# AN13420

## BTS6302U Evaluation Board Application Note

Rev. 2.1 — 15 April 2024 Application note

## 1 Introduction

This application note focuses on the BTS6302U evaluation board, the application diagram, board layout, bill of materials and control signals are described. Also some typical measurement graphs are shown, even under Digital Pre-Distortion (DPD) conditions.

Refer to the data sheet for the detailed RF performance of the BTS6302U.

The Customer Evaluation Kit contains the following items:

- BTS6302U EVB
- 5 samples

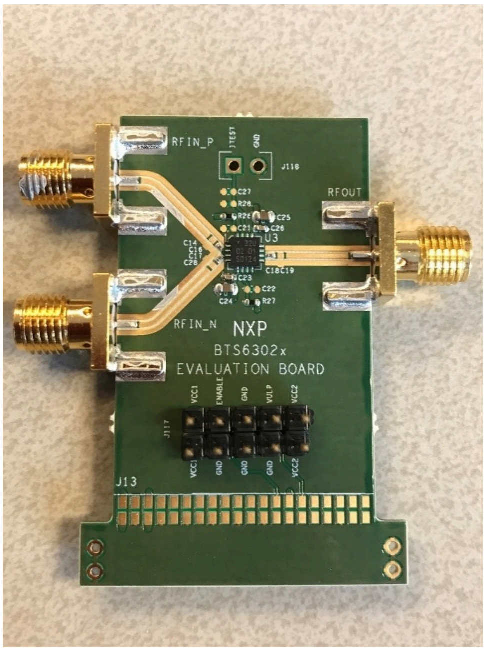



Figure 1. BTS6302U customer evaluation board (EVB)

## 2 Ordering information

Table 1. Ordering information

| Description | Part name | Ordering 12NC |
|---|---|---|
| BTS6302U Customer Evaluation Kit | OM17096/BTS6302U | 9354 239 94598 |

## 3 Product description

The BTS6302U is a wideband, high linearity, pre-driver amplifier for 5G massive MIMO infrastructure applications, with fast on-off switching time to support TDD systems. The amplifier is designed to operate between 2.3 GHz and 5 GHz. It is housed in a 3 mm × 3 mm × 0.85 mm 16 terminal plastic thin small outline package HVQFN16 (SOT758-1). The amplifier is ESD protected on all terminals.

The BTS6302U key features and benefits are listed below.

- High saturated output power $P_{o(sat)}$ = 27.9 dBm
- High power-gain $G_p$ = 38 dB
- High linearity performance ACLR = -43 dBc
- Unconditionally stable
- Fast switching to support TDD systems
- 5 V single supply, quiescent current 78 mA
- Small 16-terminal leadless package 3 mm × 3 mm × 0.85 mm
- ESD protection on all terminals
- Moisture sensitivity level 1

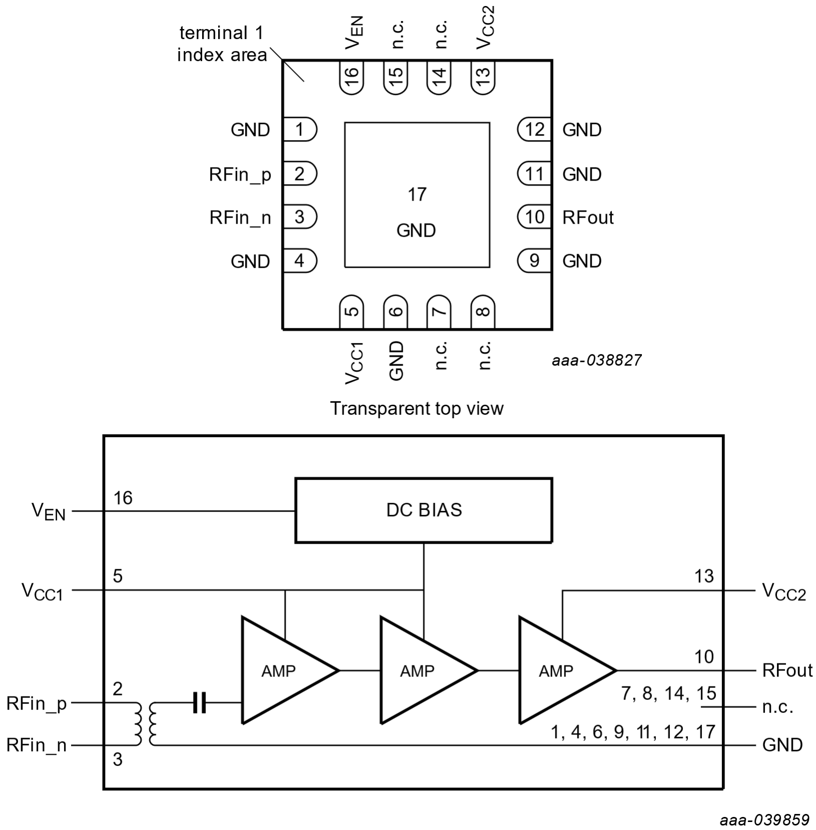



**Figure 2. BTS6302U pinout and functional diagram**

# 4 Application board

The BTS6302U evaluation board simplifies the RF evaluation of this pre driver. The evaluation board enables testing the RF performance of the device, in an isolated environment. In case no differential drive source is available, an external Balun is required. To de-embed applied RF output connector and transmission line up to the output DC blocking capacitor, de-embedding data is available on request.

The BTS6302U evaluation board is fabricated on a 26 mm x 48 mm x 1 mm thick 4 layer PCB. The 0.254 mm top layer uses R4350B for optimal RF performance. The board is fully assembled according to the schematic shown below. The board is supplied with two SMA connectors to connect input and output to the RF test equipment.

## 4.1 Application circuit

The application board circuit diagram that is implemented on the EVB is shown in Figure 3.

