

# Calculating Signal Operating Levels of Internal Subsystems in Communication Links

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Optimal levels of operation are typically in the middle of the dynamic range defined by upper and lower signal thresholds that produce acceptable operating errors. In digital communication systems the minimum and maximum signal levels are those that if exceeded give an unacceptable probability of misinterpreting the originally transmitted information. On the lower end errors are due to signal to noise ratios (S/N) below that necessary to attain an acceptable Bit Error Rate (BER). On the upper end errors are due to spurious emissions generated by high level signals that also produce an unacceptable Bit Error Rate. Many communication receiving systems have wide open front ends processing a large number of carriers before selecting the carrier of interest. This architecture poses two problems to the systems designer, one is the signal dynamic range in the wide bandwidth input multiple signal environments and the other is the narrow bandwidth single or limited number of signals environment. In order to select an optimal signal level range both environments must be considered. This scenario is a common problem in satellite communication earth stations where the input to the earth station is looking at all signals from the satellite before selecting the applicable pertinent signal or signals of interest.

## Single Signal Dynamic Range

The minimum and maximum operating levels for a single signal is usually the level above noise that gives an acceptable signal to noise ratio and the level where the system gain is compressed by 1 dB respectively. In a communications system where adjacent channel interference is a concern this definition may not be restrictive enough. The sidebands of a modulated signal are filtered and shaped in the modem prior to transmission, but when these signals are applied to the non-linear characteristics of a power amplifier the suppressed sidebands will begin to grow (called spectral regrowth) in a similar fashion that third and fifth order intermodulation products grow as signal increases in a non-linear system. In a well designed system the spectral regrowth in the final output power amplifier dominate the introduced non-linearities. To this end the spectral regrowth seen in other components such as the frequency converter should be at least 20 dB below that exhibited by the power amplifier. The typical power back-off in a High Power Amplifier (HPA) is usually about 7 dB (12 dB below the third order intermodulation intercept point), therefore the recommended signal back-off in a frequency converter 12 dB below the 1 dB compression level or 22

dB below the third order intermodulation intercept point.

## (1) Maximum Signal = Third Order Intermodulation Intercept Point - 22 dB

Lower level signals are usually required to be 10 to 15 dB above the noise to minimize transmission errors (Bit Error Rates, etc.). In the frequency converter the internally generated noise should not be a factor in determining the system noise. To insure that this is the case the signal should be at a level at least 30 dB above the noise.

Considering the aforementioned criteria the signal level can be calculated from the input converter noise:

## (2) Input Converter Noise = -174 dBm + 10 Log (Bandwidth) + Converter Noise Figure

Bandwidth is in Hz

## (3) Minimum Signal Level = Input Converter Noise + 30 dB

## Two Tone Dynamic Range

Two signals in the same communications channel create third and higher order intermodulation distortion close enough to the carrier that they cannot be filtered out. The intermodulation distortion is created by the second harmonic of one signal mixing with the fundamental of the other signal. The intermodulation products increase at twice the rate of increasing signal levels effectively limiting the upper end of the dynamic range.

The level of third order intermodulation interference is calculated as follows:

## (4) $\text{dBc}_{3\text{rd}} = -2 [ I_{3\text{rd}} - (\text{Total Power} - 3 \text{ dB}) ]$

$\text{dBc}_{3\text{rd}}$  = Third order interference product referenced to a single carrier (dBc)

$I_{3\text{rd}}$  = Third Order Intercept Point (dBm)

Total Power = Sum of the two signals in the bandwidth of interest (dBm)

Using the same criteria of backing the signal off 12 dB from the 1 dB compression point and assuming the third order intercept point is 10 dB above the 1 dB compression (a typical rule of thumb) the level of third order intermodulation distortion produced would be 50 dB below each carrier.

The minimum level criteria for each of the two carriers are the same as for a single carrier that is each carrier should be at least 30 dB above the noise.

