OTA Link Budget Calculator
Application Note

The document gives an overview and user guide about a link budget calculator for the main components of a basic OTA system. The calculator shall guide the user to plan link budgets, especially with respect to SNR requirements for the receive components and the vector signal analyzer. An Excel sheet containing the Link Budget Calculator accompanies the application note.

Note:

Please find the most up-to-date document on our homepage **https://www.rohde-schwarz.com/applications/**

This document is complemented by software. The software may be updated even if the version of the document remains unchanged

Application Note

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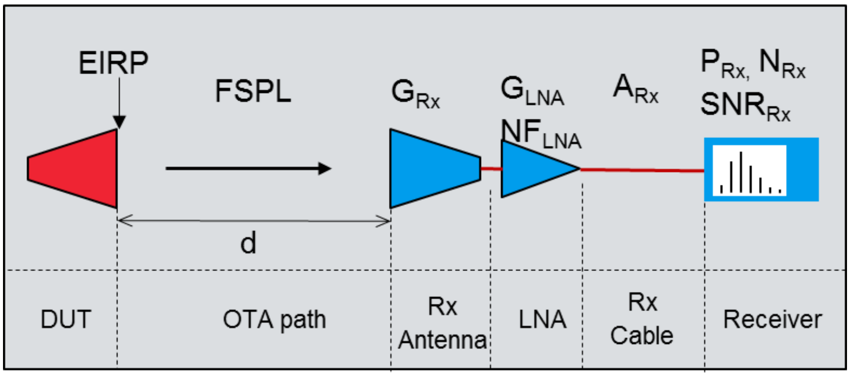
Table of Contents

1 OTA Link Budget Calculator

Wireless telecommunication applications are moving to mm-wave frequencies because of higher bandwidth requirements and congestion in the currently used bands. To overcome the significant path loss inherent to these frequencies antenna arrays are used more frequently. Many mm-wave devices do not provide testports at the transmitter side before the antenna. Therefore, it becomes necessary to measure the device performance over the air (OTA). Different to a wired test setup, OTA measurements require careful planning of the OTA site and the receive system in order to meet the desired system performance. Most importantly, the OTA system must provide decent dynamic range (signal-to-noise ratio, SNR) for the complete output power level range of the DUT. The *OTA Link Budget Calculator* is a tool that helps to illustrate the evolution of the power level and SNR from the DUT, through the OTA section to the receiver. Critical sections of the OTA setup can be identified. Different configurations and their influence on the system SNR can easily be tested.

An OTA system is typically placed into a shielded chamber. It contains a transmitter with antenna, a receive antenna, usually a horn antenna, followed by a cable or waveguide connection to a receiver, most likely a signal and spectrum analyzer. There can be additional components between the horn and receiver, like LNAs, switches, filters, etc. Rotating antenna arms may require long RF cables with high attenuation.



When planning an OTA system for characterizing the DUT performance, two aspects are of particular importance:

Signal Power

It is important that sufficient signal power is reaching the receiver, otherwise the receivers sensitivity will not suffice. On the other hand, a LNA in the signal chain must not be overdriven.

Signal to Noise Ratio:

For modulation quality measurements (e.g. by means of Error Vector Magnitude, EVM) the signal-to-noise ratio (SNR) of the OTA system must be higher than the DUT's SNR (10dB margin is a typical value). Active components (LNA, receiver) add noise to the signal and thus contribute to the overall SNR. But also significant signal power losses in the OTA path will impair the SNR.

1.1 Using the OTA Link Budget Calculator

The Excel file `OTA Link Budet.xlsm` contains the calculator. It is organized in stages, from the DUT via the OTA path, to the receiver. In the column *Value* system parameters can be entered in all cells with white background. Grey cells hold the calculation results. Light blue cells can be left empty and default values are used. To obtain the results, press the button *Calculate.* The button *Reset* will delete all results and keep the input parameters. Selecting a Value cell shows a tooltip string with a short explanation of the value.

Section 1.2 of this document gives details about the calculations with all relevant formulas.

