REDUCING ELECTROMAGNETIC EMISSIONS FROM SPACEWIRE

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ABSTRACT

SpaceWire is a high speed (2 to >400Mb/s) digital communication standard. Rather than filter transmitted signals, and use signal processing at the receiver to decode them, SpaceWire directly uses digital signal transmission. This has the advantage of simplicity and it has been shown that it can easily be implemented for the Space environment. However, such high speed digital signals produce considerable electromagnetic emissions both within an enclosure and from cables between enclosures.

Although SpaceWire is specified with well-shielded cables and good enclosure and circuit-board design practice is assumed in order to control emissions, there may be sensitive applications where further reduction is required.

We consider the precise source of emission and show that simple techniques can be used to mitigate these undesired effects. Measurements of SpaceWire signals with and without mitigation allow the achievable reduction to be quantified.

1. INTRODUCTION

SpaceWire [1] takes considerable trouble to specify cable and its use to reduce electromagnetic emissions. No specific guidelines are given for enclosures but common practice is to use shielded units. No guidance is given for non-SpaceWire signals which may pick-up and conduct SpaceWire signals through the enclosure walls. Within an enclosure we must rely on good digital design techniques.

Cables, by virtue of their length, can form affective electromagnetic radiators. Shielded cable is specified for SpaceWire to reduce radiation from the signal conductors which are, in turn, differential pairs to balance flow and return currents and limit emissions.

Nonetheless, these techniques are not perfect and, in testing, we find detectable emissions from equipment, with that from cables exceeding that from shielded and filtered enclosures.

Unfortunately, the specified connector is not designed for balanced signals and introduces noticeable imbalance between wires of a pair. This reduces the effectiveness of balanced transmission, getting progressively worse at higher frequencies, resulting in increased emissions.

Techniques such as those mentioned above reduce, but do not eliminate emissions. Further reduction by the addition of filtering and/or shielding adds mass but we present methods specific to SpaceWire that require very little, or no, additional mass yet provide significant improvements.

2. SOURCES OF ELECTROMAGNETIC EMISSIONS

Any changing voltage or current is a source of emissions. Periodic changes produce continuous emissions. Virtually all electronic systems are controlled by a continuous, more or less constant frequency generator, the ‘clock’, and thus become sources of continuous emissions.

Digital circuits also use signals that change quickly from one state to another – representing digital states, and minimise the intermediate levels whose digital states are indeterminate. Such short rise and fall times add further to the emissions produced.

Fourier analysis can be used to convert signals in the time-domain (the usual representation of digital signals) to signals in the frequency domain (the usual representation of emissions). For communication systems the emissions analysis can become complex ((pseudo-)random data results in long periodicity) and it is more usual to measure the behaviour directly in the frequency domain with a Spectrum Analyser.

We are concerned to reduce the levels of emissions so that they are not received where not required – in other words, to minimise interference. Coupling mechanisms are varied, resistive, capacitive, inductive and radiative. The first three are of more concern on a circuit board or within an enclosure whilst the last is of special concern where electrically long wires are used, typically connecting cables.

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With data rates of many Mega-Hertz and edge rise and fall times around 1ns the spectrum of emissions can easily run from 1MHz to several GHz. The corresponding wavelengths are 300 metres to less than 100 milli-metres and span the range of cable lengths used. Any cable whose length is a multiple of the wavelength of a signal becomes a particularly good radiator, or receiver, of those signals.

The lowest frequency generated in a communications system results from the longest periodicity found. This is typically several bit times – since the usual unit of transmission is a group of bits (such as an 8-bit byte). This is a sub-multiple of the bit-rate. Random data can further lower the minimum frequency by extending the periodicity – although it is likely that the basic bit grouping will still produce strong signals.