As expected, the dynamic range of each of the two carriers in the same communi-

cation channel is 3 dB less than that of the single carrier accounting for the decrease in individual carrier power by 3 dB and maintaining the same individual carrier signal to noise ratio.

## Multiple Carriers in a Communication Channel

Three carriers in the same communication channels produce spurious interference, Carrier Triple Beats (CTB), is a similar mechanism that produces two-tone third order intermodulation with the exception that a second harmonic of one of the signals is not needed. The lack of a second harmonic increases the spurious produced by 6 dB.

The Carrier Triple Beat intermodulation spurious produced by the three carriers is calculated as follows:

## (5) $\text{dBc}_{3\text{rd}} = -2 [ I_{3\text{rd}} - \text{Carrier}(\text{dBm}) ] + 6 \text{ dB}$

$\text{dBc}_{3\text{rd}}$  = Third order interference product referenced to a single carrier (dBc)

$I_{3\text{rd}}$  = Third Order Intercept Point (dBm)

Carrier(dBm) = Power in each equal power carriers in (dBm)

Third order intermodulation interference decreases at twice the rate of lowering carrier levels, therefore the 6 dB increase in intermodulation interference effectively translates to a 3 dB decrease in dynamic range when three closely spaced carriers are in a common communication channel.

Greater than three carriers in a common channel produce spurious signals, i.e. multiple carrier triple beats, over the entire operating bandwidth. If the desired carriers are equally spaced, the spurious signals produced can accumulate in the same frequency band. The total CTB level is determined by calculating the level of each CTB and adding non-coherently the number of beat signals that will fall into the respective band.

The number of carriers in each frequency slot is given by the equation:

$$(6) \text{ Beats} := \frac{N^2}{4} + \frac{[(N - M) \cdot (M - 1)]}{2}$$

Beats: Number of interference carriers in the channel

N: Number of carriers

M: Carrier position in the channel,  $1 \leq M \leq N$  (typically  $M=1$  is the lowest frequency carrier)

The maximum interference occurs in the center of the band ( $M \approx N/2$ ) where there is the maximum number of beat signals. For  $N \gg 1$  the beats ( $\text{Beat}_{\text{max}}$ ) in the center

of the band is:

$$(7) \text{ Beats}_{\text{max}} := \frac{3 \cdot N^2}{8}$$

**Beat<sub>MAX</sub>:** = Number of Non-Coherent interference carriers in the same channel  
**N** = Number of carriers

The total intermodulation distortion due to carrier triple beats, CTB(dBc) is:

$$(8) \text{ CTB(dBc)} = (-2) (I_{3\text{rd}} - \text{Carrier(dBm)}) + 6 \text{ dB} + 10 \text{ Log(Beats)}$$

The upper end of the dynamic range due to carrier triple beats is reduced by half the increase in spurious interference due to the two to one relationship of carrier level and third order spurious interference. Signal dynamic range due to multiple carrier interference is therefore reduced by 3 dB (for carrier triple beats) plus  $[10 \cdot \text{Log(Beats)}] / 2$  for multiple spurious in the same channel, taking the center channel as the worst case.

**Dynamic Range Calculations of MITEQ 9900 Series Ku-Band Dual Frequency Converters**

The 9900 series upconverter typically accepts a single carrier (70 MHz or 140 MHz) and converts it to the required transmit frequency in Ku-Band. The 9900 series downconverter theoretically converts a single satellite carrier to 70 MHz or 140 MHz, but in reality the input to the converter is wideband and accepts all of the satellite carriers in its wideband front end. Frequency (carrier) selection occurs after the first mixer where the undesired carriers are filtered out. This presents a problem in that dynamic range and optimal input signal levels must be considered in two parts, first the wideband analysis considering the aggregate total power and multiple carrier triple beat effects to the output of the first mixer and the more traditional two-tone intermodulation effects through the entire converter. The downconverter wideband (front end) analysis is also applicable to low noise block converters and low noise front end amplifiers.