Stage	Parameter	Symbol	Unit	Value
	Frequency		GHz	28,000
	Bandwidth		MHz	800,00
DUT	Equivalent Isotropically Radiated Power	EIRP	dBm	*30,00*
	Tx SNR	SNR_In	dB	*106,97*
OTA	Distance	d	m	1,00
	Free Space Path Loss	FSPL	dB	*61,38*
Rx Antenna	Receive Antenna Gain	G_Rx	dB	10,00
LNA	LNA Gain	G_LNA	dB	15,00
	LNA Noise Figure	NF_LNA	dB	2,00
Rx Cable	Cable Loss	A_Rx	dB	4,00
Receiver	Receiver DANL	DANL_RX	dBm/Hz	-144,00

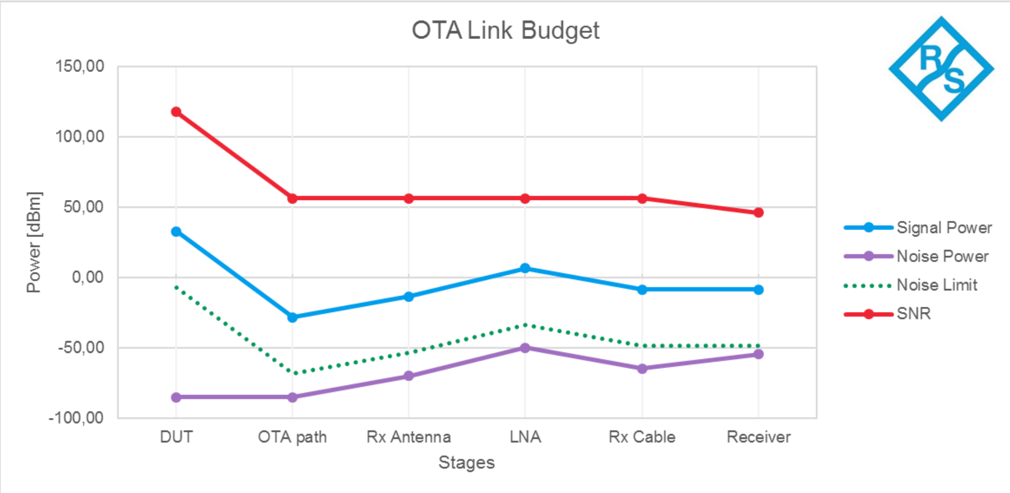
Calculate

Results	Rx Power	P_Rx	dBm	*-10,38*
	Rx Noise Power	N_Rx	dBm	*-54,43*
	Rx SNR	SNR_Rx	dB	*44,04*
	Total Gain	G_tot	dB	*-40,38*
	Total Noise Figure	NF_tot	dB	*70,93*
	Target System SNR		dB	40
	Resulting Margin		dB	*4,04*