Harmonics of digital signals extend towards infinity, in theory, but are limited in practice by the rise and fall times of digital signals. In general, the level drops by some 20dB/decade (6dB/octave) up to some 'knee' frequency where the rate of fall increases. The knee frequency is determined by the rise and fall times, being 0.5 / the rise (fall) time. For a rise/fall time of 1ns the knee frequency is 500MHz. Real data is not totally random and the spectrum loses its smoothness by gaining 'spikes' at significant frequencies as determined by the coding scheme being used.

3. SPACEWIRE WAVEFORMS AND THEIR EMISSION CHARACTERISTICS

SpaceWire encodes data and control characters in a sequence of tokens [1]. Each token contains an indicator of whether it is a data or control token of 10- or 4-bits respectively.

The only frequent individual control token is that used for flow control. Data may fully occupy the stream resulting in a periodicity of 10-bits. When no data or flow control is sent the link sends 'NULL' characters (so that a disconnection can be detected) each of which consists of a pair of control tokens – giving periodicities of 4- and 8-bits. NULL's, because they are regular and unchanging, concentrate energy into a small number of narrow-band signals, figure 1. (Data may also be a repeated sequence of the same value but it is more likely to be a stream of different values.)

The measured spectrum is very wide, even though the link speed used for these examples is only 49Mb/s. The lowest frequency is at 6MHz (49MHz / 8-bits in a NULL) with signals at multiples of that frequency. The spectrum extends, at significant levels, to the limit of the spectrum analyser being used (1GHz) – we can expect considerable levels well into the GHz.

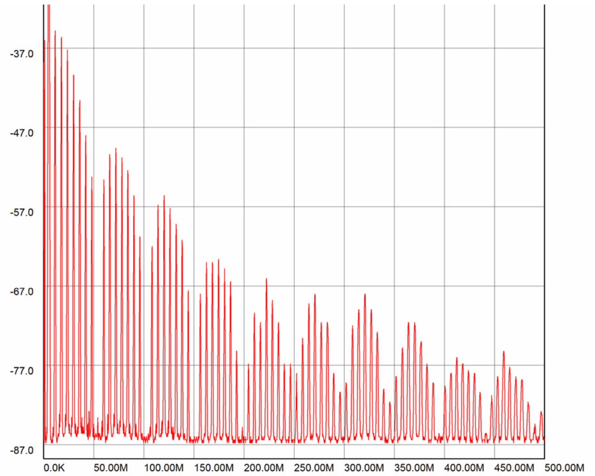

Figure 1 Measured spectrum of NULLs at 49Mb/s (vertical scale dB, horizontal scale Hz)

Measurements were taken in a system consisting of a SpaceWire module feeding 2.5m cable with a loopback connector at the end (total SpaceWire round trip of 5m). A passive network was used to attenuate and combine D and S with a transformer performing balanced to unbalanced conversion.

4. MITIGATION – TOKEN RANDOMISATION

Some communication schemes randomise data, including idle sequences, in order to spread narrow concentrations of energy over a wider frequency range. Although data randomisation is possible with SpaceWire it adds considerable complexity to an otherwise simple design – and cannot include NULL tokens, thus seriously limiting the benefit.

The spectrum changes beneficially with random data, as seen in figure 2.

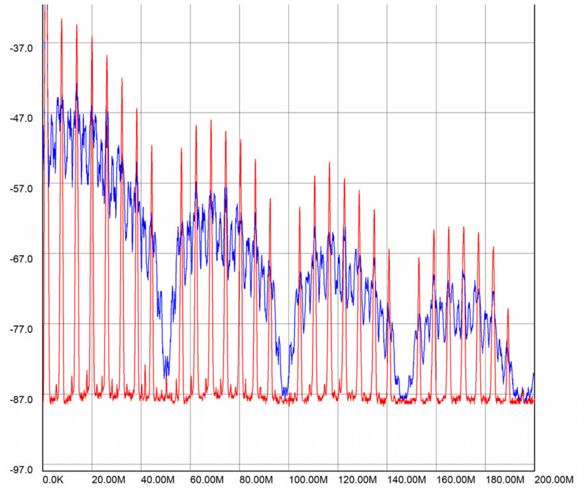

Figure 2 Measured spectrum of NULLs (red) and random data (blue)
(vertical scale dB, horizontal scale Hz)

5. MITIGATION – EDGE CONTROL

It is difficult to find slow LVDS buffers. A typical rise/fall time of 1ns is quite slow for such devices, 300ps is more typical.

