SIMULATION NONSENSE

PITFALLS IN SYSTEM SIMULATION

Simon W Day, Phasor Design www.phasor-design.uk.com

Introduction - The complexity of modern radio systems means that system simulation by numerical methods has become an essential tool in the design of wireless productions. As an example of this trend consider COFDM. Coded Orthogonal Frequency Division Multiplexing has many advantages; it can actually benefit from frequency selective fading, and allows single frequency networks where all broadcast transmitters are on the same channel so saving spectrum. The cost of this is complex electronics where the receiver must digitise the signal, perform an FFT, then the necessary error correction. CODFM is used in Wireless LAN and many broadcast systems such as DVB for television, DAB for high quality sound at VHF band II and DRM for sound in the LF, MF and HF bands.

To develop radio systems of this level of complexity requires a sophisticated methodology. The system may be broken down into transmitter, propagation channel, and receiver, and then each of these decomposed again. For example the propagation channel may include antenna characteristics, location and orientation, in addition to the effect of the radio environment. Electronic Design Automation (EDA) addresses this requirement with system simulation software, which runs on the standard PC.

Fundamental principles - There are a number of system simulation products available in the market place, which may be superficially very different. However there are some fundamental principles which are common across all of them. They

- have models of system components of varying levels of detail, and
- have models of the signal which tend to be fairly complex.

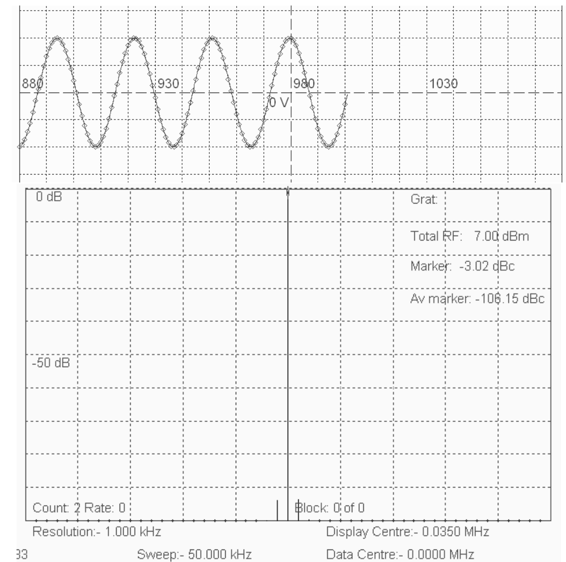
Signals can be described in either the time domain, by a sequence of samples in time, or the frequency domain. If the time domain sequence is allowed to repeat then these two methods amount to the same thing.

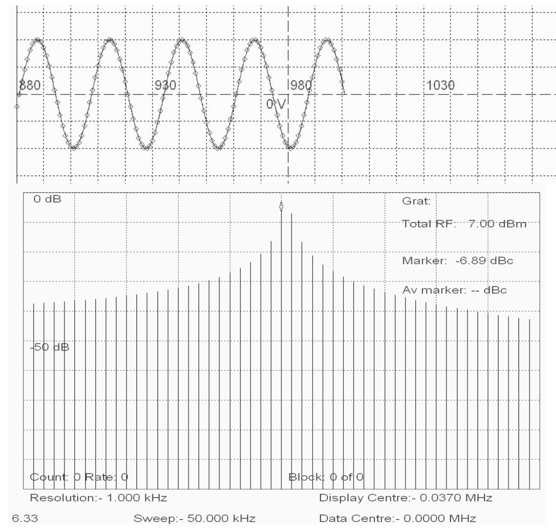
This paper seeks to identify potential pitfalls, which are common to all such products, because they are based on the very simple ideas presented above. It looks at these fundamental principles and so is independent of any specific software tool. The aim is to allow the reader to chuckle at the author's mistakes, and avoid those same errors themselves.

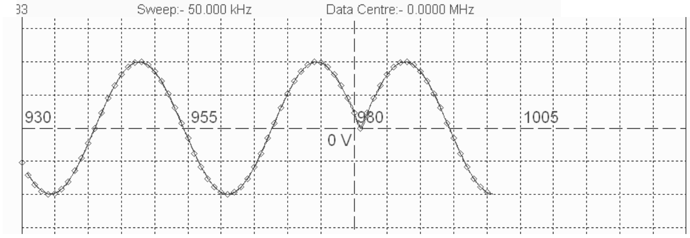
The SPLASH system simulator from Phasor Design has been used to create the examples that follow. It should be appreciated that many other simulators could have been used and the same results obtained.

