AN11680

BGS8M2UK LTE LNA with bypass switch evaluation board

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Document information

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Abstract	This document explains the BGS8M2UK LTE LNA evaluation board
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1. Introduction

NXP Semiconductors' BGS8M2UK LTE LNA Evaluation Board is designed to evaluate the performance of the LTE LNA in its typical application, using:

- NXP Semiconductors' BGS8M2UK LTE Low Noise Amplifier
- A matching inductor
- A decoupling capacitor

NXP Semiconductors' BGS8M2UK is a low-noise amplifier with bypass switch for LTE receiver applications in an extremely small Wafer-Level Chip-Scale Package (WLCSP), 0.69 mm x 0.44 mm x 0.2 mm; 6 solder bumps (0.252 mm / 0.260 mm bump pitch). The BGS8M2UK features gain of 15.4 dB and a noise figure of 0.75 dB at a current consumption of 5.8 mA. The Bypass switch insertion loss is 1.9 dB. Its superior linearity performance removes interference and noise from co-habitation cellular transmitters, while retaining sensitivity. The LNA components occupy a total area of approximately 1.3 mm^2.

In this document, the application diagram, board layout, bill of materials, and typical performance are given, as well as some explanations on LTE related RF-parameters like input third-order intercept point IIP3, gain compression and noise.

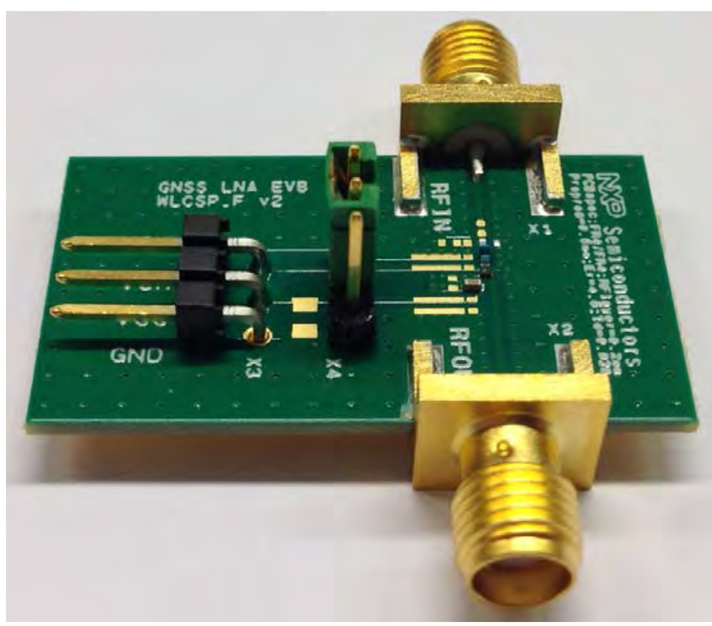


Fig 1. BGS8x2UK / BGS8x3UK LTE LNA evaluation board (used for BGS8L3UK, BGS8M2UK and BGS8H2UK)

2. General description of application & product

Modern cellular phones have multiple radio systems, so problems like co-habitation are quite common. Since the LTE diversity antenna needs to be placed far from the main antenna to ensure the efficiency of the channel, a low noise amplifier close to the antenna is used to compensate the track-losses (and SAW-filter losses when applicable) on the printed circuit board. A LTE receiver implemented in a mobile phone requires a low current consumption and low Noise Figure. All the different transmit signals that are active in smart phones and tablets can cause problems like inter-modulation and compression. Therefore also a high linearity is required.

2.1 BGS8x2UK / BGS8x3UK: Advantage of integrated By-pass function

The major advantage of having a bypass-switch option is the very low current consumption (<1µA) when LTE LNA is not needed in the receive chain (at high RSSI/CQI level, 3~5dB higher than the Sensitivity level). Fig 2 gives a graphical explanation of this advantage.

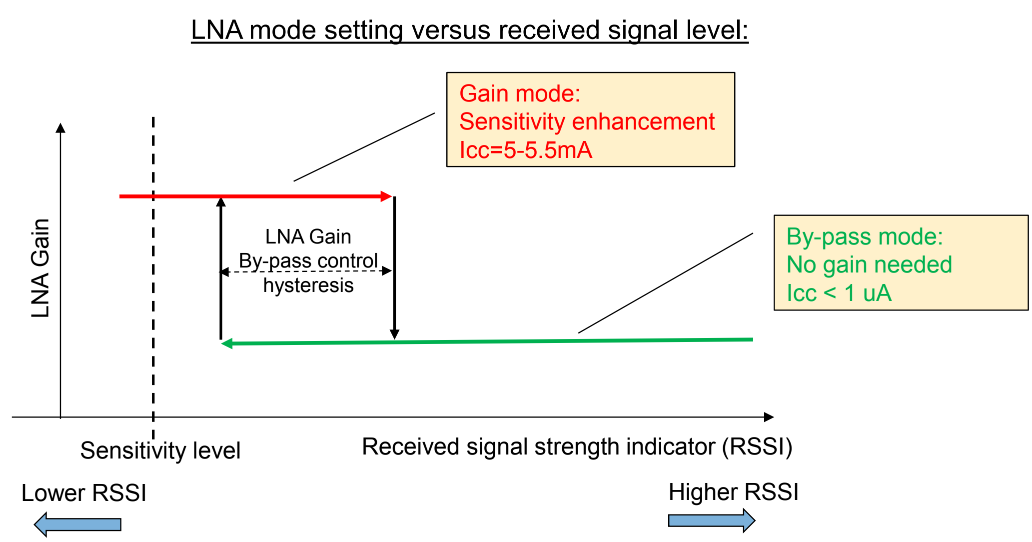


Fig 2. LNA mode setting versus received signal level

To avoid frequently switching between Gain- and bypass-mode around chosen Receiver Signal Strength Indicator (RSSI) switching level, one should take a Hysteresis Loop into consideration in the switching logic of the control chip (transceiver or baseband chip), see Fig 2.

3. BGS8M2UK LTE LNA evaluation board

The BGS8M2UK LNA evaluation board simplifies the RF evaluation of the BGS8M2UK LTE LNA applied in a LTE front-end, often used in mobile cell phones. The evaluation board enables testing of the device RF performance and requires no additional support circuitry. The board is fully assembled with the BGS8M2UK including the input series inductor and decoupling capacitor. The board is supplied with two SMA connectors for input and output connection to RF test equipment. The BGS8M2UK can operate from a 1.5 V to 3.1 V single supply and consumes typical 5.8 mA.

