Optimizing and Comparing the Hyper Wide Dynamic Range (HWDR) Link and the Standard L-Band HTS Link

This paper explains the dynamic range capability of the ***ViaLiteHD*** L-Band HTS Hyper Wide Dynamic Range (HWDR) Series 2 (S2) link, compared to a standard ***ViaLiteHD*** L-band HTS link. It also explains how dynamic range can be manipulated to improve P1dB, IP3, Intermodulation (IMD) and Minimum Detectable Signal (MDS), plus what trade-offs occur when you optimize each of these values.

Introduction

With RF there is always a trade-off when you want to optimize a certain characteristic. This is because the Spurious Free Dynamic Range (SFDR) of the RF over fiber system is a fixed window that can be moved up or down with gain or attenuation, but that does not change size. This is therefore a good place to start when characterizing and differentiating between the ***ViaLiteHD*** HWDR link and the standard L-Band HTS link.

Calculating Spurious Free Dynamic Range

There are two key aspects that determine dynamic range: the P1dB and the noise figure of the RF over fiber link.

To calculate the SFDR you use the following elements:

Available Noise Power in a 1 Hz Bandwidth (*kT)*

kT_0 is the available noise power in a bandwidth BW = 1 Hz at T_0, expressed in dBm. T_0 is the system temperature in kelvins, and **k** is Boltzmann's constant (1.38×10^{-23} joules per kelvin = −228 dBW/(kHz)). If the system temperature and bandwidth is 290 K and 1 Hz, then the effective noise power available in 1 Hz bandwidth from a source is −174 dBm (174 dB below the one milliwatt level taken as a reference).

Noise Figure of the Link

The Noise Figure (NF) of the fiber optic link is the measure of the degradation of the Signal to Noise Ratio (SNR).

Third Order Intercept Point (IP3)

The intercept point is a purely mathematical concept and does not correspond to a practically occurring physical power level. In many cases, it lies far beyond the damage threshold of the device. However, within RF over fiber links this is 12 dB above the P1dB.

SFDR Calculation

SFDR = *(kT* + NF - IP3)*2/3

The equation uses 2/3's because it is calculating the third order SFDR, sometimes expressed as SFDR3.

SFDR in a standard L-Band HTS Link

These figures are for a ***ViaLiteHD*** L-Band HTS RF over fiber link with a gain of -11 dB

NF = 20

P1dB = -1

IP3 = -1 + 12 =11

Therefore:

SFDR = (-174 + 20 - 11)*2/3 = **110 dB/Hz 2/3**

SFDR in a HWDR S2 Link

The ***ViaLiteHD*** HWDR S2 link has the same P1dB as the standard link, but a lower noise figure. It therefore has a 5 dB wider SFDR.

NF = 12.5 dB

P1dB = -1 dBm

IP3 = -1 + 12 =11

Therefore:

SFDR = (-174 + 12.5 – 11) = **115 dB/Hz 2/3**

However, SFDR is only based on 1 Hz bandwidth due to using ***kT***. To work out the useable dynamic range you will need to introduce the Bandwidth (BW) of your signal.

Dynamic Range Calculation

To determine the dynamic range of the two links you need to know the upper input power (P1dB) and also the MDS. This gives you the range of the highest and lowest signal you can put through the link, which is the dynamic range.

This example uses 500 MHz of BW to compare the two types of links.

Calculation for MDS

MDS = (kT[-174]+10*log(Traffic BW in Hz))+ NF

Therefore MDS for each link is as follows:

Standard link NF = 20

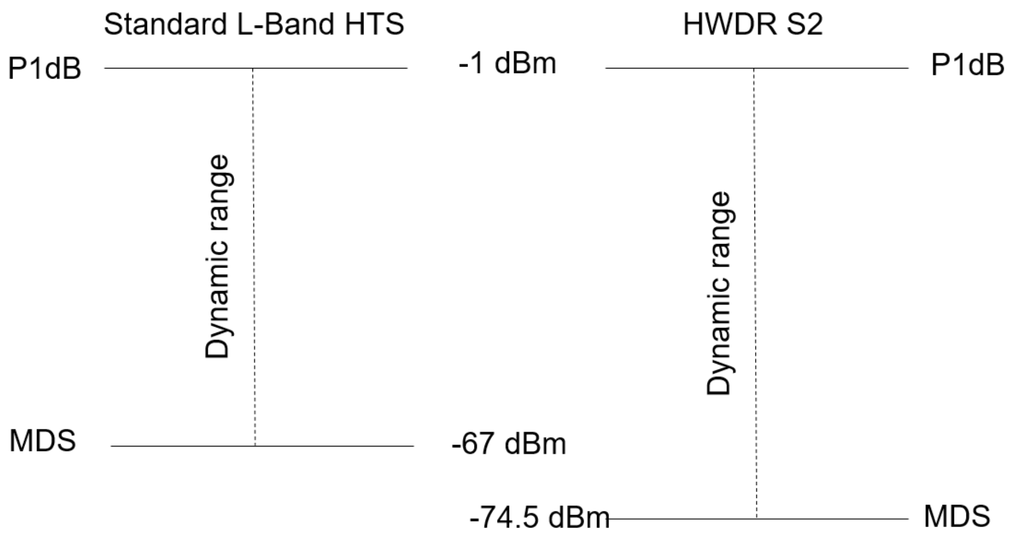
MDS = (-174 + 10*Log(500,000,000))+20 = -67 dBm

HWDR S2 link NF = 12.5

MDS = (-174 + 10*Log(500,000,000))+12.5 = -74.5 dBm

The first part of the equation remains the same for a constant BW. Therefore, the only thing that affects the MDS is the NF of the links. This means the change in MDS is the difference between the noise figures of the links 20 dB (std) – 12.5 dB (HWDR S2) = 7.5 dB and (std MDS) -67 dBm - (HWDR S2 MDS) -74.5 dBm = 7.5 dB.

The dynamic range of the links is the difference between the P1dB and the MDS is shown below.



Using the example, we can look at how this dynamic range window can be moved up and down to achieve the performance that is needed.

Lowering MDS to Transport Smaller Signals or Increase SNR

We will first look at reducing the MDS to be able to transport smaller signals over the fiber optic link. If this is the “minimum” then how can it be reduced? The easy answer is that it is the “minimum” for the given NF of the link; to reduce the MDS, the noise must also be reduced.

In any RF amplified system the NF can be reduced by increasing the gain of amplifiers at the front end of the system. In a fiber optic link case this is the Optical Transmit card (Tx) which has amplifiers at its input stage. However, as the input signal is amplified into the system, the lower the input needs to be as it will start to saturate the Tx laser. Therefore, the P1dB has to come down as gain is added to the Tx card.

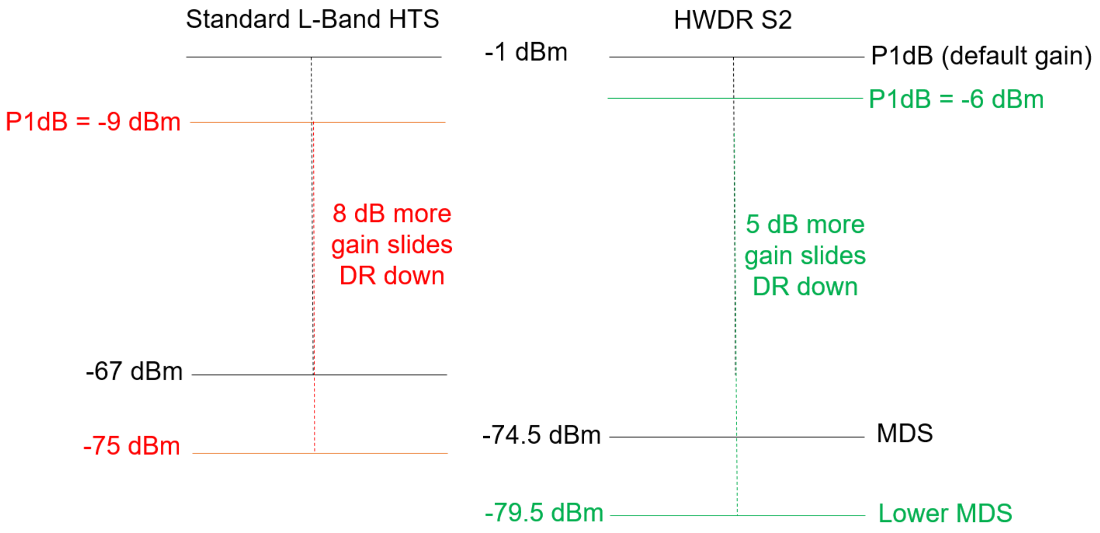
For reference the default P1dB and gain settings are shown below for each of the links discussed.