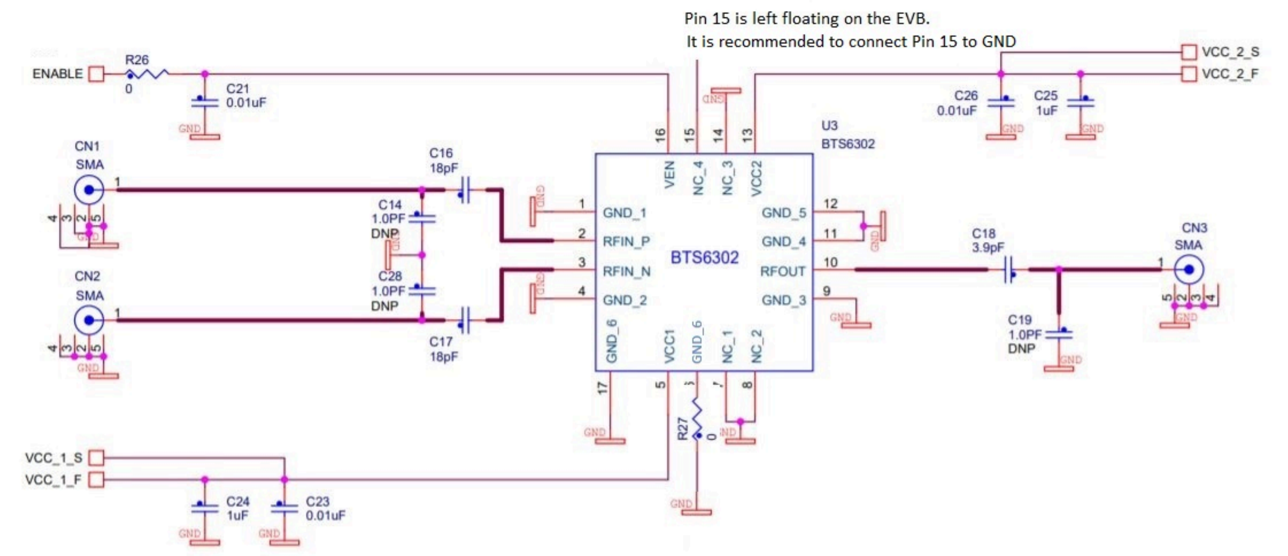



**Figure 3. Application board circuit diagram**

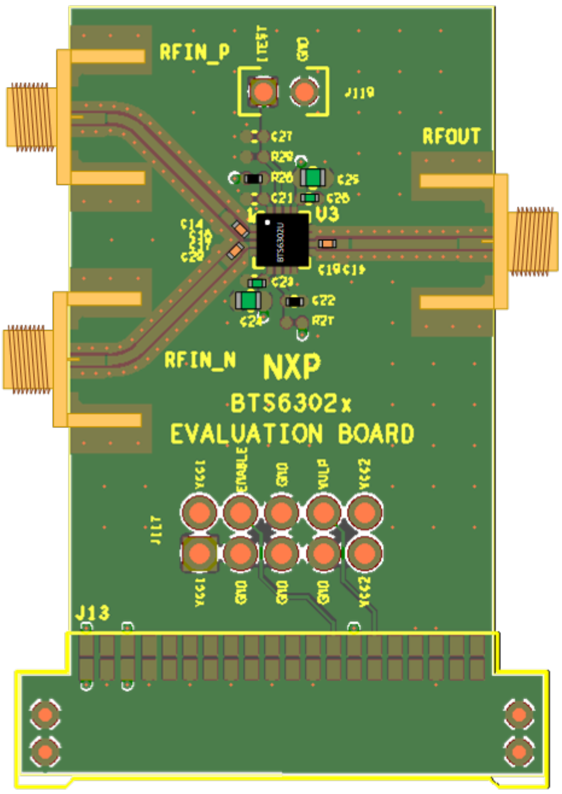
The differential RF input (RFin_P, RFin_N) is supplied via CN1 and CN2. Output signals can be applied via SMA connector CN3. Capacitors C16, C17, and C18 are DC-blocking capacitors. Although the RF input ports are DC free, blocking capacitors are recommended in order not to short both differential inputs for DC. These blocking capacitors also prevent DC voltages above the maximum specified value.

***Note:*** *The components indicated with DNP are not necessary (Do Not Place), but provide means to experiment on matching and decoupling if necessary.*

## 4.2 PCB Layout information and component selection

- A good PCB layout is an essential part of an RF circuit design. The evaluation board of the BTS6302U can serve as a guideline for laying out a board using the BTS6302U.
- The evaluation board uses micro strip coplanar ground structures for controlled impedance lines for the high frequency input and output.
- $V_{CC1}$ and $V_{CC2}$ are bypassed via C23, and 24, and C25, and C26 decoupling capacitors respectively. C23, and C26 should be located as close as possible < 1 mm to the device, to avoid AC leakage via the bias lines. For long bias lines, it may be necessary to add decoupling capacitors along the line further away from the device.
- In this report as well as in the data sheet the value of C1, and C2 are stated as 18 pF. The values of C1, and C2 are critical for power on/off settling time. In case the value for those capacitors is increased significantly the switching time is affected.
- 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. The layout and component placement of the BTS6302U evaluation board is given in Figure 4
- Resistor R26 in the $V_{EN}$ Line on EVB is chosen to be 0 Ω. For current limitations in the system application, it is recommended to use a resistor value 2 kΩ

### 4.2.1 Evaluation board layout




Location C22 is for R27. $V_{ULP}$ is not used in this application.

**Figure 4. BTS6302U evaluation board layout and component**

### 4.2.2 PCB stack and recommended footprint

The PCB material used to implement the pre-driver circuit is a symmetrical stack. Applying 2 times 0.254 mm R4350B low loss material at a core of FR4 with 0.432 mm thickness. See Figure 5. The official drawing of the recommended footprint can be found via following link SOT758-1.pdf. When using micro strip coplanar PCB technology, it is recommended using at least 12 ground-via holes of 300 µm diameter in the ground plane under the device. This technique is also used on the EVBs as shown in Figure 6.