3.1 Application Circuit

The circuit diagram of the evaluation board is shown in Fig 3. With jumper JU1 the control input can be connected either to Vcc (Gain-mode) or GND (Bypass mode).

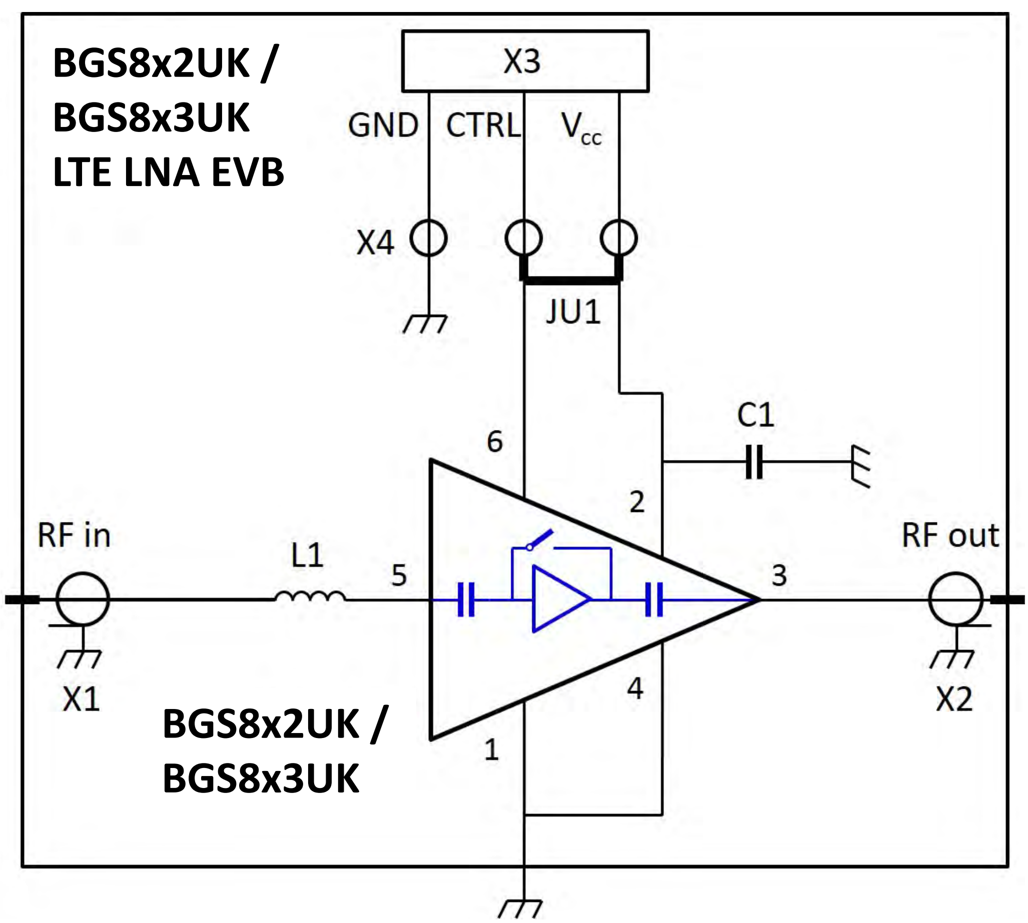


Fig 3. Circuit diagram of the BGS8x2UK / BGS8x3UK LNA evaluation board (used for BGS8L3UK, BGS8M2UK and BGS8H2UK)

3.2 PCB Layout

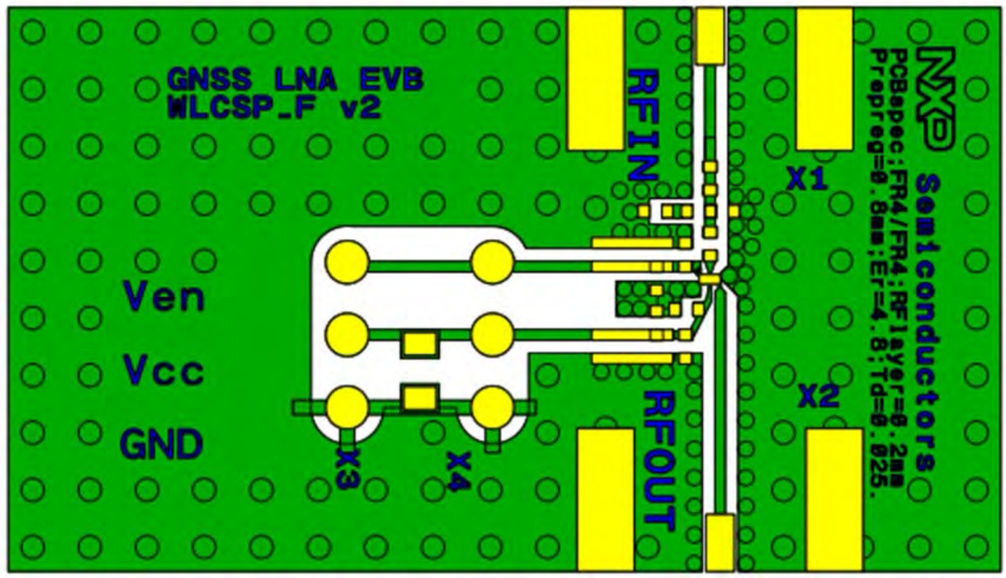
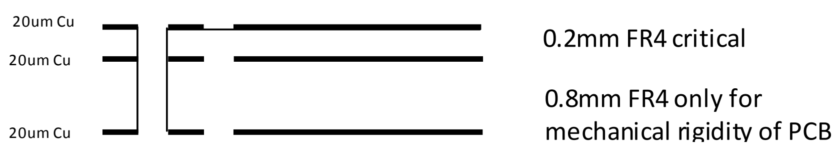


Fig 4. Printed-Circuit Board layout of the BGS8x2UK / BGS8x3UK LNA evaluation board (used for BGS8L3UK, BGS8M2UK and BGS8H2UK)

A good PCB layout is an essential part of an RF circuit design. The LNA evaluation board of the BGS8M2UK can serve as a guideline for laying out a board using the BGS8M2UK.

