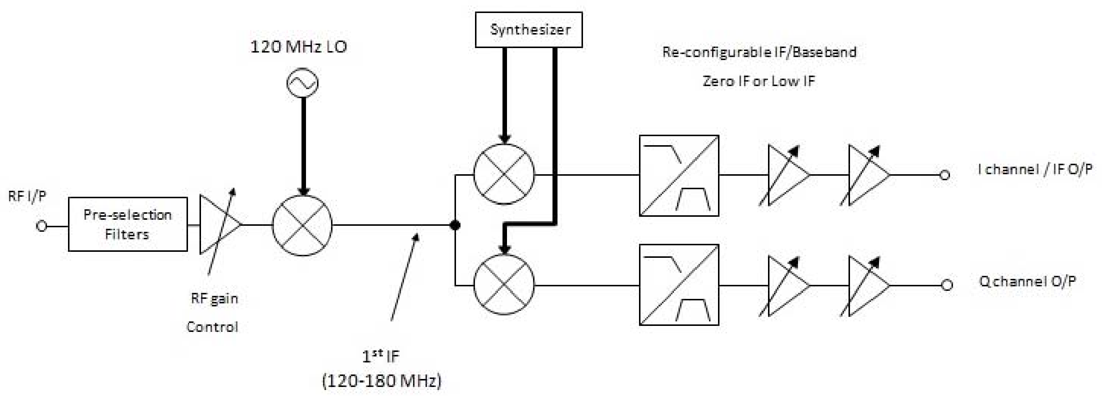


Figure 1

The RSP1A uses a double-conversion architecture to cover frequencies from 1 kHz to 60 MHz. A fixed frequency block converter up-converts the 1kHz – 60 MHz range of spectrum to 120.001 – 180 MHz and the frequency synthesizer is used to mix a selected section of spectrum to either a low IF (LIF) or zero IF (ZIF). The integrated post mixer filters can be dynamically re-configured to operate as low pass filters (for zero IF mode) or complex poly-phase bandpass filters (for low IF mode). In low IF mode, the I/Q down conversion mixers/poly-phase filters provide image rejection for the down-conversion mixing process.

Prior to the block up-converter, there is both RF pre-selection and RF gain control. The RF pre-selection filter ranges are 0-2 MHz, 2-12 MHz, 12-30 MHz and 30-60 MHz and there is also a MW notch filter. These pre-selection and notch filters provide protection from overload and spurious responses from signals outside of the range of interest.

How does this relate to the settings in SDRuno?

SDRuno 'hides' the fact that the RSPs use a double conversion architecture for frequencies below 60 MHz. The relationship between the LO frequency in SDRuno and the synthesizer frequency is:

$LO = F_{synth} – F_{LO1} - F_{LIF}$

Where F_{synth} is the synthesizer Frequency

F_{LIF} is the frequency of the Low IF (0 Hz in ZIF mode)

F_{LO1} is the frequency of the first LO used in the block converter (nominally 120 MHz)

Spurious Responses

The performance of any receiver deteriorates when large signals are subject to non-linearities in the signal path. Amplifiers, for example, can be driven into compression. When multiple signals are received this can lead to a phenomenon called intermodulation. However, where the receiver contains frequency translation via mixing processes, there is a completely different undesirable phenomenon called 'higher order mixing', which is not caused by compression and is distinctly different from intermodulation.

Intermodulation (IMD) vs Higher Order Mixing effects

Intermodulation occurs where two or more signals interact through the process of distortion to create additional spurious signals. The position of these these signals is always fixed in a relative way to the position of the signals that lead to their generation. The process can be illustrated by figure 2

Consider two signals of equal power at frequencies F_1 and F_2. Third order distortion leads to the generation of third order intermodulation (IM3) products A and B, where the frequency of A = $2xF_1$-F_2 and the frequency of B = $2xF_2$-F_1

An increase of 1 dB in signals F_1 and F_2 will generally (but not always) lead to a 3 dB increase in products A and B and so the difference in power between the original signals and their third order intermodulation products (X) will reduce by 2 dB.