Parameter	Standard L-Band HTS Link	HWDR S2
Max Gain	-3 dB	0 dB
Default Gain	-11 dB	-5 dB
Min Gain	-18.5 dB	-15.5 dB
Default P1dB	-1 dBm	-1 dBm

A standard L-Band link with an input signal at P1dB (-1dBm) and the gain set to the default setting of -11 dB, will be going into the laser at its P1dB. If the gain is increased to the maximum level of -3 dB, then an input signal at -1 dBm signal is overdriving the laser. This means that the input needs to be reduced to ensure that the laser isn’t overdriven; therefore the P1dB also has to be reduced. An increase in gain reduces the NF by the amount of gain in dB and also reduces the P1dB by the same amount of gain in dB.

Increase in Tx Gain	Reduction in P1dB	Reduction in NF
↑	↓	↓

The effects on the dynamic range are as follows:



Maximum gain from default Standard L-Band HTS vs HWDR S2

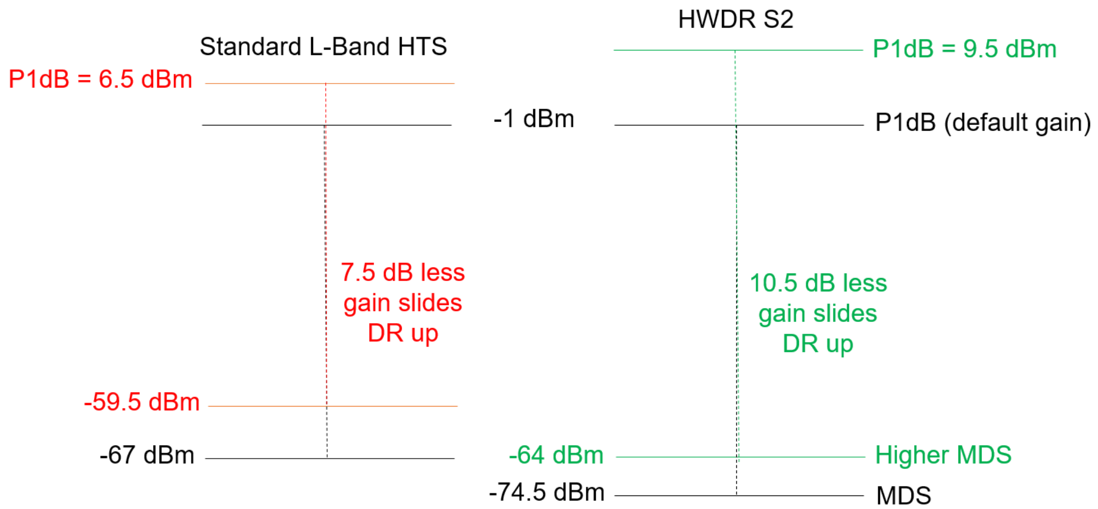
Even though the standard L-Band Tx card has more gain from default (8 dB), it has less overall dynamic range than the HWDR card. Therefore if both are run at maximum gain, the HWDR has 4.5 dB lower MDS and 3 dB greater P1dB; giving greater flexibility. For the same input level the SNR will also increase by 5 dB.