Things look different in the frequency domain

The spectrum of the 35kHz sine wave looks very pure with simulation generated spurs over 90dB down. The same simulation for a 37.5kHz sine wave is very different with spurs just a few dB down.

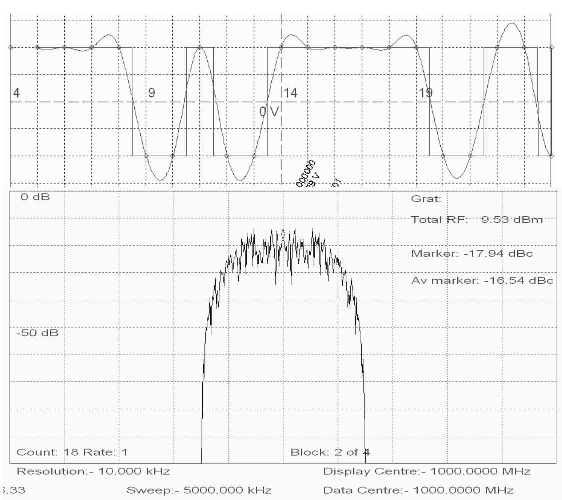


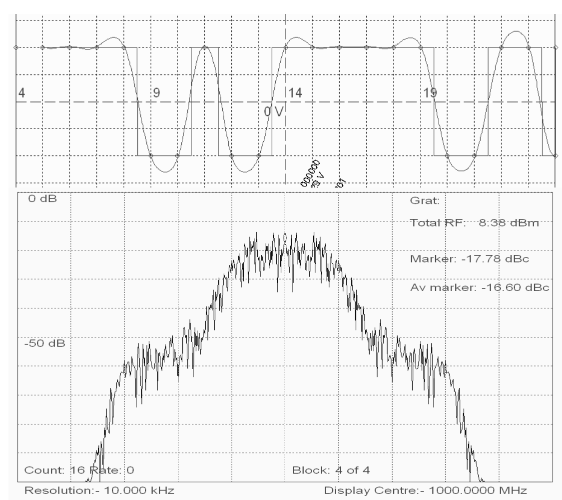




The actual 37.5kHz wave-form simulated has this discontinuity which causes the radically different spectrum. Note that 1000 samples over 1ms are simulated.

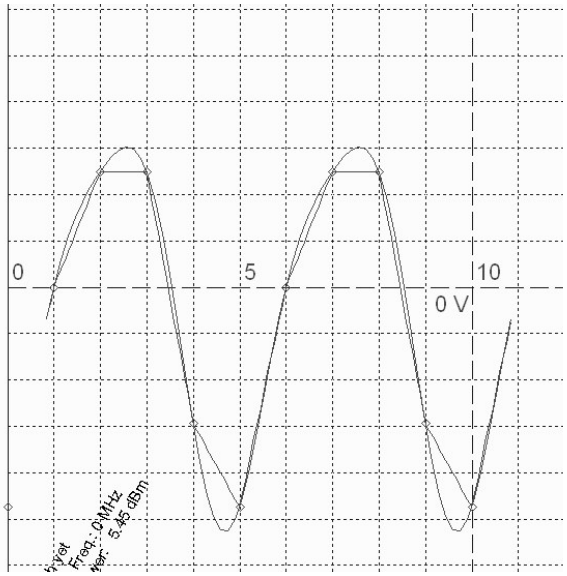
The effect of 3rd order non-linearities is to alter the spectrum greatly but the waveform only in a subtle way. Note that gain of 1.1dB was applied to re-register the amplitudes in the following plots.





These two examples show that the wave-form may be a poor guide to behaviour in the spectrum.

Aliasing



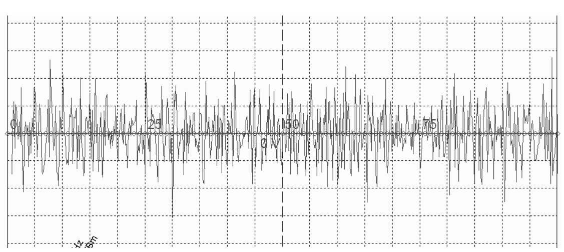
An interesting example of aliasing is a clipped 200kHz sine wave of two cycles shown here and listed below.