The pertinent characteristics for determining dynamic range and optimum operating signal levels are noise figure, gain, and intercept point. Intercept point is usually given with respect to the output but since the optimum input signal level is the parameter of interest the intercept points will be transformed to the input.

$$(9) \text{ IP3(in)} = \text{IP3(out)} - \text{Gain}$$

Where:

**IP3(in)** in dBm is the third order intermodulation intercept point with respect to the input

**IP3(out)** in dBm is the third order intermodulation intercept point with respect to the output

**Gain** in dB is the gain of the system under

consideration

**Determining Minimum Signal Levels**

Minimum signal levels are determined by calculating the system noise and adding the minimum signal to noise ratio (in dB) that will enable the system to perform at a required maximum Bit Error Rate. System noise is determined from the system noise figure and demodulation bandwidth.

**Table 1**

Converter Operational Criteria	
Bandwidth	10 MHz
Third Order Spurious Max.	-50 dBc
S/N Min.	30 dB

**Table 2: Upconverter**

Gain Reduction	0	5	10	15	20	25	30 dB
Gain Max.	33	33	33	33	33	33	33 dB
Actual Gain	33	28	23	18	13	8	3 dB
Noise Figure	14	14.8	18.9	23.5	28.4	33.3	38.3 dB
Intercept Point - Out	22.5	23.6	23.6	23.6	23.4	23.0	21.8 dBm
Intercept Point - In	-10.5	-4.4	0.6	5.6	10.4	15.0	18.8 dBm
Minimum Signal	-54.0	-53.2	-49.1	-44.5	-39.6	-34.6	-29.6 dBm
Maximum Signal	-35.5	-29.4	-24.4	-19.4	-14.6	-10.0	-6.2 dBm

Signal to noise ratios greater than 15 dB usually meets most system requirements. Individual system components such as satellite frequency converters should have a secondary effect on the overall system performance and therefore should have at least a 30 dB signal to noise ratio, which would degrade the system performance by less than 0.14 dB. Signal levels for a specified S/N are calculated as follows:

$$(10) \text{ Noise} = 10 \text{ Log}_{10} (kTB) + NF$$

**K** = Boltzman's Constant ( $1.38 \cdot 10^{-23}$  Watts/°K)

**T** = Temperature in degrees Kelvin (Room Temperature = 298°K)

**B** = Bandwidth (For this example the bandwidth is assumed to be 40 MHz)

**NF** = Noise Figure (dB)

$$(11) \text{ Noise} = -97.8 \text{ dBm} + NF$$

**Table 3: Downconverter signal data and maximum wideband power**

Downconverter Operational Criteria	
Bandwidth	10 MHz
Third Order Spurious Max.	-50 dBm
S/N Min.	30 dB
Input Bandwidth	500 MHz
Assumed No. of Carriers	50
Wideband Input IP3	5.6 dBm
Wideband Carrier Level	-30.9 dBm
Maximum Aggregate Input Level	-13.9 dBm

**Table 4: Downconverter signal data and minimum and maximum signal levels**

Downconverter Narrow Band							
Gain Reduction	0	5	10	15	20	25	30 dB
Gain Max.	46	46	46	46	46	46	46 dB
Actual Gain	46	41	36	31	26	21	16 dB
Noise Figure	8.4	8.4	8.6	8.9	9.5	10.6	12.5 dB
Intercept Point - Out	30	31.9	29.3	25.6	21.2	16.4	11.5 dBm
Intercept Point - In	-16.0	-9.1	-6.7	-5.4	-4.8	-4.6	-4.5 dBm
Maximum Signal (Narrow Band)	-41.0	-34.1	-31.7	-30.4	-29.8	-29.6	-29.5 dBm
Minimum Signal	-65.6	-65.6	-65.4	-65.1	-64.5	-63.4	-61.5 dBm
Maximum Signal Level	-41.0	-34.1	-31.7	-30.9	-30.9	-30.9	-30.9 dBm

(Bandwidth = 40 MHz)