- Use controlled impedance lines for all high frequency inputs and outputs.
- Bypass Vcc with decoupling capacitors, preferably located as close as possible to the device.
- For long bias lines it may be necessary to add decoupling capacitors along the line further away from the device.
- Proper grounding of the GND pins is also essential for good RF performance.
- Either connect the GND pins directly to the ground plane or through vias, or do both, which is recommended.
- To ensure optimal performance of BGS8M2UK in the application it is advised to simulate the overall application performance using the S-parameter and noise models of the device, the models for the external components (SAW filter, input inductor) and the models for the PCB. Models for the BGS8M2UK are available via NXP sales representatives.

The material that has been used for the evaluation board is FR4 using the stack shown in Fig 5.



(1) Material supplier is ISOLA DURAVER; εr = 4.6-4.9: $T\delta = 0.02$

Fig 5. Stack of the PCB material

3.3 Bill of materials

Table 1. BOM of the BGS8M2UK LTE LNA evaluation board

Designator	Description	Footprint	Value	Supplier Name/type	Comment
-	BGS8M2UK	0.69 mm x 0.44 mm x 0.2 mm, 6 solder bumps (0.252 mm / 0.260 mm bump pitch)		NXP	WLCSP
PCB		20 x 35mm		BGS8M2UK LTE LNA EV Kit	
C1	Capacitor	0402	1µF	Murata GRM1555	Decoupling
L1	Inductor	0402	3.9nH	Murata LQW15	Input matching
X1, X2	SMA RD connector	-	-	Johnson, End launch SMA 142-0701-841	RF input/ RF output
X3	DC header	-	-	Molex, PCB header, Right Angle, 1 row, 3 way 90121-0763	Bias connector
X4	JUMPER Stage	-	-	Molex, PCB header, Vertical, 1 row, 3 way 90120-0763	Connect Ven to Vcc or separate Ven voltage
JU1	JUMPER				

3.4 BGS8M2UK

NXP Semiconductors' BGS8M2UK LTE low noise amplifier is designed for the LTE low band. The integrated biasing circuit is temperature stabilized, which keeps the current constant over temperature. It also enables the superior linearity performance of the BGS8M2UK. The BGS8M2UK is also equipped with an enable function that allows it to be controlled via a logic signal. In disabled mode it consumes less than1 µA.

The output of the BGS8M2UK is internally matched between 1805 MHz and 2200 MHz, whereas only one series inductor at the input is needed to achieve the best RF performance. The input and output are AC coupled via an integrated capacitor.

It requires only two external components to build a LTE LNA having the following advantages:

- Low noise
- System optimized gain
- High linearity under jamming
- 0.69 mm x 0.44 mm x 0.2 mm; 6 solder bumps (0.252 mm / 0.260 mm bump pitch). WLCSP.
- Low current consumption
- Short power settling time

3.5 Series inductor

The evaluation board is supplied with Murata LQW15 series inductor of 3.9 nH. This is a wire wound type of inductor with high quality factor (Q) and low series resistance (Rs) like the Murata LQW15A series (see Table 2). This type of inductor is recommended in order to achieve the best noise performance. High Q inductors from other suppliers can be used. If it is decided to use other low cost inductors with lower Q and higher Rs the noise performance will degrade.

Table 2. Series Inductor options

Type	Murata	Size 0201	Size 0402	Size 0603	Comment
Multilayer Non-Magnetic Core	LQG		15H NF↑↑	18H NF↑	
Film	LQP	03T NF↑↑	15M NF↑		
Wirewound Non-Magnetic Core	LQW		15A **Default**	18A NF↓	Lowest NF

4. Typical LNA evaluation board results

4.1 S-Parameters

The measured S-Parameters and stability factor K are given in the figures below. For the measurements, a BGS8M2UK-LNA EVB is used ((see Fig 21). Measurements have been carried out using the setup shown in Fig 22.

Fig 6. BGS8M2UK S-Parameters (typical values). Vcc=2.8V, Pin=-30dBm. Gain mode and Bypass mode