For a data rate of 49Mb/s the bit-period is 20ns and although rise/fall times should be a fraction of this, typical LVDS buffers are an order of magnitude faster than is necessary. Such over-specification provides increased working margin – at the expense of a greatly extended emission spectrum.

If the rise and fall times were matched to the data rate we could achieve some margin and limit the highest frequencies produced.

One possible way to do this is to note that LVDS transmitters are current sources and thus it is possible to control edge rates by capacitive loading. Adding a capacitor across each of the transmit pairs has a very significant effect – figure 3.

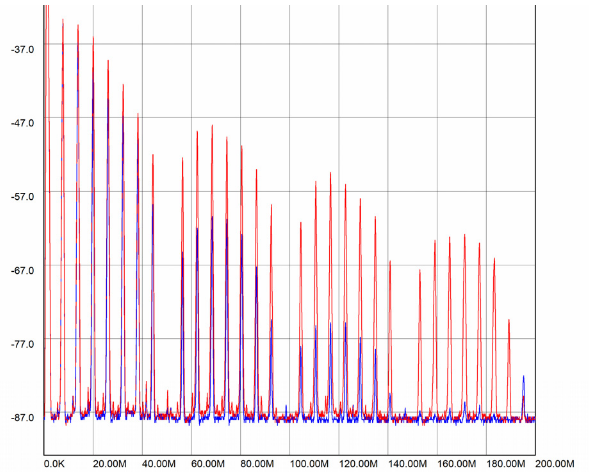

Figure 3 Measured spectrum of NULLs without (red) and with (blue) capacitive loading (100pF) (vertical scale dB, horizontal scale Hz)

It is seen that better matching the rise and fall time to the bit period makes a considerable difference.

The capacitance used with be determined by the data rate, the length of cable used and the receiver characteristic.

6. MITIGATION – RATE RANDOMISATION

It is possible, however, to apply another randomisation technique to an unchanged SpaceWire design. To see how this is possible we must remember data is encoded on two (differential pairs of) signal lines, "Data" ("D") and "Strobe" ("S"). These two signals form a Gray code where only one changes at a time but there is always a transition at a bit boundary. The transmit clock can be recovered as D XOR S – see figure 4.

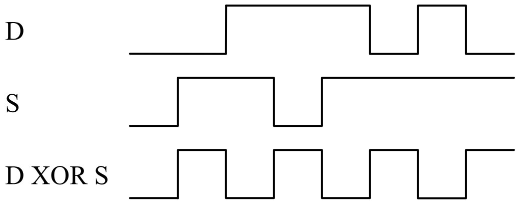

Figure 4 D, S and recovered clock

Although the SpaceWire standard refers to jitter in the D and S signals, this is not actually a limiting factor. It is necessary to recover the transmit clock and to use this to latch (on both edges) D to recover the data stream. The real limiting factor is determined by the quality of the recovered clock and this is determined by the edge-to-edge spacing in the DS signals (D to D, D to S, etc.). The actual frequency of the clock is unimportant so long as it exceeds a minimum value, determined by the timeout detector (~2Mb/s), and is below a maximum value determined by the receiver implementation. SpaceWire, with its direct clock recovery, has no need to use phase-locked-loops and places no restriction on the rate of change of data rate. It is perfectly allowable for the data rate to change from one extreme to the other (or any lesser range) from one bit to the next (incidentally, providing a potentially useful power saving facility). In fact, it is required to do so since a link must start at 10Mb/s and then change – mid-bit-stream – to the working rate.