Example:  
 For 30 dB S/N in a system with a 14 dB

Noise Figure

$$(12) \text{ Signal Minimum} = -97.8 \text{ dBm} + NF + S/N$$

Signal Minimum = -97.8 dBm + 14 dB + 30 dB = -53.8 dBm

**Determining Maximum Signal Levels**

Maximum signal levels are usually determined by the spurious intermodulation products produced by high level signals in a non-linear system. Spurious emissions dominated by third order intermodulation distortion can be determined from the specified third order intercept point, the number of carriers, and the maximum signal operating level. Spurious emissions including intermodulation distortion less than -50 dBc typically meet most system requirements. The intermodulation products of concern are the result of two signals closely spaced in frequency such that the signals and their respective third order products fall in the bandwidth of interest. The intermodulation products are calculated as follows:

(13)  $dBc_{3rd} = -2 [ I_{3rd} - Carrier(dBm) ]$

$dBc_{3rd}$  = Third order interference product referenced to a single carrier (dBc)  
 $I_{3rd}$  = Third Order Intercept Point (dBm)  
 Carrier(dBm) = Power in each equal power carriers in (dBm)

Solving for carrier power:

(14)  $Carrier(dBm) = I_{3rd} + dBc_{3rd} / 2$

Where  $dBc_{3rd}$  is a negative number

Example:

$I_{3rd} = -10.5$  dBm (Input Intercept point)  
 $dBc_{3rd} = -50$  dBc

Carrier Power = -35.5 dBm Maximum

The resultant optimum operating signal dynamic range is therefore >-53.8 dBm and less than -35.5 dBm

**MITEQ 9900 Series Upconverter Dynamic Range Calculations**

The operational dynamic range can be calculated from the converter characteristics when the bandwidth, minimum signal to noise ratio, and maximum spurious level (third order intermodulation interference) are defined. A typical criterion is shown in Table 1.

Based on these criteria the optimal signal level into the upconverter can be calculated as a function of upconverter gain reduction, shown in Table 2.

Using the proper gain reduction (attenuator) setting the 9900 series upconverter can accommodate signals levels from -54 dBm to -6.2 dBm.

**MITEQ 9900 Series Downconverter Dynamic Range Calculations**

Downconverter dynamic range calculations require the maximum power to be calculated two separate ways, a wideband front end calculation using total aggregate

power of a large number of input signals and a narrow band calculation of maximum power, assuming a maximum of two tones. The valid maximum power is always the lower of the two numbers. Minimum power calculations are performed in a similar fashion as in the upconverter analysis.

**Wideband Maximum Power**

The wideband input maximum signal is determined from the converter characteristics using the composite intercept point at the output of the first mixer reflected to the system input (9900 series downconverter has no input attenuator so this calculation is valid for all attenuation ranges).

In the example below a 10 MHz carrier is to be received from a fully loaded

**Table 5: Downconverter signal data and maximum wideband power for a 40 MHz carrier**

Downconverter Operational Criteria	
Bandwidth	40 MHz
Third Order Spurious Max.	-50 dBm
S/N Min.	30 dB
Input Bandwidth	500 MHz
Assumed No. of Carriers	12
Wideband Input IP3	5.6 dBm
Wideband Carrier Level	-27.8 dBm
Maximum Aggregate Input Level	-17.0 dBm

**Table 6: Downconverter signal data and minimum and maximum signal levels for a 40 MHz carrier**

Downconverter Narrow Band							
Gain Reduction	0	5	10	15	20	25	30 dB
Gain Max.	46	46	46	46	46	46	46 dB
Actual Gain	46	41	36	31	26	21	16 dB
Noise Figure	8.4	8.4	8.6	8.9	9.5	10.6	12.5 dB
Intercept Point - Out	30	31.9	29.3	25.6	21.2	16.4	11.5 dBm
Intercept Point - In	-16.0	-9.1	-6.7	-5.4	-4.8	-4.6	-4.5 dBm
Maximum Signal (Narrow Band)	-41.0	-34.1	-31.7	-30.4	-29.8	-29.6	-29.5 dBm
Minimum Signal	-59.6	-59.6	-59.4	-59.1	-58.5	-57.4	-55.5 dBm
Maximum Signal Level	-41.0	-34.1	-31.7	-30.4	-29.8	-29.6	-29.5 dBm