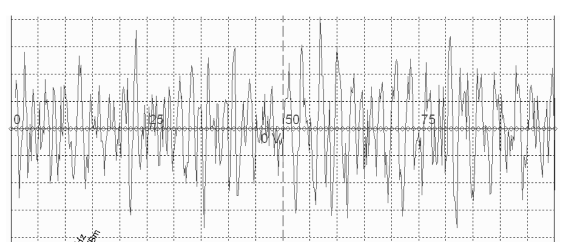
```
+0.00000
+0.50000
+0.50000
-0.58778
-0.95106
-0.00001
+0.50000
+0.50000
-0.58778
-0.95106  10
```

Although this data seems simple enough there is a question of interpretation. If the sample rate is 1 MHz then only frequencies up to 500kHz can be represented. But clearly the clipping of a 200kHz signal will produce harmonics greater than 500kHz. The two plot lines show the two possible interpretations: the straight-line connections between points are in reality only notional; the actual wave form modelled in the frequency domain is the continuous plot which corresponds to frequency components within the acceptable range.

Statistics

A statistical approach, unfortunately, becomes necessary as both the noise and the signal can have random properties. A very simple example of noise measurement illustrates the hazards. The following two noise waveforms of 100 samples were simulated and the total power measured on ten occasions





Case A - Total power in dBm:

-17.64, -17.97, -18.15, -17.24, -17.86,
-17.80, -17.50, -17.99, -18.01, -17.44

Standard deviation is 0.28dB

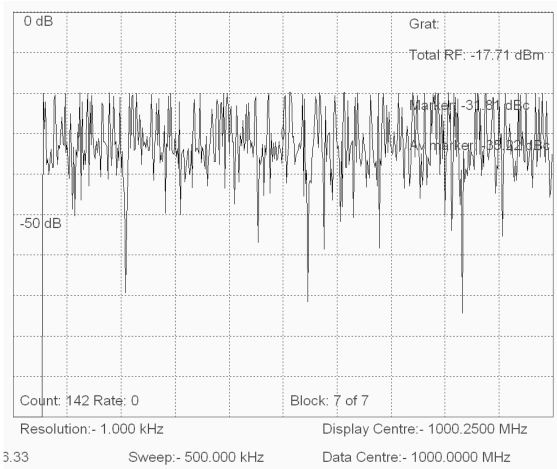
Case B - Total power in dBm:

-40.45, -39.83, -38.31, -39.88, -38.30,
-38.90, -39.69, -39.08, -38.69, -39.42

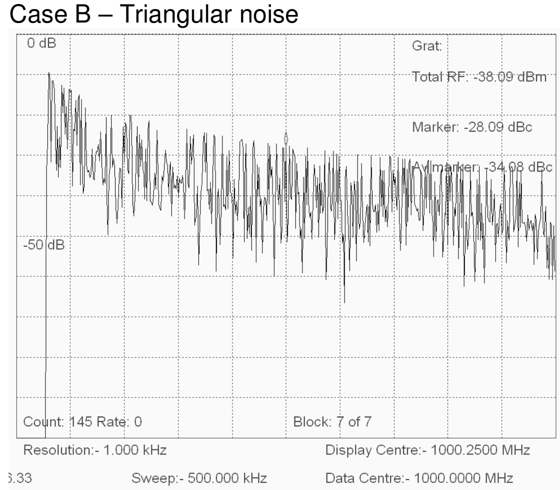
Standard deviation is 0.68 dB

It is clear that the spread of values in case B is much wider. The difference is the noise distribution being flat in case A and triangular in case B.

Case A – Flat noise



Case B – Triangular noise



The general point is that slowly changing features of the simulation require long simulation times to gain adequate statistical information. How long a simulation time is open to judgement, but the simple case illustrated indicates that it may not always be very obvious. A short simulation time could easily give you the values that you may prefer rather than the correct ones!

Data reduction oddities

There can be a very large range of time-scales within a simulation. For example a 1.8GHz radio may require a sample rate of say 4GHz to include the carrier frequency, but also be subject to Rayleigh fading which is modelled as a noise source to 20Hz. This situation suggests that a minimum simulation of one second would use 4,000,000,000 samples. In order to make the simulation feasible a trick is needed, and this is provided by the 'low pass equivalent' method. In summary, the carrier is moved to zero frequency and represented as I & Q channels.

The low pass equivalent is widely used within system simulation as it makes the 1.8GHz radio subject to Rayleigh fading a feasible simulation but it does have oddities, which can be disturbing.

- Odd order non-linearities are handled very well but even order non-linearities, which would appear out of band in reality, result in spurious in-band components.