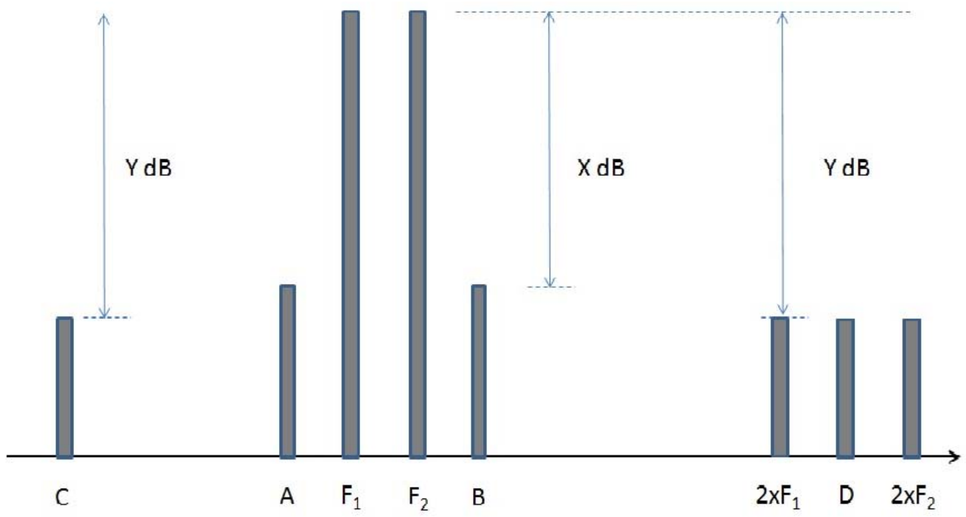


Figure 2. Intermodulation

If the power of the signals into the receiver is continuously increased, the output power will eventually limit via the process of compression, but it is possible to extrapolate the output power of the applied signals and the resulting 3rd order intermodulation products until they theoretically meet. This is illustrated in figure 3. This theoretical point is called the 3rd order intercept point and can be projected as an input (IIP3) or and output (OIP3). The OIP3 is always the IIP3 multiplied by the linear gain.

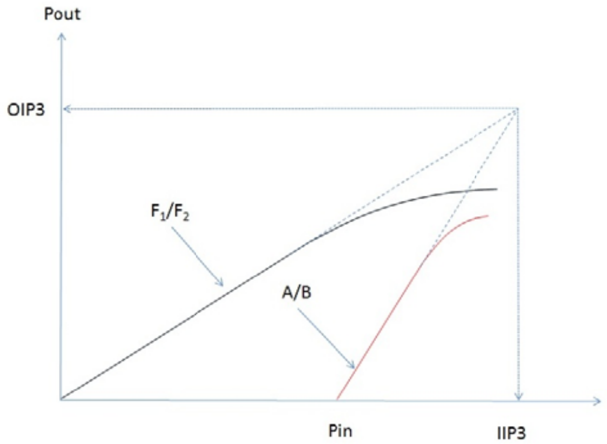


Figure 3 – Intermodulation and the 'Intercept point'

It is important to remember that the IIP3 does not in reality exist. It is simply a 'figure of merit', that illustrates the propensity of a given circuit to generate third order intermodulation.

As well as third order intermodulation, there may also be second order intermodulation effects and these are caused by second order distortion. Signals C and D in figure 2 are illustrations of second order intermodulation, where C = F_2-F_1 and D = F_2+ F_1. These products will typically be at the same level as the second harmonics of the two applied signals. The typical characteristic of second order intermodulation products is that a 1 dB increase in the applied signals will result in a 2 dB increase in the second order intermodulation (IM2) products, so the difference between the IM2 products and the wanted signal (Y) will change by 1 dB for every 1 dB change in input power. In other words, IM2 products increase more slowly as the applied signal power increases than IM3 products and it is normal therefore for the second order input intercept point (IIP2) to be greater than the IIP3 for a given level of linearity.