Reset

Parameter Description	
DUT	
EIRP [dBm]	Equivalent Isotropically Radiated Power The DUT is summarized by its EIRP (output power + antenna gain). If an external antenna is used with the DUT, the EIRP can be calculated manually
Tx SNR [dB]	SNR of the DUT. If this cell is left empty, an ideal signal is assumed, with no noise contribution except thermal noise. The SNR is then calculated against the thermal noise floor. Alternatively a real DUT SNR value can be entered
OTA (Over the Air section)	
Distance [m]	Distance between Tx and Rx antenna. All measurements should be done in the Far Field. Below the Link Budget Calculator is a small table that computes the Far Field distance based on the antenna aperture. The larger aperture of the Tx and Rx antenna must be used here. On the sheet *Horn Calculator* the dimensions of the horn for different waveguides and gains can be calculated. Compact Antenna Test Ranges: The FSPL only applies to the distance between feed and reflector.
FSPL [dB]	Free Space Path Loss (see Section 1.2)
Rx Antenna	
Gain [dB]	Receive antenna gain
LNA (Low Noise Amplifier)	
Gain [dB]	LNA gain. If no LNA is used, set the value to zero. Pay attention to the power level reaching the LNA! Keep a safety margin to the 1dB compression point.
Noise Figure [dB]	LNA Noise Figure. If no LNA is used, set the value to zero.
Rx Cable	
Cable Loss [dB]	Loss in dB given as a positive value
Receiver (spectrum analyzer)	
DANL [dBm/Hz]	Displayed Average Noise Level. Parameter given in the spectrum analyzer's data sheet. A built-in preamplifier lowers the DANL. These values are also given in the data sheet. Pay attention to the input power when using a preamplifier.
Results	
Rx Power [dBm]	Signal power at the receiver input
Rx Noise Power [dBm]	Noise power including the noise contribution of the receiver. DUT noise as well as contributions from the components are included.
Rx SNR [dB]	Signal to noise ratio inside the receiver.
Total Gain [dB]	Includes all gains and losses (also the OTA section)
Total Noise Figure [dB]	Noise Figure of the complete transmission path (including OTA section)
Target System SNR [dB]	Enter a desired SNR to be achieved for the whole system.
Resulting Margin [dB]	Margin between Target System SNR and Rx SNR

A graph shows the Signal Power, Noise Power and SNR for each stage of the system. Additionally a limit line for the noise is shown. The noise power must stay below this limit in order to reach the Target SNR.



1.2 Mathematical Background

- Thermal noise floor for bandwidth *B* at 290K:

  $N_{th} = -174dBm/Hz + 10log_{10}(B)$

- Free space path loss:

  $FSPL = 20log_{10}\left(\frac{4\pi fd}{c}\right)$

  f - carrier frequency in Hz

  d - distance in m

  c - speed of light in m/s

- Far field distance:

  $d > \frac{2D^2}{\lambda}$

  D - antenna aperture in m

  λ - wavelength in m

Each stage of the OTA system can be described with the following equations:

- $S_{out} = GS_{in}$

  S_{out} *… output power,* S_{in} *… input power, G…gain*

- $N_{out} = N_a + GN_{in}$

  N_{out} *… output noise power,* N_{in} *… input noise power,* N_a *… noise added by the component*

- $N_a = (F-1)GN_{in}$

  F … noise factor

The output values of stage *i* can be calculated based on the output values of the preceding stage *i-1*:

$S_{out,i} = G_i S_{out,i-1}$

$N_{a,i} = (F_i - 1)G_i N_{th}$

$N_{out,i} = N_{a,i} + G_i N_{out,i-1}$

Stages		
	Gain G	**Noise Figure NF**
OTA Section	*- FSPL*	*FSPL*
Rx Antenna	Antenna gain	Ideal antenna without loss is assumed. Only thermal noise is added $N_a = N_{th}$
Rx Cable	$-A_{Rx}$	A_{Rx}
Receiver	*0dB*	*DANL + 174dBm/Hz*

1.3 Examples

Example 1:

The task is to measure EVM of a DUT with a patch antenna directly connected to the transmitter. The DUT has an expected EVM that should be measured with a defined error. It is assumed that noise is limiting the DUT and system performance. In that case the simplified assumption SNR_{DUT} = -EVM holds.

The SNR of the OTA system incl. the receiver must be higher than SNR_{DUT} for a reasonable measurement error. For example 6dB margin give 1dB measurement error on the EVM result. The OTA calculator can be used to compute the system SNR and estimate the margin. This is done by using an ideal signal as input with only thermal noise limiting the SNR_{DUT}.