- Asymmetrical filtering requires special care as illustrated by the block diagram of a band-pass filter shown here. The band-pass filter must be decomposed into the in-phase and quadrature low pass equivalent filters. In the real world it is unlikely that narrow band filters are truly symmetrical, so unfortunately the effort of creating a full simulation is necessary.

In practice it may be necessary to perform simulations on both a low pass equivalent basis and also a second simulation with 'real' frequencies. No simulator that we are aware of automatically performs this dual simulation.

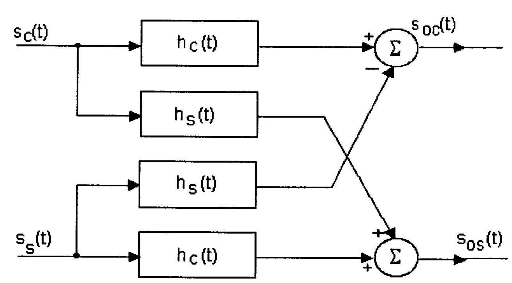


Figure 27: Complex-Envelope Filter Operation

produces

$$s'_c(t) = s_c(t) * h_c(t) - s_s(t) * h_s(t) ,$$

and

$$s'_s(t) = s_c(t) * h_s(t) + s_s(t) * h_c(t) ,$$

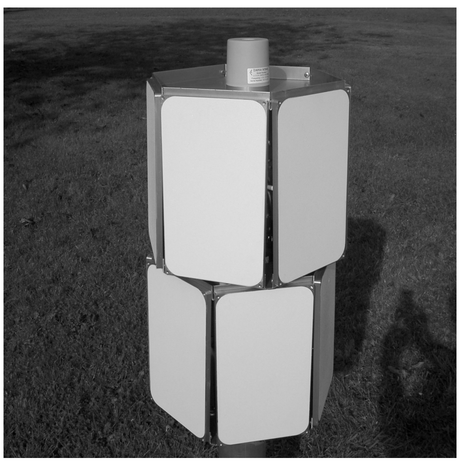
Verification and validation

According to ISO9000, verification is an activity which ensures design output meets design and development inputs. On the other hand, validation confirms that the resulting product will fulfil the requirements of its intended use. This distinction is a useful one because it makes clear the need to both do internal checks on the design, and also operate the equipment in the way that a user would. A radio system should be checked on the bench via attenuators, to ensure sensitivity is in line with expectations. That same system should also be checked by actually using it. It is at this point one may discover that the radiation from the transmitter antenna enters its own power lead and shuts down the power supply.

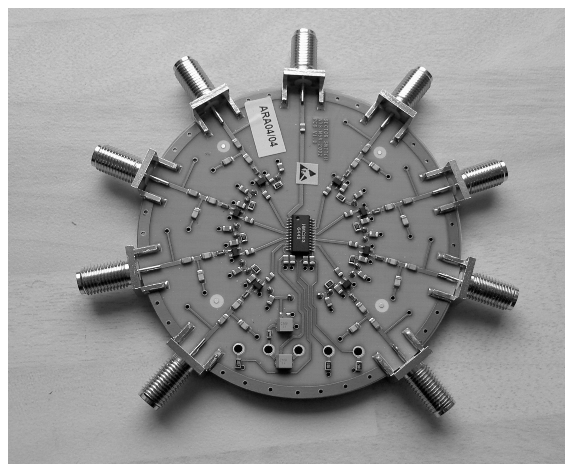
System simulation is an essential part of the verification activity. It is important to realise that system simulation does not replace validation. The following example illustrates this point.

Airborne radio system example

An airborne radio system has been developed with provides a high quality link of over 30 km range. An array of directional antennas are required and these are switched automatically by the system to maintain the link.



Antenna array (revised patch type)



Microwave Switch

System analysis indicated that the range would be achieved and bench tests supported this view. However when validation was attempted the required range of was not obtained. A careful examination of the system eventually showed that the helical antennas first selected were not functional, despite data provided by their manufacturers indicating good gain figures. The reason for this proved to be an incorrect material, which differed from the prototype on which the data had been measured. A solution was found by the use of a patch type antenna (photograph above), which gave the required range.

System simulation is important part of radio system design. It is a tool in the design process, an important part of verification, and must cover all of the disciplines involved. Radio system design is a truly multidisciplinary endeavour and the tools should reflect this. The pitfalls examined in this paper are intended to provide an insight into the strengths and weakness of simulation, so that engineers get the best from the tools available.

Acknowledgements

The kind permission of Navtech Systems to include the airborne radio material and their help in preparation is gratefully acknowledged.