Thus it is possible to alter the edge-to-edge spacing (bit period) in a random sequence – a technique used elsewhere and known as spread-spectrum-clocking. This spreads the energy in single-frequency spikes over a range of nearby frequencies and reduces the peak levels significantly. It can easily be applied to SpaceWire. The effect is shown in figure 5.

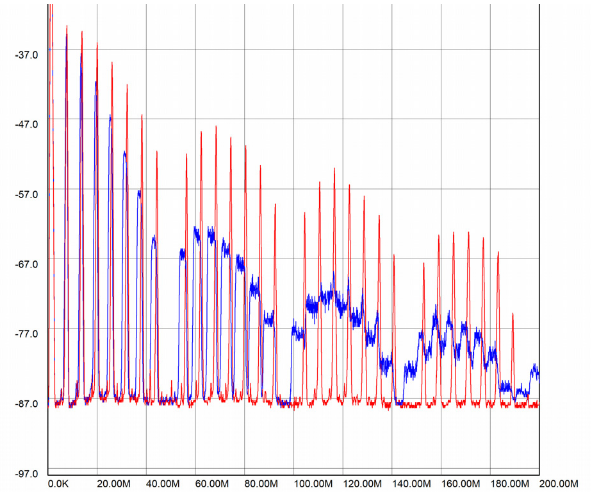

Figure 5 Measured spectrum of NULLs without(red) and with(blue) spread-spectrum clocking (vertical scale dB, horizontal scale Hz)

The effect of spreading – rate randomisation – is to smear the energy of single frequency peaks over a band of frequencies. This reduces the average level. The reduction depends on the amount of spread (4% in figure 5) and on the spikiness of the signal. There is a smaller (but nonetheless useful) reduction for random data which already occupies a spread of frequencies.

Reductions of 3 to 12dB are obtainable.

7. MITIGATION – COMBINED APPROACH

Using both edge control and spread-spectrum clocking results is a very significant reduction in the generated spectrum and thus reduced emissions within the system. Figure 6, shows a 500MHz bandwidth plot comparing normally produced NULLs and NULLs produced with 4% spread spectrum clocking and 100pF rate control capacitive loading at the LVDS transmitter output.

8. CONCLUSION

Although SpaceWire cables have been carefully specified to reduce emissions they are not perfect. Logic and wiring on circuit boards can also produce emissions. SpaceWire is specified in such a way that it permits customisation to reduce emissions, both by reducing higher-frequency edge energy and by spread-spectrum clocking to reduce single-frequency spikes. Reductions of more than 20dB can be obtained with very small changes to circuits.

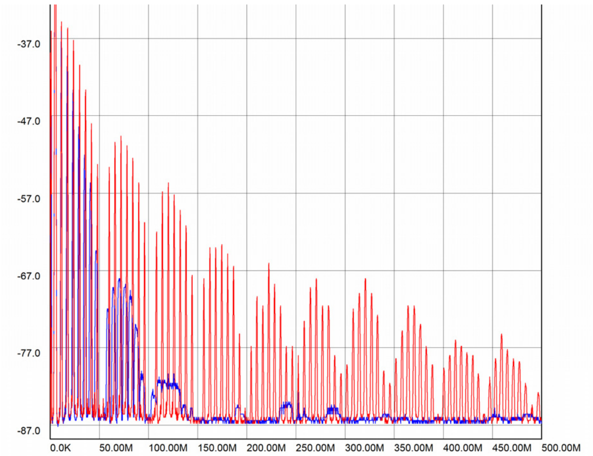

Figure 6 Measured spectrum of NULLs without any mitigation (red) and with both edge rate control and spread-spectrum clocking (blue)
(vertical scale dB, horizontal scale Hz)

9. REFERENCES

1. ECSS-E-50-12A (24 January 2003), SpaceWire, Links, Nodes, Routers and Networks