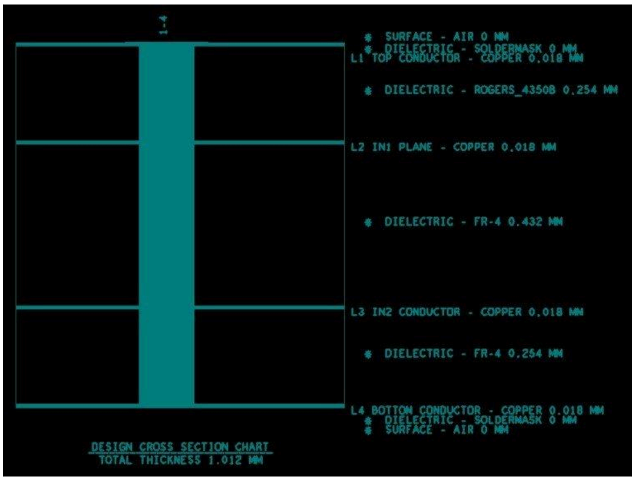



Figure 5. Cross section of the PCB Layer stack

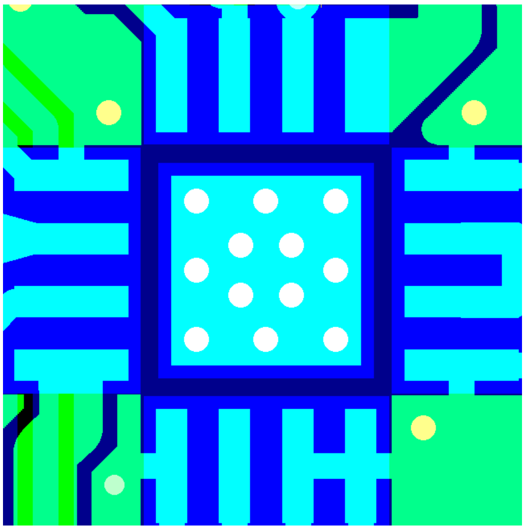


Figure 6. Recommended footprint

## 4.3 Bill of materials

**Table 2. Evaluation board BOM**

*Gives the bill of materials as is used on the EVB*

| Designator | Description | Footprint | Value | Supplier Name/type | Comment/function |
|---|---|---|---|---|---|
| IC1 | BTS6302U | | | | |
| PCB | 26 mm x 48 mm x 1 mm | | | | RO4350 |
| C14, C19, C28 | capacitor | 0402 | n.a. | | for experimenting only |
| C16, C17 | capacitor | 0201 | 18 pF | Murata | DC block |
| C18 | capacitor | 0201 | 3.9 pF | Murata | DC block |
| C21, C22, | capacitor | 0402 | 10 nF | Murata | optional |
| C23, C26 | capacitor | 0402 | 10 nF | Murata | supply decoupling |
| C24, C25 | capacitor | 0603 | 1 µF | Murata | |
| R26, R27 | resistor | 0402 | 0 Ω | Phycomp | bridge (Location for R27 is C22) |
| J1, J2, and J3 | DC header | | | Johnson Emmerson | DC connections |
| J117 | DC header | | | Amphenol | DC connections |

# 5 Evaluating the BTS6302U

All RF performance results given in the next chapters are referenced to the SMA connectors on the evaluation board. In the data sheet characteristics, board connectors and PCB tracks are de-embedded up-to the product input and output DC blocking capacitors.

The typical device performance given in the data sheet is characterized on the evaluation board equal to the board described in this application note. The BTS6302U mounted on the evaluation board in the customer evaluation kit is industrially tested on the most important RF parameters. Like Gain, Noise Figure, $IP3_o$, and $P_{L(1dB)}$.

All connection names are clearly displayed on the board. See Figure 1.

***Note:*** *Because of the standard layout, the board is used for different products. Not all connections are used, like $V_{ULP}$.*

## 5.1 Typical results

For detailed performance of the BTS6302U, we refer to the device product data sheet.

**Table 3. Typical results**

*f = 3.5 GHz; $V_{CC}$ = 5 V; $V_{EN}$ = 1.8 V; $T_{amb}$ = 25 °C; input 100 Ω, and output 50 Ω; unless otherwise specified. Values under Min/Max in boldface font are guaranteed via test; Values in lightface font are based on simulation or characterization.*

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| $I_{CC}$ | supply current | ON state, $P_o$ = 15 dBm | - | 98 | **120** | mA |
| | | ON state, quiescent | - | 68 | **88** | mA |
| | | OFF state | - | 1 | 1.5 | mA |
| $G_p$ | power gain | ON state, $t_{amb}$ = -40 °C to 115 °C [1] | | | | |
| | | f = 2.6 GHz | 35.7 | 38 | 40.6 | dB |
| | | f = 3.5 GHz | 35.8 | 38 | 40.8 | dB |
| | | f = 4.2 GHz | 33.8 | 36 | 38.6 | dB |
| | | OFF state | - | -60 | -45 | dB |
| $P_{L(1dB)}$ | output power at1 dB gain compression | f = 2.6 GHz | 27.8 | 28.1 | - | dBm |
| | | f = 3.5 GHz | 27.3 | 27.6 | - | dBm |
| | | f = 4.2 GHz | 26 | 26.3 | - | dBm |
| $IP3_o$ | output third-order intercept point | 2-tone; tone spacing = 100 MHz; $P_o$ = 15 dBm | 27 | 33 | - | dBm |

[1] These values are guaranteed via final test at $t_{amb}$

## 5.2 S-parameters

The measured S-parameters and Rollett stability factor K, are given in the graphs below. For the measurements, a typical BTS6302U EVB is used. All the S-parameter measurements have been carried out using the setup Figure 20.