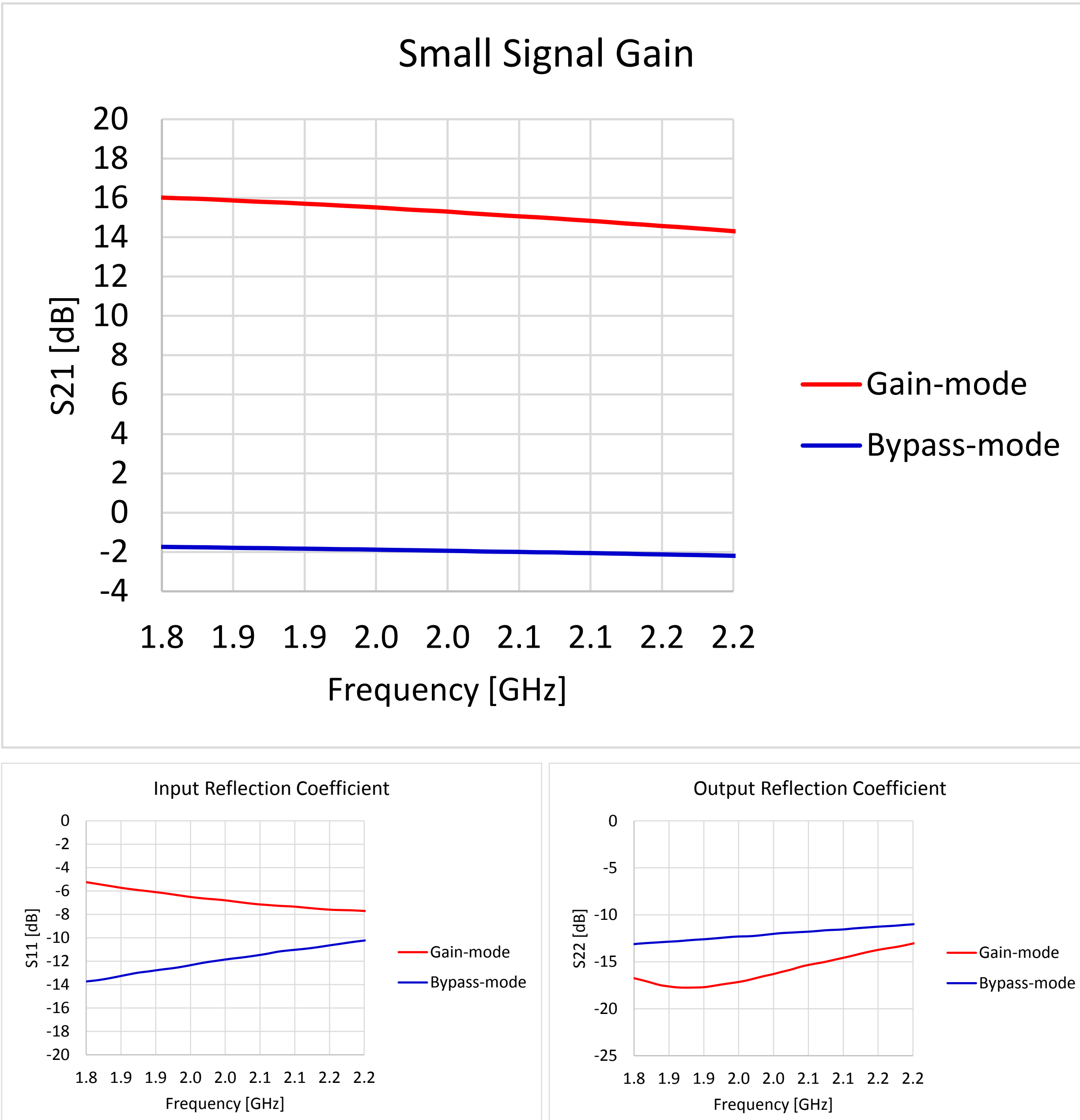
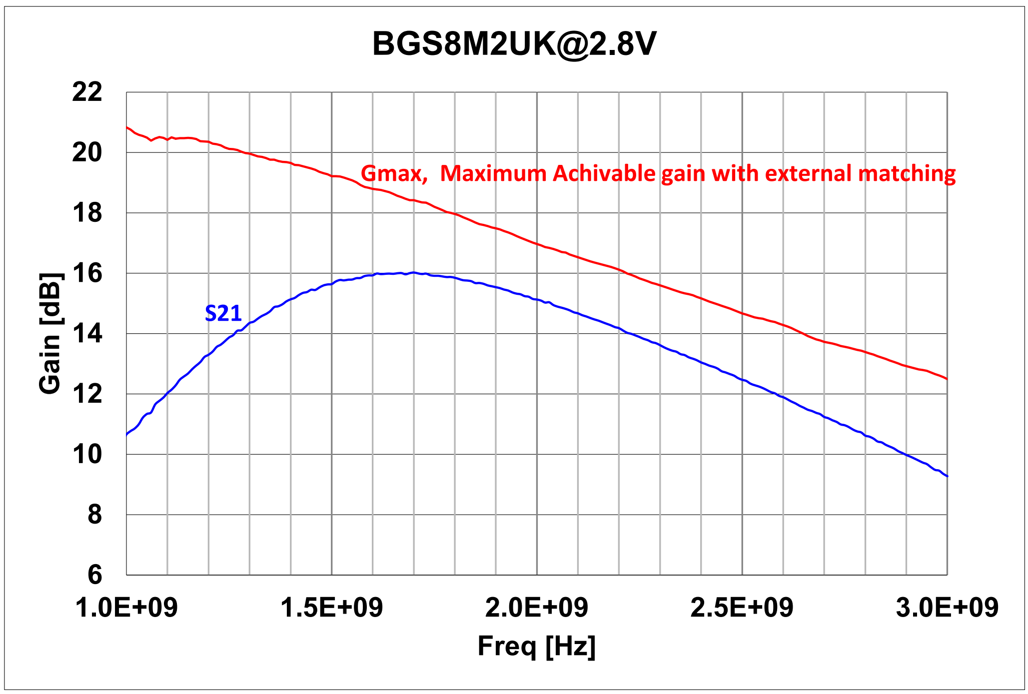


Fig 7. BGS8M2UK S-Parameters (typical values). Vcc=2.8V, Pin=-30dBm, Gain mode and Bypass mode (Frequency range zoomed in).

4.2 Improving the Gain by optimized matching

The design of the BGS8x2UK / BGS8x3UK LTE LNA's are optimized for best RF-performance using only one input matching coil. In some cases, the Gain can be increased if more in- and output components are used. Fig 8 gives the theoretical maximum gain (Gmax) using (ideal) optimized in- and output matching circuits, and S21 (typical measured performance) of a BGS8M2UK demoboard.



freq [MHz]	Gmax(dB)	S21 (dB)	S11 (dB)	S22 (dB)	S12(dB)
1840	17.7	15.7	-5.5	-15.3	-24.4
1960	17.1	15.3	-6.4	-15.4	-23.8
2140	16.3	14.5	-7.3	-13.1	-23.1

Fig 8. S21 and Maximum achievable gain (Gmax) typ. values (Gain mode)

Fig 9 and Fig 10 give an implementation of an improved matching circuit using 3 inductors to increase the Gain.

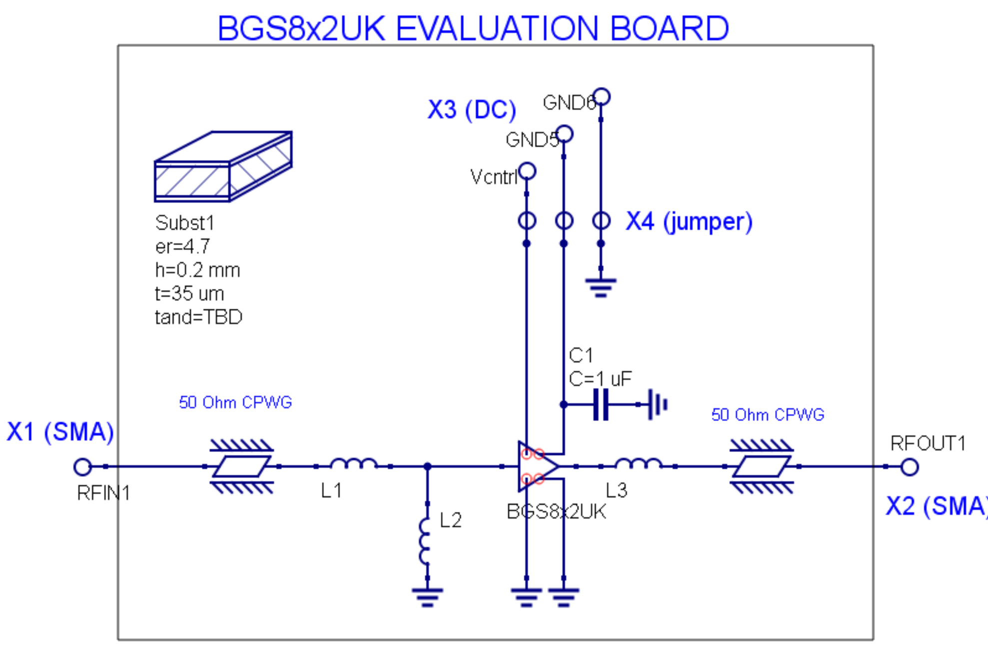


Fig 9. Circuit diagram of the BGS8x2UK / BGS8x3UK LNA evaluation board using 2 input and one output inductor to optimize the Gain.