Increasing P1dB to achieve higher IP3/IMD & C/I

Increasing the gain of the Tx card decreases P1dB. The converse is true, as if the gain is decreased, it increases the P1dB.

Decrease in Tx Gain	Increase in P1dB	Increase in NF
↓	↑	↑

As with increasing gain, the dynamic range window moves proportionally with the change in gain. However this time it moves up with the increase in P1dB as below.



Minimum Tx gain from default Standard L-Band HTS vs HWDR S2

Again, due to the extended dynamic range of the HWDR link, it has a higher P1dB (3 dB more) and the MDS is 4.5 dB lower.

Intermodulation Ratio (IMR)

The IP3 is 12 dB higher than the P1dB, therefore if the HWDR link is set to minimum gain (-15.5 dB), an IP3 of 21.5 dB can be achieved, which is 3 dB higher than the standard link. This allows better IMD performance than the standard link. The example below shows the carrier to interferer (C/I) and IMR for both a standard L-Band link and a HWDR link with an input signal of -10 dBm at maximum/default and minimum gain.

C/I Calculation

C/I = 2 x (IP3-Input Signal)

To achieve a common IMR of 40 dBc the signal needs to be backed off 8 dB and 18 dB for an IMR of 60 dBc.

The table below shows an input level of -10 dBm and the C/I it also details the IMR for each link at each gain level.

Gain	Gain dB	P1dB	IP3	Input Signal	C/I	Max Input Signal for 40 dBc IMR (in dBm)	Max Input Signal for 60 dBc IMR (in dBm)
HWDR Min	-15.5	9.5	21.5	-10	63	1.5	-8.5
HWDR Def.	-5	-1	11	-10	42	-9	-19
HWDR Max	0	-6	6	-10	32	-14	-24
Gain	**Gain dB**	**P1dB**	**IP3**	**Input Signal**	**C/I**	**Max Input Signal to for 40 dBc IMR**	**Max Input Signal for 60 dBc IMR**
Std Min	-18.5	6.5	18.5	-10	57	-1.5	-11.5
Std Default	-11	-1	11	-10	42	-9	-19
Std Max	-3	-9	3	-10	26	-17	-27

If the HWDR link is set to minimum gain, a 21 dB improvement in C/I and a >60 dBc IMR can be achieved, which is not possible with the standard L-Band HTS link.

Conclusion

This paper has described the calculations used in determining dynamic range in ***ViaLiteHD*** standard L-Band HTS and HWDR links.

It demonstrates that the higher SFDR of the HWDR link gives more flexibility in range for transporting both small and large signals, compared to the standard L-Band HTS link. If a lower MDS is needed to either transport smaller signals or improve SNR, then increasing the Tx gain will achieve this. If transport of larger signals or an improvement in C/I or IMR performance is needed, the Tx gain must be decreased to achieve this.

The ***ViaLiteHD*** HWDR links have been designed for those needing an even greater dynamic range. The S2 has an SFDR with an extra 5 dB/Hz over the standard L-Band HTS link. This SFDR is important for HTS satellites as they use more bandwidth, meaning that there is a need for higher dynamic range RF over fiber links. Fiber links that have an SFDR of 100 dB/Hz 2/3 or less are difficult or impossible to use in HTS applications.

For more information on the importance of dynamic range in fiber optic links, read our white paper here.

Glossary of Abbreviations

BW	Bandwidth
C/I	Carrier to Interferer
dB	Decibel
dBc	Decibel relative to carrier
dBm	Decibel milliwatt
P1dB	Power at one decibel gain compression
DR	Dynamic Range
HTS	High Throughput Satellite
HWDR	Hyper Wide Dynamic Range
Hz	Hertz
IMD	Intermodulation
IMR	Intermodulation Ratio
IP3	Third Order Intercept Point
kHz	Kilohertz
MHz	Megahertz
MDS	Minimum Detectable Signal
NF	Noise Figure
RF	Radio Frequency
Rx	Receiver
S2	Series 2
SFDR	Spurious Free Dynamic Range
SNR	Signal to Noise Ratio
Tx	Transmitter