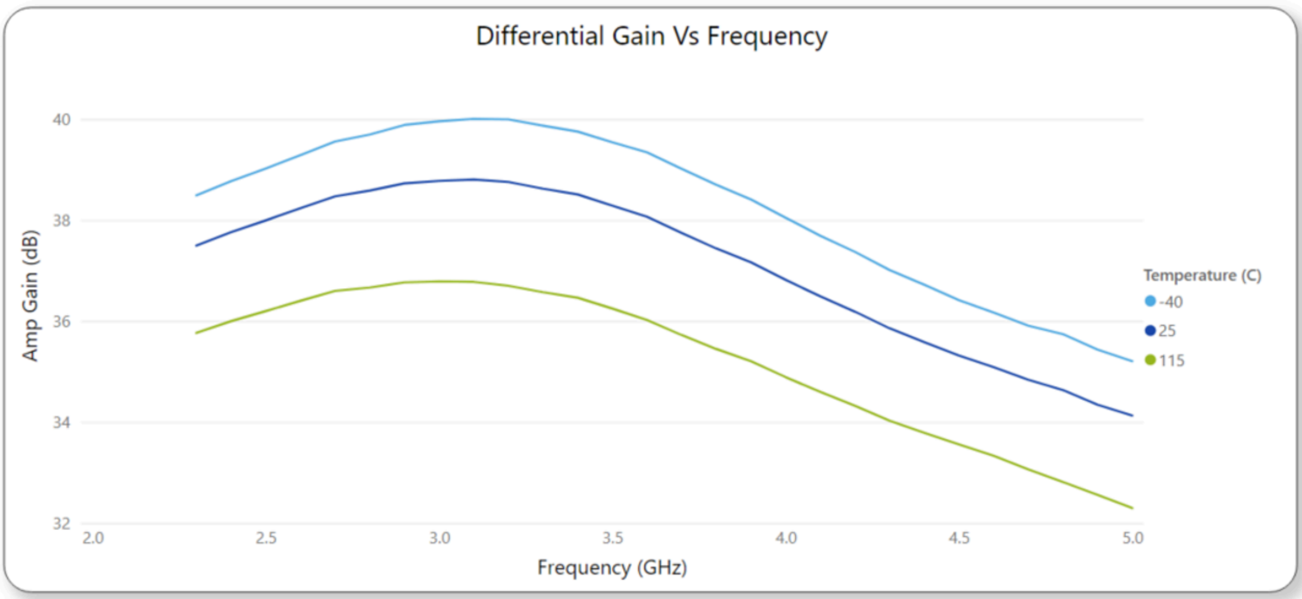



**Figure 7. BTS6302U differential gain (typical values). $V_{CC}$ = 5 V, Pi = -25 dBm**

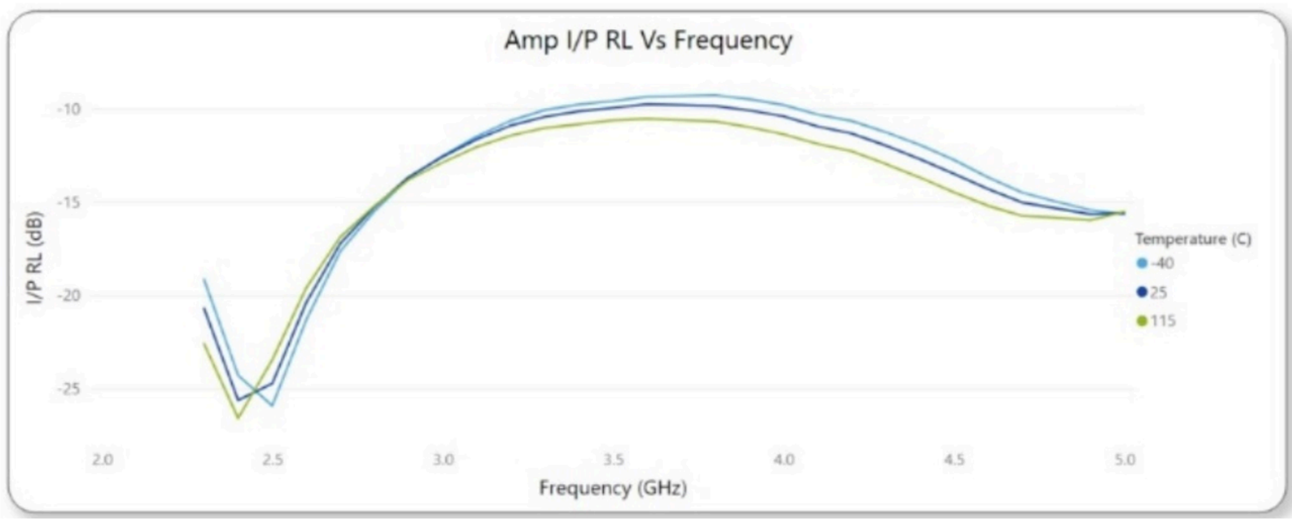



**Figure 8. BTS6302U differential RLi (typical values). $V_{CC}$ = 5 V, Pi = -25 dBm**

## 5.2 S-parameters...*continued*

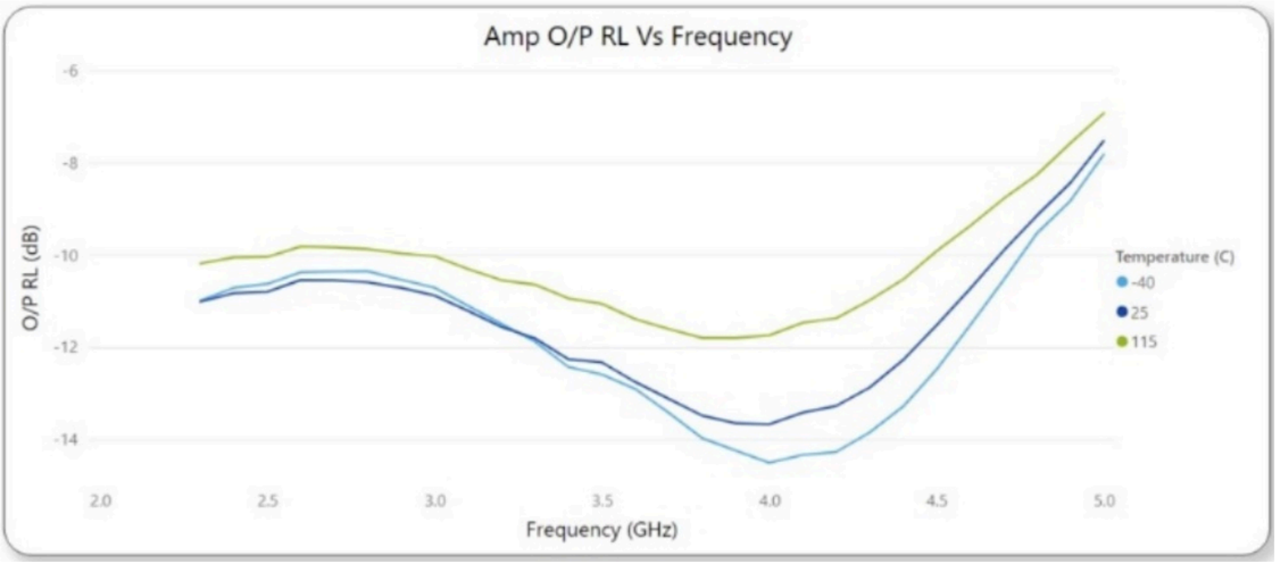



**Figure 9. BTS6302U $RL_o$ (typical values). $V_{CC}$ = 5 V, $P_i$ = -25 dBm**

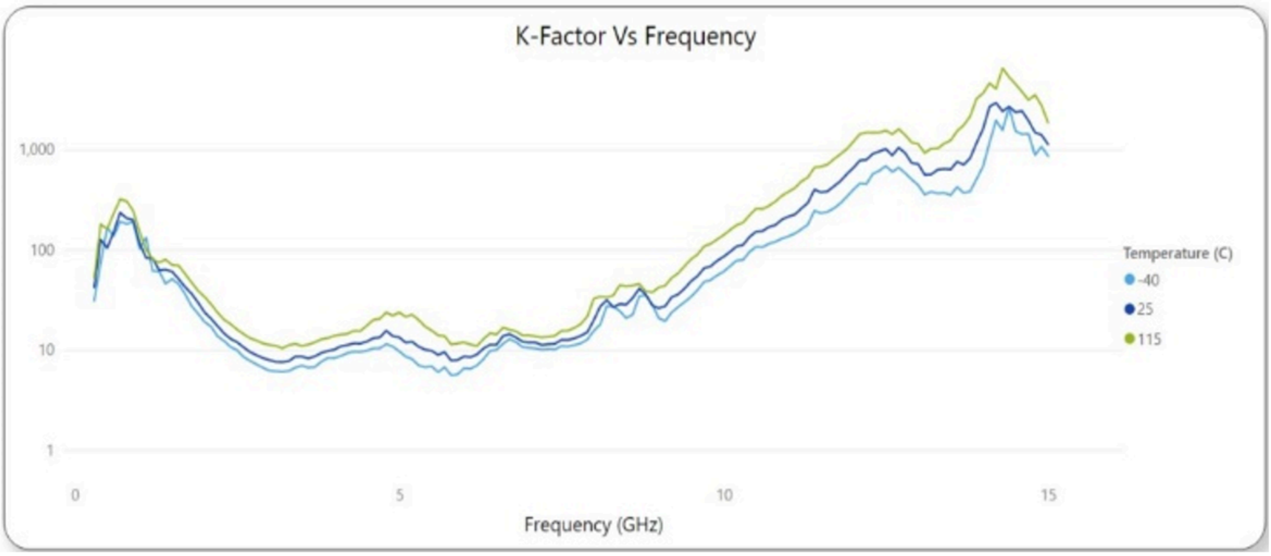