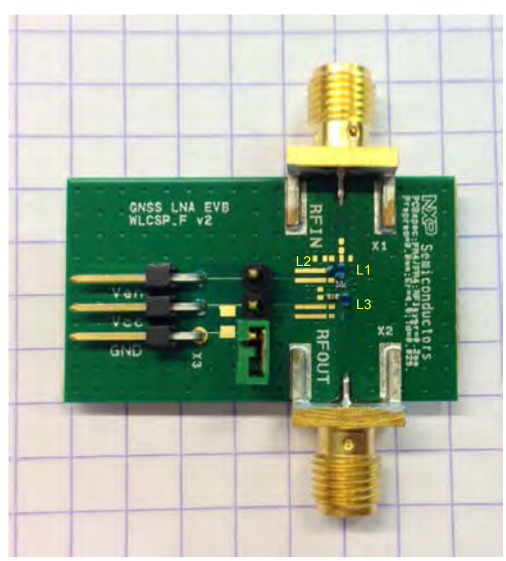


Fig 10. EVB detail of the BGS8x2UK / BGS8x3UK LNA evaluation board using 2 input and one output inductor to optimize the Gain.

4.3 1dB gain compression

Strong in-band cell phone TX jammers can cause linearity problems and result in third-order intermodulation products in the LTE frequency band. In this chapter the effects of these strong signals is shown. For the measurements, a BGS8M2UK-LNA EVB is used ((see Fig 21). Measurements have been carried out using the setup shown in Fig 22. The gain as function of input power of the DUT was measured between port RFin and RFout of the EVB at the low LTE center frequencies. The figures below show the gain compression curves at LNA-board.

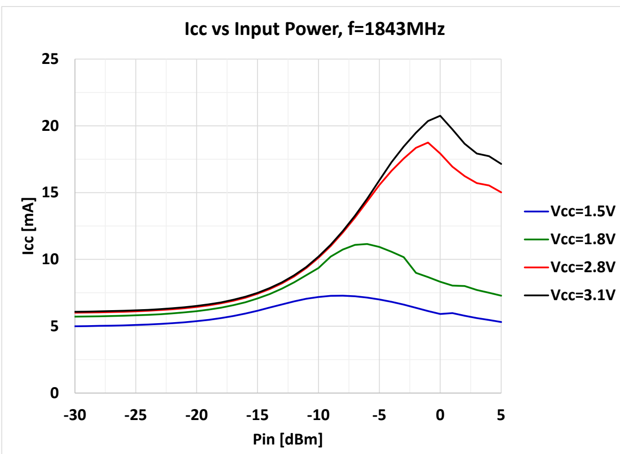


Fig 11. Icc versus input power , f=1843MHz (band 3)

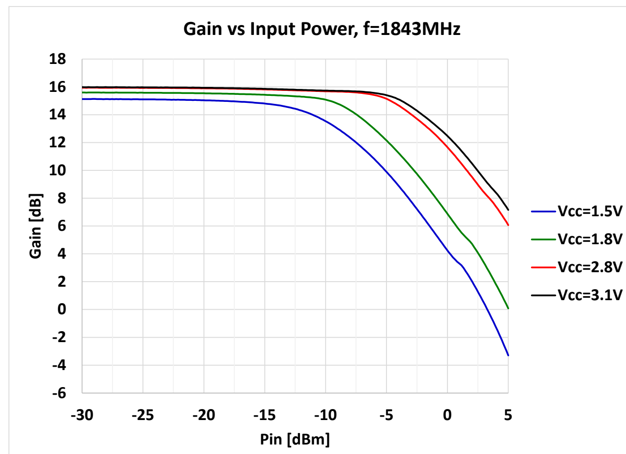


Fig 12. Gain versus input power , f=1843 (band 3)

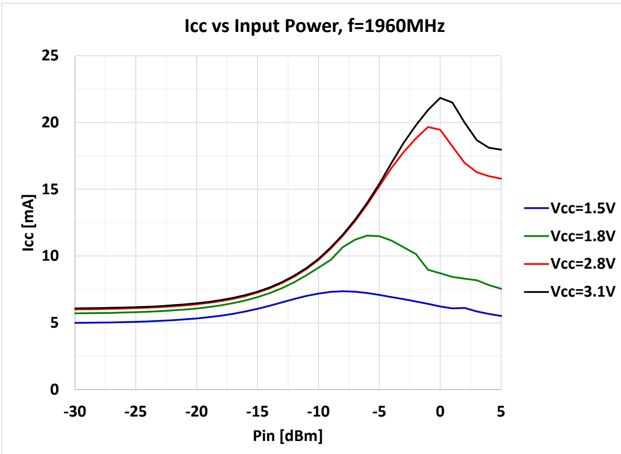


Fig 13. Icc versus input power , f=1960MHz (band 2)

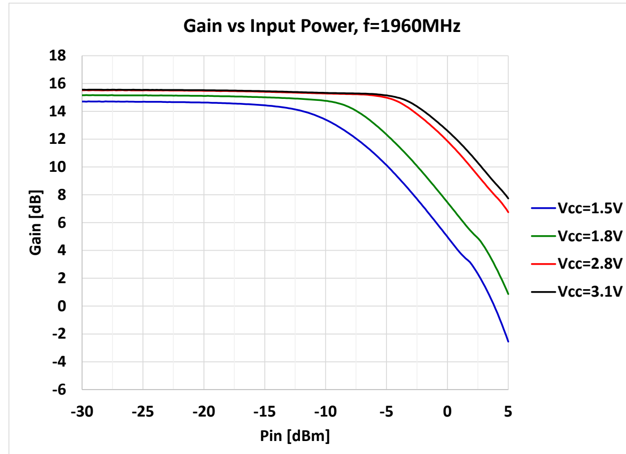


Fig 14. Gain versus input power , f=1960MHz (band 2)