Parameters:

- 802.11ad DUT at 60.48GHz with 1.76GHz bandwidth
- Expected DUT EVM = -30dB
- Measurement error < 1dB => at least 6dB margin
- Tx SNR: leave empty, assumes an ideal signal with only thermal noise contribution
- Target System SNR: enter SNR_{DUT} + Margin => 30+6 = 36dB

- Resulting margin: 0dB indicates that the required system SNR is just met. Positive values indicate extra margin.
  => total margin is 6+2.1=8.1dB (0.6dB error)
- Rx SNR shows the dynamic range of the whole system

Stage	Parameter	Symbol	Unit	Value
	Frequency		GHz	60,480
	Bandwidth		MHz	1760,00
DUT	Equivalent Isotropically Radiated Power	EIRP	dBm	22,00
	Tx SNR	SNR_In	dB	103,54
OTA	Distance	d	m	0,30
	Free Space Path Loss	FSPL	dB	57,62
Rx Antenna	Receive Antenna Gain	G_Rx	dB	15,00
LNA	LNA Gain	G_LNA	dB	20,00
	LNA Noise Figure	NF_LNA	dB	4,00
Rx Cable	Cable Loss	A_Rx	dB	3,00
Receiver	Receiver DANL	DANL_RX	dBm/Hz	-135,00
Results	Rx Power	P_Rx	dBm	-3,62
	Rx Noise Power	N_Rx	dBm	-41,72
	Rx SNR	SNR_Rx	dB	38,10
	Total Gain	G_tot	dB	-25,62
	Total Noise Figure	NF_tot	dB	65,44
	Target System SNR		dB	36
	Resulting Margin		dB	2,10

Figure 1: Link Budget for Example 1

Example 2:

In this example, the overall performance of the DUT and OTA system is of interest. The total SNR should be higher than a given value. The actual DUT SNR is entered in the field *Tx SNR*. *Rx SNR* then give the total SNR including the OTA system.

Parameters:

- 5G signal with 800MHz bandwidth at 28GHz
- DUT SNR of 50dB
- No LNA
- 5dB cable loss before the receiver
- The overall SNR should be higher than 40dB
- For the given parameters the total SNR is only 37.7dB (Rx SNR)

Stage	Parameter	Symbol	Unit	Value
	Frequency		GHz	28,000
	Bandwidth		MHz	800,00
DUT	Equivalent Isotropically Radiated Power	EIRP	dBm	31,00
	Tx SNR	SNR_In	dB	50,00
OTA	Distance	d	m	0,60
	Free Space Path Loss	FSPL	dB	56,95
Rx Antenna	Receive Antenna Gain	G_Rx	dB	15,00
LNA	LNA Gain	G_LNA	dB	0,00
	LNA Noise Figure	NF_LNA	dB	0,00
Rx Cable	Cable Loss	A_Rx	dB	5,00
Receiver	Receiver DANL	DANL_RX	dBm/Hz	-143,00
Results	Rx Power	P_Rx	dBm	-15,95
	Rx Noise Power	N_Rx	dBm	-53,67
	Rx SNR	SNR_Rx	dB	37,72
	Total Gain	G_tot	dB	-46,95
	Total Noise Figure	NF_tot	dB	77,98
	Target System SNR		dB	40
	Resulting Margin		dB	-2,28

Figure 2: Link Budget for Example 2

- adding a 10dB LNA before the receiver improves the overall SNR

Stage	Parameter	Symbol	Unit	Value
	Frequency		GHz	28,000
	Bandwidth		MHz	800,00
DUT	Equivalent Isotropically Radiated Power	EIRP	dBm	31,00
	Tx SNR	SNR_In	dB	50,00
OTA	Distance	d	m	0,60
	Free Space Path Loss	FSPL	dB	56,95
Rx Antenna	Receive Antenna Gain	G_Rx	dB	15,00
LNA	LNA Gain	G_LNA	dB	10,00
	LNA Noise Figure	NF_LNA	dB	2,00
Rx Cable	Cable Loss	A_Rx	dB	5,00
Receiver	Receiver DANL	DANL_RX	dBm/Hz	-143,00
Results	Rx Power	P_Rx	dBm	-5,95
	Rx Noise Power	N_Rx	dBm	-51,63
	Rx SNR	SNR_Rx	dB	45,68
	Total Gain	G_tot	dB	-36,95
	Total Noise Figure	NF_tot	dB	68,28
	Target System SNR		dB	40
	Resulting Margin		dB	5,68

Figure 3: LNA added for Example 2

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