**Figure 10. BTS6302U K-factor (typical values). $V_{CC}$ = 5 V, $P_i$ = -25 dBm**

## 5.3 P-out, and Gain versus P-in

The $P_o$ and Gain are measured versus $P_i$ using the setup shown in Figure 20.

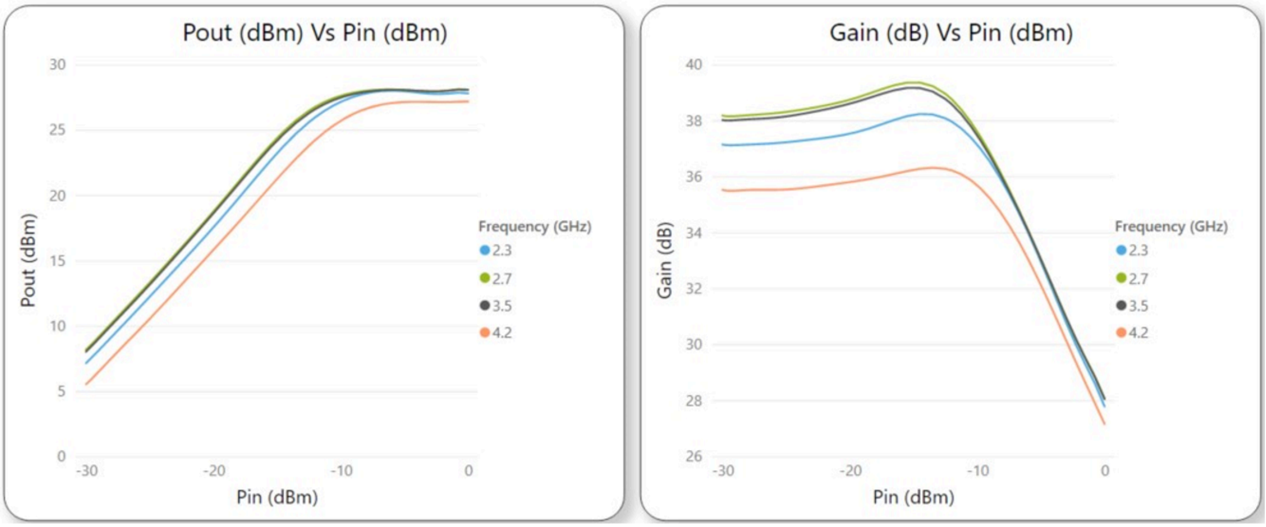



**Figure 11. Pout, and Gain versus input power (typical values). $V_{CC}$ = 5 V**

## 5.4 Noise Figure

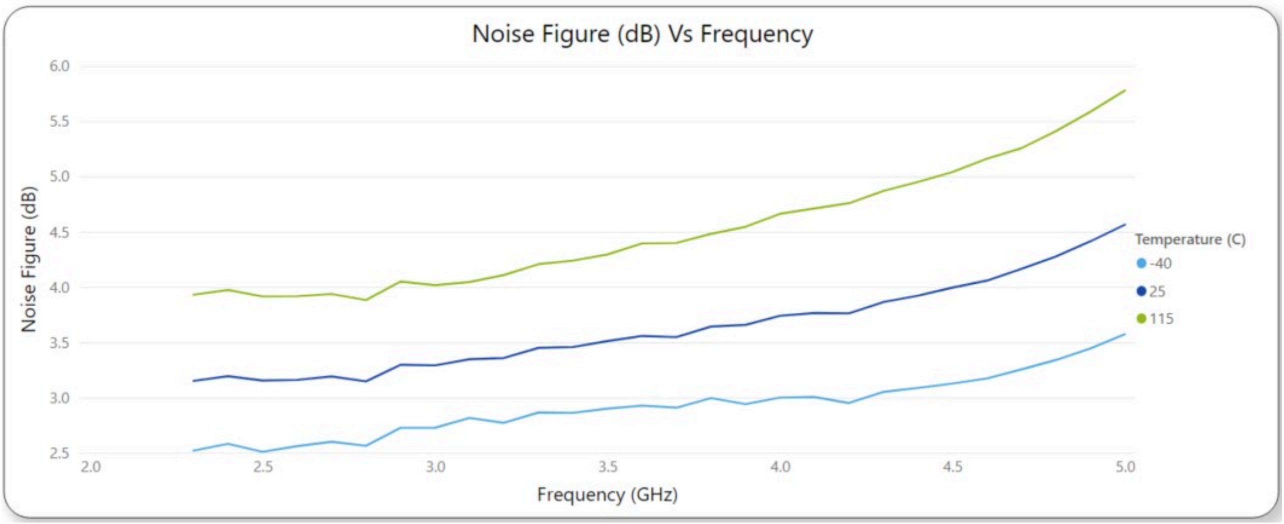



**Figure 12. BTS6302U Noise Figure vs Frequency (typical values). $V_{CC}$ = 5 V**

## 5.5 Saturated output power

The saturated output power is measured using the setup shown in Figure 21.