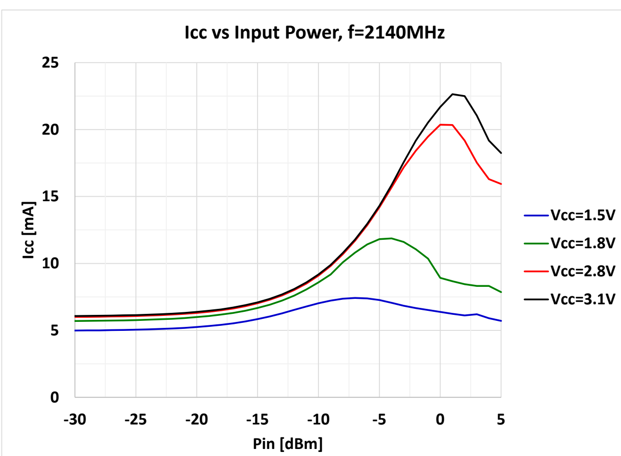


Fig 15. Icc versus input power , f=2140MHz (band 1)

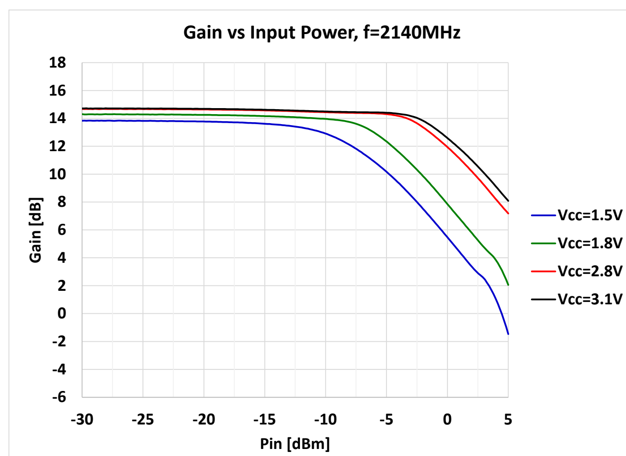


Fig 16. Gain versus input power , f=2140MHz (band 1)

4.4 IIP3 2-Tone Test

The figures below show measured input-IP3-results of the DUT measured with a 2-Tone test at the LTE-bands. For the measurements, a BGS8M2UK-LNA EVB is used (see Fig 21). Measurements have been carried out using the setup shown in Fig 22.

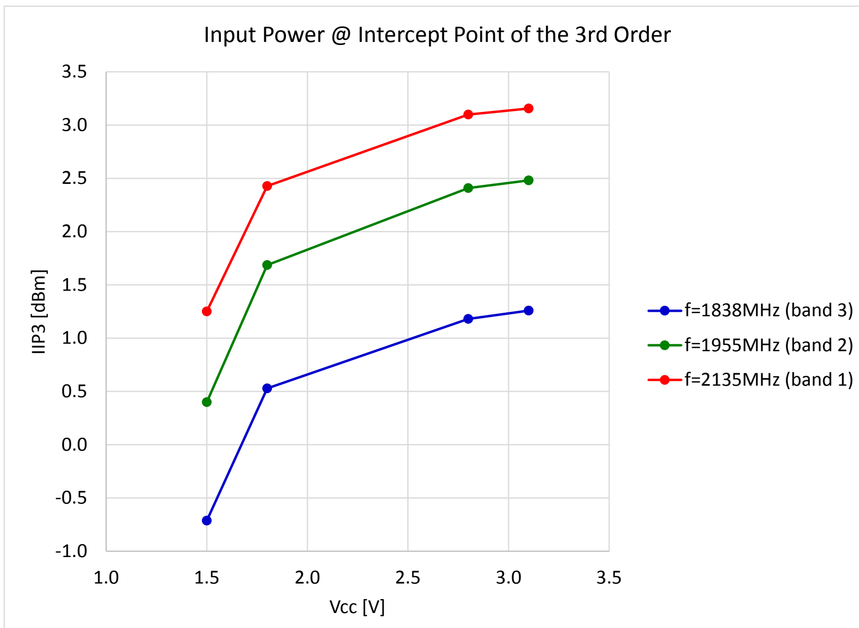


Fig 17. IIP3=F(Vcc), Pin=-30dBm

4.5 Enable Timing Test

The following diagram shows the setup to test LNA Turn ON and Turn OFF time.

Set the waveform generator to square mode and the output amplitude at 3Vrms with high output impedance. The waveform generator has adequate output current to drive the LNA therefore no extra DC power supply is required which simplifies the test setup.

Set the RF signal generator output level to -20dBm at a frequency between 1805 MHz and 2200 MHzand increase its level until the output DC on the oscilloscope is at 5mV on 1mV/division, the signal generator RF output level is approximately -3dBm.

It is very important to keep the cables as short as possible at input and output of the LNA so the propagation delay difference on cables between the two channels is minimized.

It is also critical to set the oscilloscope input impedance to 50ohm on channel 2 so the diode detector can discharge quickly to avoid a false result on the Turn OFF time testing.

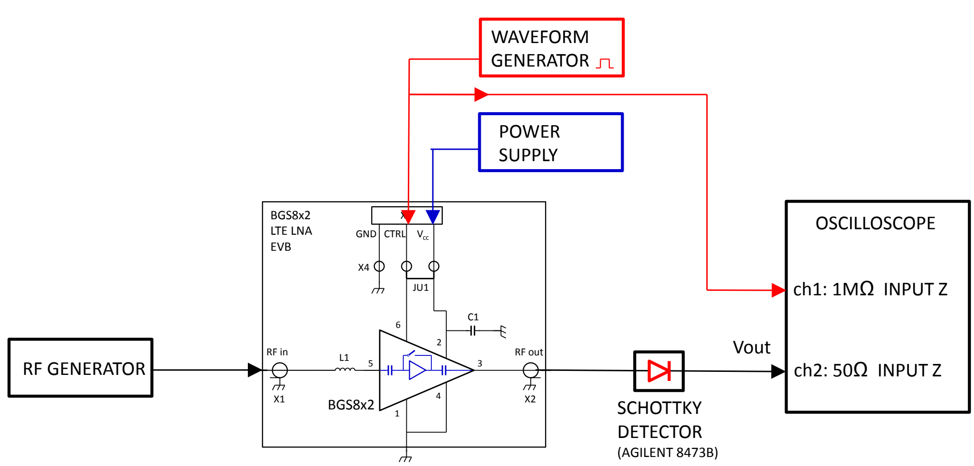


Fig 18. Setup Enable Timing Test

Fig 19 and Fig 20 show the measured Ton and T_bypass test.