It is important to remember that this illustration is a simplification of reality. In reality, in any wideband receiver, there is likely to be many more than two input signals present and the wider the RF bandwidth, the more signals will be present. As well as IM3 and IM2 effects, there can also be 5th order, 7th order etc IMD products and another effect called cross-modulation. Cross modulation is a process where the modulation from one signal becomes superimposed on top of another signal and is particularly evident with AM signals such as those found in the MW band. All of these effects are undesirable and are a result of non-linearity in the receiver transfer function.

Higher order mixing products are a completely different phenomenon from intermodulation products, but are often confused with them. Higher order mixing products do NOT arise from non-linearity of the gain transfer function of the signal path and are therefore not a result of signal path overload. Rather, higher order mixing products arise from non-linearities in the oscillator paths.

To get acceptable performance from frequency mixers (multipliers), it is necessary to drive the oscillator path into hard compression. As a consequence, the oscillators should not be considered as sine waves, they are really better illustrated as square waves. Square waves have a harmonic profile that is 1/x. In other words, the 3rd harmonic will have a magnitude of 1/3 that of the fundamental, the 5th, 1/5 that of the fundamental etc. Perfect square waves only consist of odd order harmonics and so it is generally safe to ignore even order effects.

Supposing we have a 1 MHz signal at the input of our receiver. The block converter, will up-convert this to an intermediate frequency (IF) of 121 MHz using the 120 MHz LO. However the 120 MHz LO is really a square wave and will have a 3rd harmonic at 360 MHz, a 5th harmonic at 600 MHz etc. These will also mix with the 1 MHz signal to produce 'Higher order IFs' at 361 MHz, 601 MHz etc. The magnitude of these IFs will go down with a 1/x profile and so the 361

MHz IF will be 1/3rd the magnitude of the fundamental (-10 dB) and the 5th will be 1/5th (-14 dB) etc.

If we set our synthesizer frequency to 120.1 MHz in zero IF mode (LO = 100 kHz in SDRuno), then the 1 MHz input signal will translated to 900 kHz at the I/Q baseband outputs. Now, it is important to remember that the synthesizer waveform will also be a square wave and so will have a 3rd harmonic of 360.3 MHz and a 5th harmonic of 600.5 MHz etc. These harmonics will also have the same 1/x characteristic and will mix with the higher order IFs generated by the first mixer and first LO. As a consequence, the synthesizer 3rd harmonic will mix with 361 MHz signal (3rd IF) to produce a signal at 700 kHz at the I/Q outputs and the 5th harmonic will mix with the 601 MHz (5th IF) to produce a signal at 500 kHz. Because of the 1/x harmonic characteristic of both oscillators, the 700 kHz and 500 kHz 'spurious signals' will be at -20 dB and -28 dB with respect to the real 900 kHz signal. The 500 kHz and 700 kHz spurious signal are not as a result of overload. Instead they are as a result of higher order mixing products and the nature of the dual conversion architecture. They also have a 1:1 correspondence with the power of the input signal, so a 1 dB change in the input power will also result in a 1 dB change in these unwanted products and that is very different from products that result from overload. In that regard, adjusting the RF gain will not help with this phenomenon. The other interesting characteristic of these products is that they 'move' as the synthesizer frequency moves. With the synthesizer at 120.1 MHz, these spurious products appear to be 200 kHz and 400 kHz below the real signal. However, supposing the synthesizer is tuned to 120.15 MHz? The 1 MHz 'real' signal will now move to 850 kHz at the I/Q outputs. The synthesizer 3rd and 5th harmonics now move to 360.45 MHz and 600.75 MHz. These now mix with the 3rd and 5th IFs to produce tones at 550 kHz and 250 kHz, which are 300 kHz and 600 kHz away from the real signal.