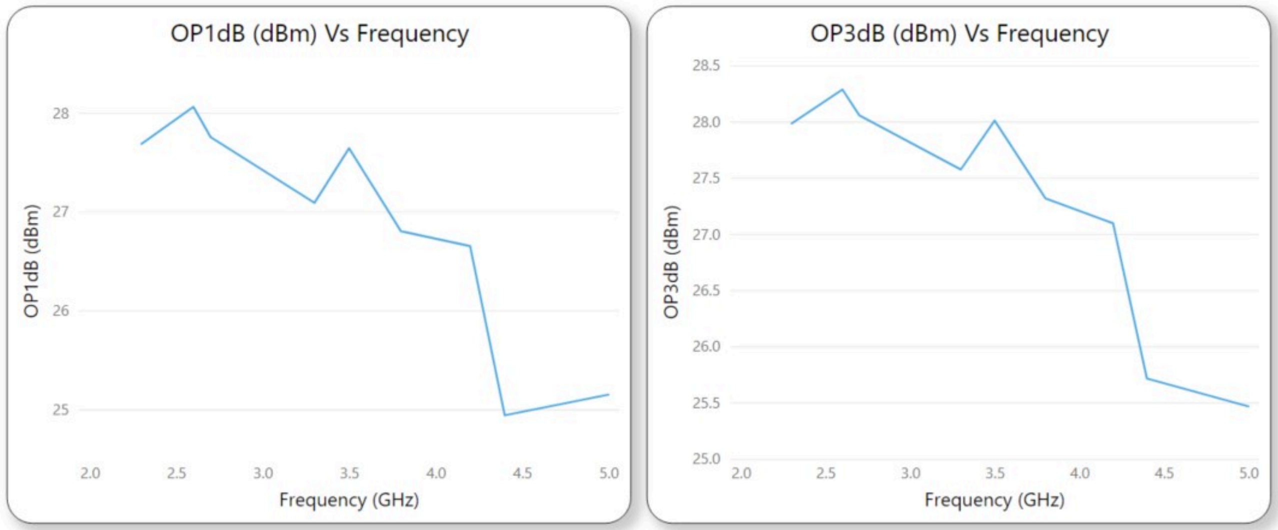



**Figure 13. BTS6302U $P_{o(1dB)}$, and $P_{o(3dB)}$ versus Frequency (typical values). $V_{CC}$ = 5 V**

## 5.6 Third order intercept point

$IP3_o$is measured using a setup shown in Figure 21.

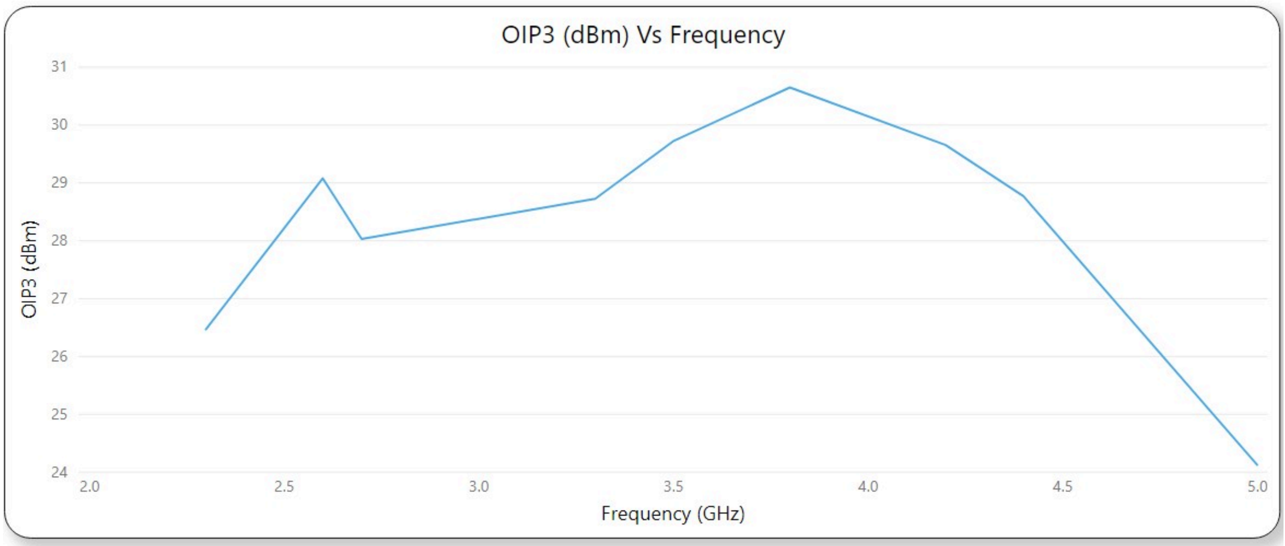



**Figure 14. BTS6302U $IP3_o$ at 100 MHz spacing output tone power 15 dBm**

## 5.7 ACLR under DPD

In the TX line ups for mMIMO, Digital Pre-Distortion (DPD) is applied to linearize the final stages. So efficiency, and linearity-related parameters such as EVM are improved, after DPD is executed.

To what extend the BTS6302U must be predistorted depends on factors like, applied output power, and crest factor at the BTS6302U. As an example, the BTS6302U is measured on ALCR at given Pout with and without applying DPD to note the differences.

The DPD engine applied, is from the FSW of Rohde & Schwarz, option K18D. The applied method is Memory Polynomial, and the coefficients derived from this option are listed in table below.