**Table 7: Upconverter optimum signal levels**

Gain Reduction (dB)	Converter Gain (dB) (Nom.)	10 MHz Bandwidth (Min.) (dBm) (Max.) (dBm)		40 MHz Bandwidth (Min.) (dBm) (Max.) (dBm)	
0	33	-60.0	-35.5	-54.0	-35.5
5	28	-59.2	-29.4	-53.2	-29.4
10	23	-55.1	-24.4	-49.1	-24.4
15	18	-50.5	-19.4	-44.5	-19.4
20	13	-45.6	-14.6	-39.6	-14.6
25	8	-40.7	-10.0	-34.6	-10.0
30	3	-35.7	-6.2	-29.6	-6.2

500 MHz bandwidth satellite. The total aggregate number of carriers is assumed to be 500/10 = 50. Since the power spectral density coming down from the satellite is the same across the band the carriers could be of various bandwidths without significantly affecting the out come of this calculation.

Under these conditions the maximum carrier power level is -30.9 dBm and the maximum aggregate input power level (all carriers emanating from the satellite) is -13.9 dBm.

Table 4 calculates the minimum and maximum input signal level for a 30 dB

change in converter attenuation level.

The converter minimum signal level at -65.6 dBm remains relatively constant with up to 15 dB of attenuation. The maximum level into the converter is -30.9 dBm limited by the total aggregate power of all carriers coming down from the satellite creating intermodulation products in the converter front end (converter input to the first mixer output).

Another calculation was performed assuming the carrier bandwidth is 40 MHz.

The maximum carrier level increased but as expected the maximum aggregate

input power level decreased.

The minimum input signal level is increased to -59.6 dBm reflecting the increase in bandwidth. The maximum signal level increased to -29.5 dBm because it is no longer limited by the converter front end.

**Summary of Optimum Operating Levels for MITEQ 9900 Series Up and Downconverters**

Optimum operating signal level data was tabulated for 9900 series up- and downconverters over a 30 dB gain adjustment range at carrier bandwidths of 10 MHz and 40 MHz.

**Table 8: Downconverter optimum signal levels**

Gain Reduction (dB)	Converter Gain (dB) (Nom.)	10 MHz Bandwidth		40 MHz Bandwidth	
		(Min.) (dBm)	(Max.) (dBm)	(Min.) (dBm)	(Max.) (dB)
0	46	-65.6	-41.0	-59.6	-41.0
5	41	-65.6	-34.1	-59.6	-34.1
10	36	-65.4	-31.7	-59.4	-31.7
15	31	-65.1	-30.9	-59.1	-30.4
20	26	-64.5	-30.9	-58.5	-29.8
25	21	-63.4	-30.9	-57.4	-29.6
30	16	-61.5	-30.9	-55.5	-29.5

**Conclusion**

Signal levels should always be set to optimize the conflicting requirements of high level above noise and the resultant non-linear behaviors associated with the high levels. Levels in the ranges stated should give excellent performance, with performance enhanced for signals closer to the center of the stated minimum and maximum ranges.

It should be noted that the results obtained are based on nominal system performance characteristics. System requirements that significantly differ from the assumed operating criteria may cause the optimal dynamic range to shift or compress.

**References**

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Howard Hausman received his BSEE and MSEE degrees from Polytechnic University and is currently Vice President, Engineering at MITEQ, Inc. During his career, he has designed microwave systems and components for satellite communications, radar and reconnaissance, that includes receivers, transmitters, and synthesizers. Mr. Hausman was also an Adjunct Professor at Polytechnic University and Hofstra University where he taught graduate and under graduate courses in Electrical Engineering. In his capacity as Engineering Vice President and Adjunct Professor, he has presented many lectures and authored many papers relating to microwave systems, communication systems, Radar, and Reconnaissance systems.