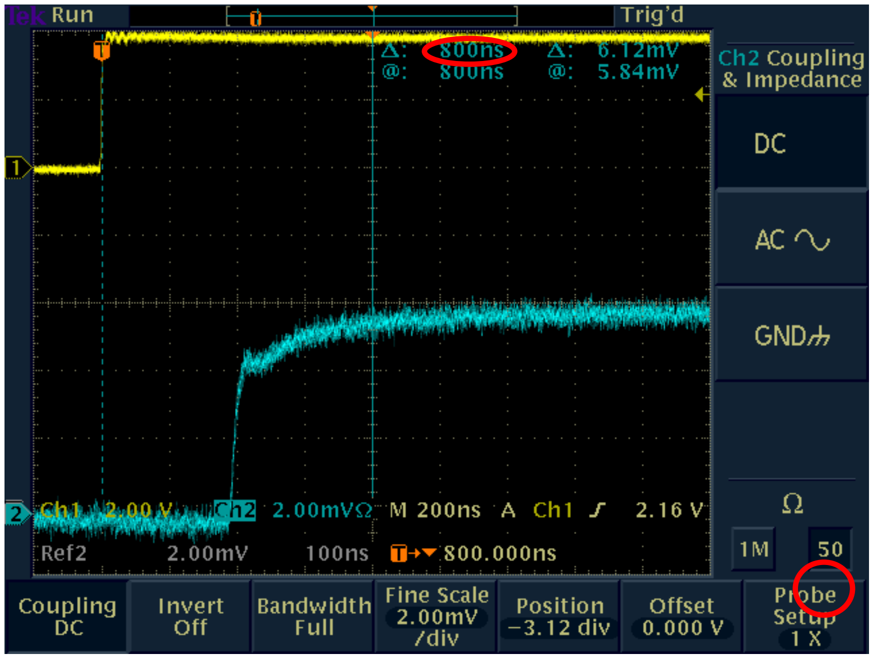


Fig 19. Results Enable Timing Test. Frq=1960MHz, Pin=-20dBm, Vcc=2.8V : Ton~800 ns.

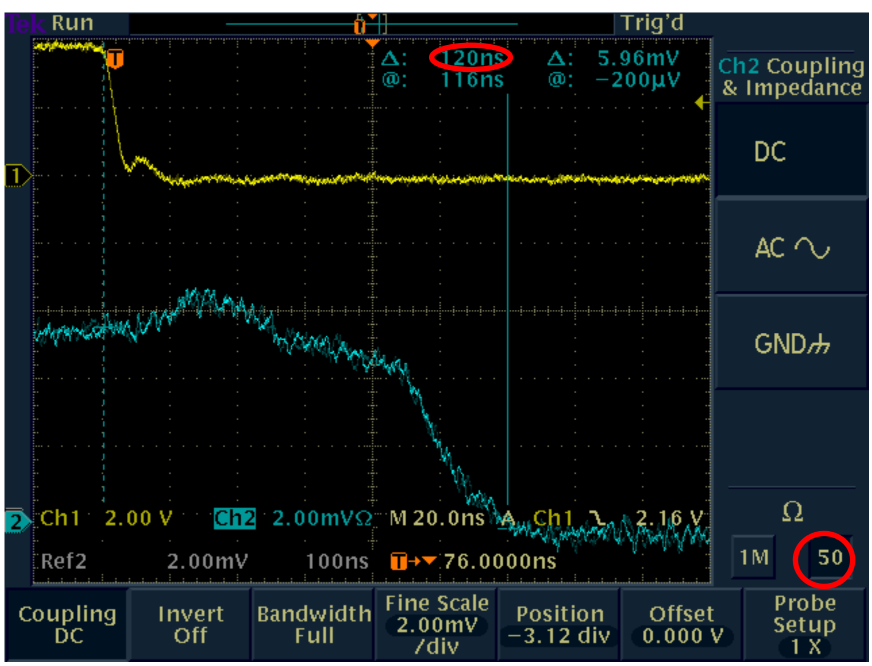


Fig 20. Results Enable Timing Test. Frq=1960MHz, Pin=-20dBm, Vcc=2.8V : T_Bypass~120 ns.

5. Required Measurement Equipment

In order to measure the evaluation board the following is necessary:

- ✓ DC Power Supply up to 30 mA at 1.5 V to 3.1 V
- ✓ Two RF signal generators capable of generating RF signals at the LTE operating frequencies between 1805 MHz and 2200 MHz.
- ✓ An RF spectrum analyzer that covers at least the LTE operating frequencies of 1805 MHz to 2200 MHz as well as a few of the harmonics. Up to 6 GHz should be sufficient.
  "Optional" a version with the capability of measuring noise figure is convenient
- ✓ Amp meter to measure the supply current (optional)
- ✓ A network analyzer for measuring gain, return loss and reverse isolation
- ✓ Noise figure analyzer and noise source
- ✓ Directional coupler
- ✓ Proper RF cables

6. Connections and setup

The BGS8M2UK LTE LNA evaluation board is fully assembled and tested (see Fig 21). Please follow the steps below for a step-by-step guide to operate the LNA evaluation board and testing the device functions.

1. Connect the DC power supply to the V_{cc} and GND terminals. Set the power supply to the desired supply voltage, between 1.5 V and 3.1 V, but never exceed 3.1 V as it might damage the BGS8M2UK.
2. Jumper JU1 is connected between the V_{cc} terminal of the evaluation board and the V_{en} pin of the BGS8M2UK.
3. Connect the RF signal generator and the spectrum analyzer to the RF input and the RF output of the evaluation board, respectively (Fig 21). Do not turn on the RF output of the signal generator yet, set it to approximately -30 dBm output power at center frequency of the wanted LTE-band and set the spectrum analyzer at the same center frequency and a reference level of 0 dBm.
4. Turn on the DC power supply and it should read approximately 6 mA.
5. Enable the RF output of the generator: The spectrum analyzer displays a tone around –15 dBm.
6. Instead of using a signal generator and spectrum analyzer one can also use a network analyzer in order to measure gain as well as in- and output return loss, P1dB and IP3 (see Fig 22).
7. For noise figure evaluation, either a noise figure analyzer or a spectrum analyzer with noise option can be used. The use of a 5 dB noise source, like the Agilent 364B is recommended. When measuring the noise figure of the evaluation board, any kind of adaptors, cables etc. between the noise source and the evaluation board should be minimized, since this affects the noise figure (see Fig 23).