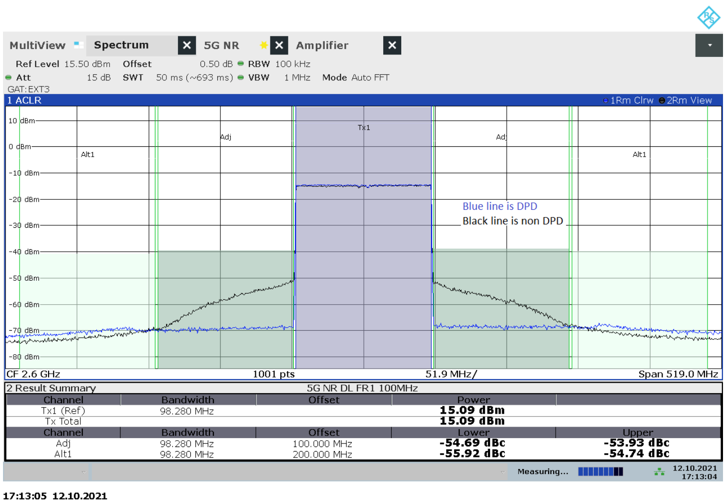



**Figure 15. BTS6302U ACLR DPD versus none-DPD at 2.6 GHz center frequency and $P_o$ = 15 dB, CF 11.7 dB**

MultiView | Spectrum | 5G NR | Amplifier

Ref Level 20.00 dBm | Capture Time 15 ms | TTS 1.099996 ms
Att 25 dB | Freq 2.6 GHz | Meas BW 298.28 MHz | SRate 372.85 MHz | I/Q Avg Count 3/5
TRG:EXT3 YIG Bypass

9 Memory DPD Coefficients

| Polynomial Order | Memory Order | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| 1 (Real) | 0.299972 | -1.3136 | 3.53104 | -2.67974 | 1.57722 | -0.410708 |
| 1 (Imag) | -0.0586761 | 0.139899 | -0.0671529 | -0.141021 | 0.184586 | -0.0855077 |
| 2 (Real) | -0.0087438 | 0.0288751 | 0.19598 | 0.0509433 | -0.0249672 | 0.0246781 |
| 2 (Imag) | -0.0135121 | 0.012211 | 0.109528 | 0.0138478 | -0.0115462 | 0.00937388 |
| 3 (Real) | -0.0426053 | 0.0841948 | -0.782948 | -0.465861 | 0.0999483 | -0.094921 |
| 3 (Imag) | 0.040575 | -0.0205658 | -0.352559 | -0.0738228 | 0.096887 | -0.04263 |
| 4 (Real) | 0.105656 | -0.167711 | 0.61376 | 0.706692 | -0.165811 | 0.150322 |
| 4 (Imag) | -0.0500464 | 0.0122209 | 0.460484 | 0.0994052 | -0.133206 | 0.045428 |
| 5 (Real) | -0.0703414 | 0.110114 | 1.47283e-5 | -0.330532 | 0.0623277 | -0.0687072 |
| 5 (Imag) | 0.0229834 | -0.00505706 | -0.209174 | -0.0468412 | 0.0645939 | -0.0149003 |

Memory Polynomial generated | Measuring... | 12.10.2021 17:17:28

17:17:28 12.10.2021

**Figure 16. BTS6302U memory polynomial DPD coefficients as applied for the DPD at 2.6 GHz**

## 5.7 ACLR under DPD...*continued*

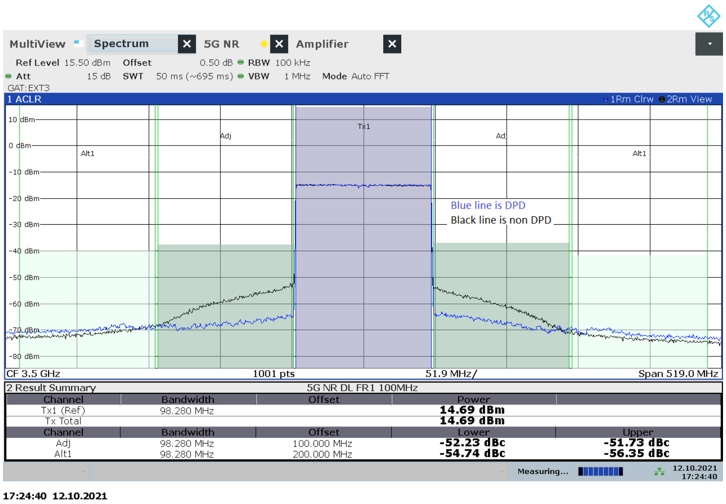
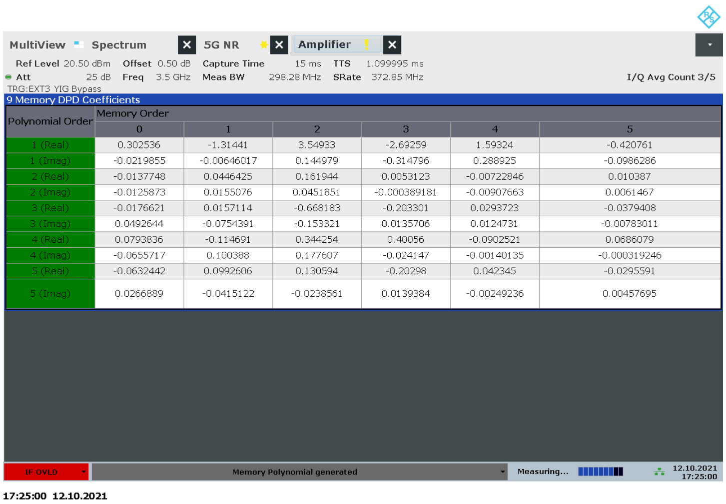



**Figure 17. BTS6302U ACLR DPD versus none-DPD at 3.5 GHz center frequency and $P_o$ = 15 dBm, CF 11.7 dB**




| Polynomial Order | Memory Order 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 (Real) | 0.302536 | -1.31441 | 3.54933 | -2.69259 | 1.59324 | -0.420761 |
| 1 (Imag) | -0.0219855 | -0.00646017 | 0.144979 | -0.314796 | 0.288925 | -0.0986286 |
| 2 (Real) | -0.0137748 | 0.0446425 | 0.161944 | 0.0053123 | -0.00722846 | 0.010387 |
| 2 (Imag) | -0.0125873 | 0.0155076 | 0.0451851 | -0.000389181 | -0.00907663 | 0.0061467 |
| 3 (Real) | -0.0176621 | 0.0157114 | -0.668183 | -0.203301 | 0.0293723 | -0.0379408 |
| 3 (Imag) | 0.0492644 | -0.0754391 | -0.153321 | 0.0135706 | 0.0124731 | -0.00783011 |
| 4 (Real) | 0.0793836 | -0.114691 | 0.344254 | 0.40056 | -0.0902521 | 0.0686079 |
| 4 (Imag) | -0.0655717 | 0.100388 | 0.177607 | -0.024147 | -0.00140135 | -0.000319246 |
| 5 (Real) | -0.0632442 | 0.0992606 | 0.130594 | -0.20298 | 0.042345 | -0.0295591 |
| 5 (Imag) | 0.0266889 | -0.0415122 | -0.0238561 | 0.0139384 | -0.00249236 | 0.00457695 |