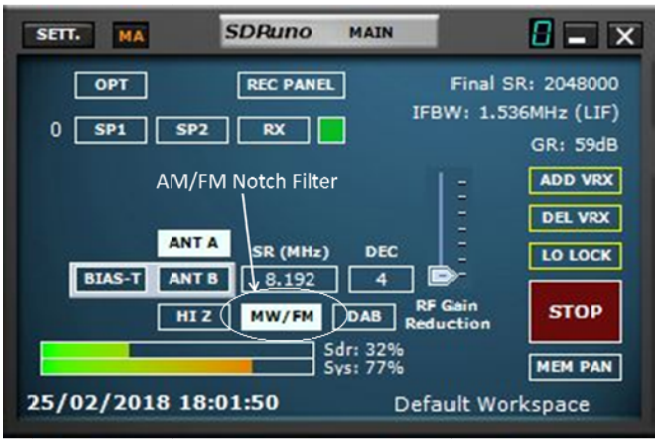
So how can we tell if a spurious signal is as a result of intermodulation or higher order mixing effects?

1. Intermodulation products *do not* move relative to real signals when the synthesiser frequency is changed. In SDRuno, change the LO. If the spurious signal does not move, then it is a result of intermodulation.
2. Reducing the input power with an external attenuator or via the RF gain control will reduce intermodulation products relative to real signals
3. Higher order mixing products *do* move relative to real signal as the synthesizer frequency is changed. Change the LO in SDRuno. If the spurious signal moves, then it is a result of higher order mixing effects.
4. Applying RF attenuation via the RF gain control will NOT reduce the higher order mixing products relative to real signals.
5. Reducing the input power with an external attenuator will reduce the level of higher order mixing products, but will NOT reduce the higher order mixing products relative to real signals.

How do we mitigate these effects when operating at Low Frequency or Medium Wave?

The RSP1A has both a 2 MHz low pass filter and a MW notch filter. Here is a strategy for minimising both intermodulation effects and higher order mixing products:

1. Ensure that LO is below 2 MHz. This will enable the 2 MHz low pass filter and attenuate unwanted signals above 2 MHz.
2. If you are monitoring signals at LW or below, enable the medium wave (AM) notch filter in SDRuno



3. Set the IF mode to Low IF and select a sample rate of 8.192 MHz with a decimation of 4. This will select a second IF of 2.048 MHz, which means that the synthesizer frequency has to be increased by an additional 2.048 MHz. As a result of this increase, the majority of signals that will produce an in-band response will be above 2 MHz and will be attenuated by the 2 MHz low pass filter.
4. Adjust the RF gain/gain reduction slider in SDRuno to find the best setting to optimise the trade-off between intermodulation and the noise floor

I have really strong AM signals where I live and I have tried the above, but I still have problems. What else can I do?

For the overwhelming majority of people, the above strategy will be effective in mitigating spurious responses at VLF, LF and MW. However, if problems persist, try the following:

1. Add additional notch filters for the MW/AM band
2. Apply a fixed attenuator or 10-20 dB in line with your antenna
    a. A 1 dB reduction in the receiver input power will reduce third order intermodulation products by 3 dB and second order intermodulation products by 2 dB
    b. Atmospheric noise can be easily 40 dB above KTB below 10 MHz. Adding 10-20 dB of external RF attenuation will increase the receiver noise figure by 10-20 dB, but there is a good chance that the increase in the noise floor will not be materially visible above the background atmospheric noise at the lower HF frequencies.

What about operation at HF?

The higher up you go into the HF band, the less likely it is that you will see higher order mixing products, but if you have problems with overload from MW AM signals:

1. Ensure that your LO is set to greater than 2 MHz
2. Enable the MW/AM notch filter
3. Adjust the RF gain/Gain reduction slider to give the best trade-off between intermodulation and noise
4. Try adding a fixed external attenuator of 10 or 20 dB
5. Try adding an additional external MW/AM notch filter

Will any of these things help with the RSP2?

Yes, but less so. The RSP2 does not have pre-selection filters on the Hi-Z port, which is the recommended port for use at HF and below. However, fixed external attenuators or MW notch filters should help protect against intermodulation and selecting Low IF mode (8.192 MHz sample rate, Dec=4) will have the effect of moving the synthesizer frequency to a frequency such that the higher order mixing products will come from a more benign region of spectrum than the MW/AM band and are therefore less likely to be visible.

Legal Information