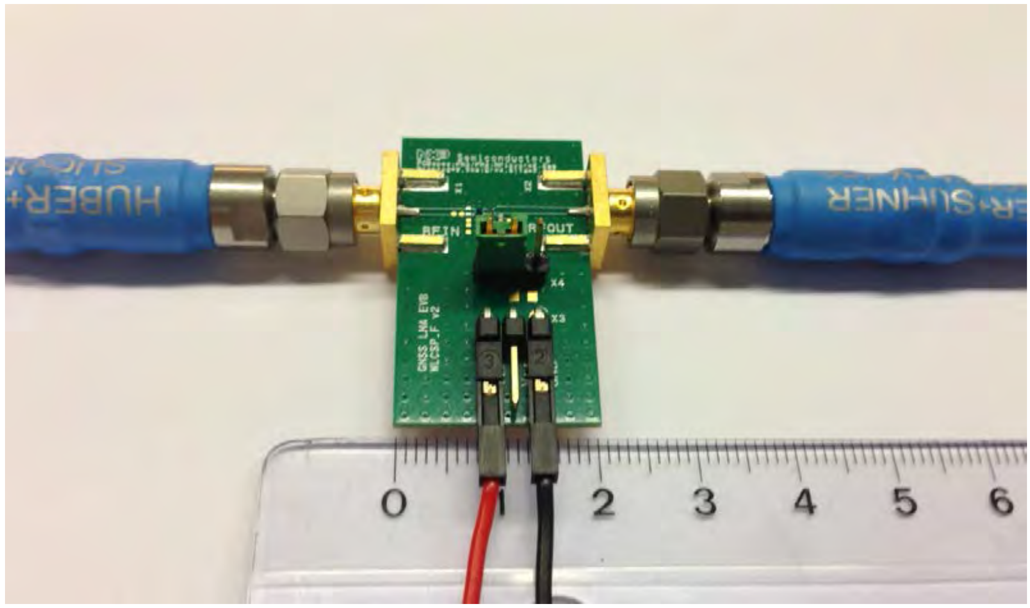


Fig 21. Evaluation board including its connections

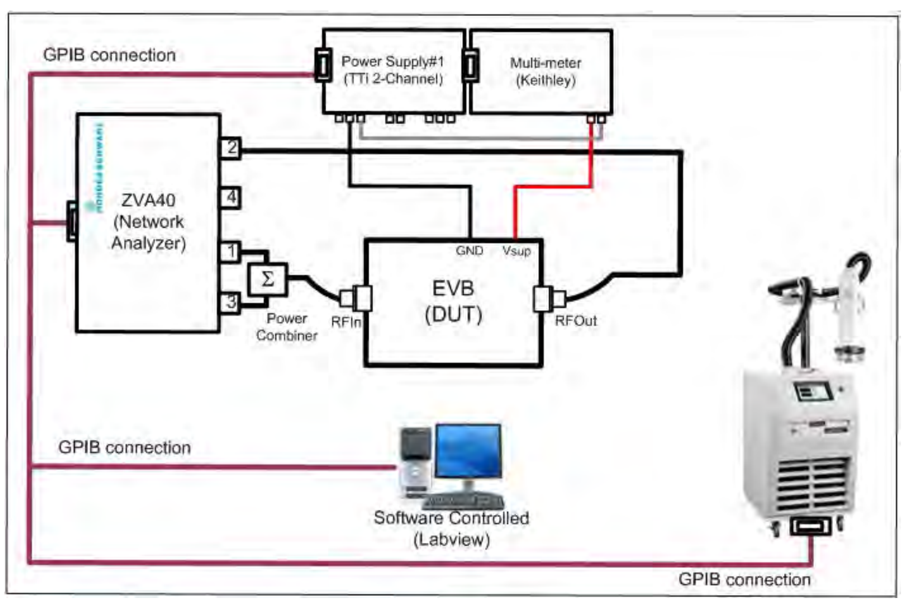


Fig 22. 2-Tone Setup for 50Ω LNA board tests (S-Parameters, P1dB and 2-Tone-tests)

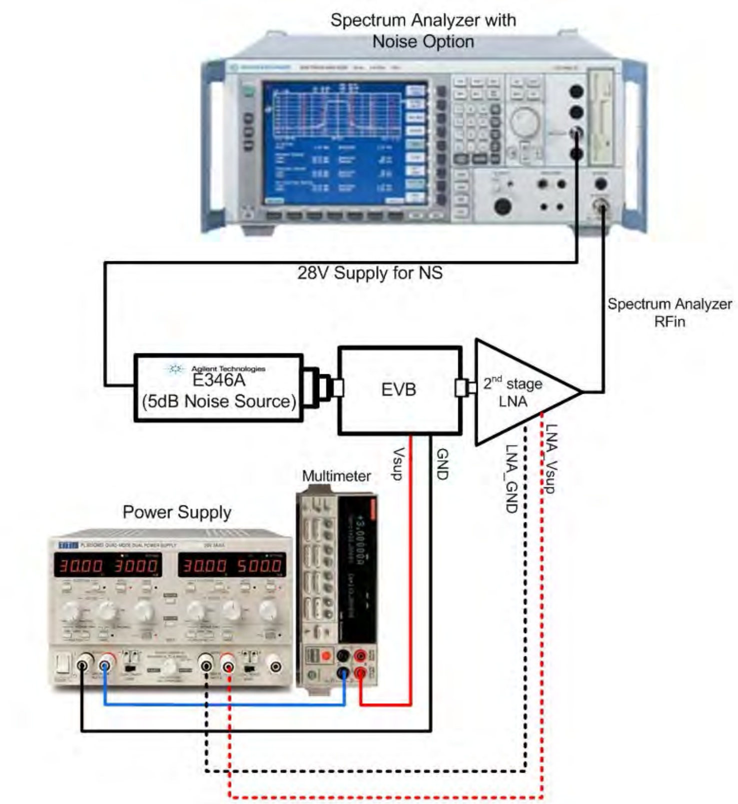


Fig 23. Setup diagram for 50Ω LNA-board NF-Measurements.

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