**Figure 18. BTS6302U memory polynomial DPD coefficients as applied for the DPD at 3.5 GHz**

## 5.8 Required Equipment

For the BTS6302U evaluation, the following equipment is needed as a base-line:

- 1 DC power supply 5 V, 200 mA ($V_{CC1}$, and $V_{CC2}$)
- 1 DC power supply 1.8 V, 5 mA ($V_{EN}$), or a pulse generator in case pulsed measurements are required
- A suitable Balun like: Krytar model 4020080. See Figure 19
- A network analyzer for S-parameter, and $P_{1dB}$ measurements. In case the NA is a 4-port version, 2 ports can be defined as differential outputs, in this case a Balun is not required. When the 2 ports are defined as differential outputs S-parameters, and the differential mode-related parameters can be evaluated
- 2 RF generators up to 12 GHz plus a combiner for IP3 measurements
- A spectrum analyzer with NF option for IP3 and Noise figure measurements
- High Quality RF cables with SMA/3.5 mm RF connectors
- DC currents meters.


**Figure 19. Example of the Balun used for the different measurements**

$V_{CC1}$ and $V_{CC2}$ can be combined and fed to the 5 V PSU. After switching on the power supply, the BTS6302U comes up in the quiescent current. 1.8 $V_{EN}$ must be applied.

If necessary, to switch on the power supplies separately the preferable start-up sequence is as follows.

First switch on $V_{CC1}$ second $V_{CC2}$ and third $V_{EN}$.

***Note:*** *If you want to switch on $V_{CC1}$, and $V_{CC2}$ separately you need an extra 5 V, 200 mA power supply.*

The typical current at 5 V supply is 78 mA, in power down-mode $V_{EN}$(0 V), 0.5 mA.

## 5.9 Connection and setup

1. Connect the EVB to a calibrated network analyzer see Figure 20, we advise the following settings for S-parameter measurements:
   a. Port power -25 dBm
   b. IF Bandwidth 100 Hz
2. The network analyzer can also be used for the 1 dB gain compression evaluation, for this evaluation we advise the following NWA setting
   a. Port 1 power sweep -30 dBm up to -10 dBm
   b. Port 2 20 dB attenuation on the receiver port b2.
   c. IF Bandwidth 100 Hz.
3. Gain and $P_{1dB}$ gain compression data can also be determined using an RF generator and spectrum analyzer.
4. Turn on the DC power supplies and it should read typical $I_{cc}$ = ? mA.
5. Nonlinear distortion measurements IP3 can be performed with a set-up like is depicted in Figure 21. The following settings are recommended to perform the IP3 evaluation.
   a. -20 dBm for each fundamental tone.
   b. RBW and VBW of the spectrum analyzer 100 Hz
   c. Tone spacing 100 MHz

**Table 4. Evaluation measurement setups**

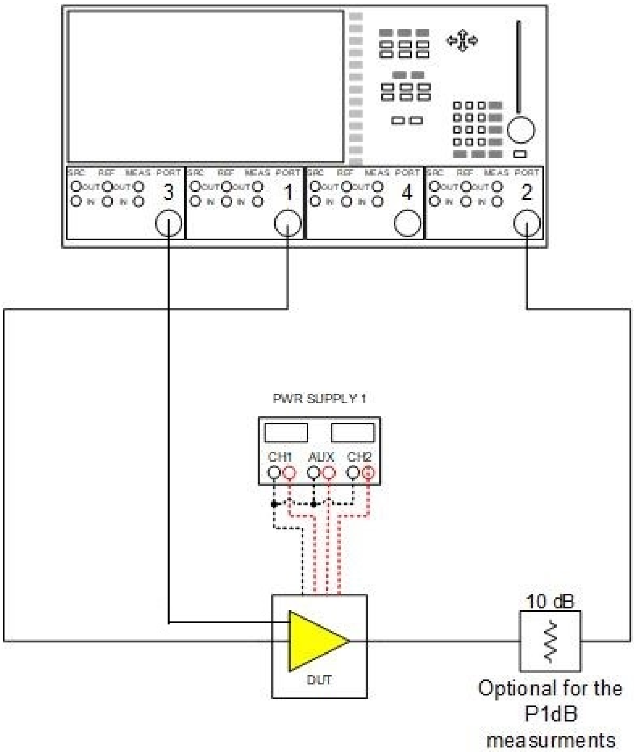



**Figure 20. S-parameter and $P_{1dB}$ gain compression setup**

**Table 4. Evaluation measurement setups***...continued*

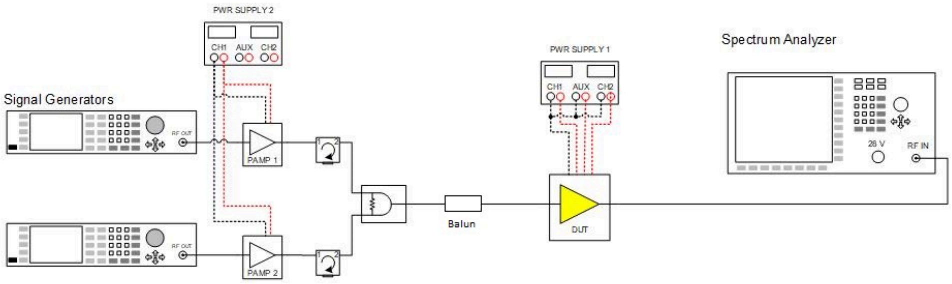



**Figure 21. Third order intercept point measurement setup**

## 6 EMC information

**CAUTION**

This product has not undergone formal EMC assessment. It is the responsibility of the user to ensure that any finished assembly complies with applicable regulations on EMC interference. EMC testing, and other testing requirements for CE is the responsibility of the user.

## 7 Revision history

**Table 5. Revision history**

| Document ID | Release date | Description |
|---|---|---|
| AN13420 Rev. 2.1 | 12 April 2024 | • Updated Legal information and brought to current standard |
| AN13420 Rev. 2 | 1 December 2022 | • Added EMC information |
| AN13420 Rev. 1 | 2 November 2021 | • Initial release of application note |

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**Date of release: 15 April 2024**
**Document identifier: AN13420**