

Anaren 0404 BD2425NnRF balun optimized for Nordic Semiconductors nRF24L01 and nRF24L01+ Transceivers

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Introduction

With the drive for miniaturization and integration intensifying in recent years, the challenges concerning the trade offs between small form-factors, repeatability, cost and time to market have continued to drive innovation. More recently we have seen an adoption of wireless technologies in non-traditional applications where the OEM has limited experience in Wireless and RF technology especially in high volume applications. These designs must be optimized to deliver consistent performance with the lowest possible bill of material cost. The total cost not only depends on the number and the types of components in the BOM, but also on the size of the PCB and mechanical enclosure.

Anaren has been focused on developing products and developing solutions that address the trade off's between: minimum real estate whilst maintaining repeatability, cost and time to market. This objective is achieved through the integration of 100% RF tested components.

The following application note demonstrates these objectives clearly as we present a small and simple balun solution optimized for use with Nordic Semiconductors' nRF24L01 and nRF24L01+ chip. The nRF24L01 is a true single-chip 2.4 GHz Proprietary Ultra Low Power compliant RF transceiver chip, designed for low-power wireless applications. The reference design presented in this application note uses only two components for the impedance matching: a 1mm² Anaren multilayer balun and an inductor for final impedance matching. This implementation results in, a design minimizing PCB real-estate and performs according to the specifications stated in the Nordic Semiconductor nRF24L01 and nRF24L01+ data sheet's.

The nRF24L01 is a low-cost, highly integrated solution for robust wireless communication in the 2.4 GHz unlicensed ISM band,. nRF24L01 is designed to be compliant with SRD

regulations covered by ETSI EN 300 328 and EN 300 440 class 2 (Europe), FCC CFR47 Part 15 (US) and ARIB STD-T66 (Japan). The nRF24L01 provides extensive hardware support for packet handling, data buffering, burst transmissions, data encryption, data authentication, clear channel assessment, link quality indication and packet timing information, whereas the nRF24L01+ is a drop-in compatible device for the nRF24L01 but demonstrates improved wideband blocking at 2Mbps, improved RX front-end AGC, integrated receive power detector (-64dB threshold) and 250 kbps air data rate compatibility which is a 3x range improvement vs 1Mbps supported by the nRF24L01 with no significant penalty in current consumption.

For more information about this or any other products currently available in the Anaren product portfolio, please visit our website at www.anaren.com for datasheets, S parameters and general corporate information.

For more information on Proprietary Ultra Low Power Wireless products from Nordic Semiconductors please visit www.nordicsemi.com for product information.

Descriptions of Balanced Matching Networks

Nordic Semiconductor Single Ended Matching Network

The nRF24L01 and nRF24L01+ chips have a balanced RF output at pins ANT1 and ANT2 which is connected directly to the RF receiver and the RF transmitter. Nordic Semiconductor provided a single ended matching network in the product specification for the nRF24L01 (see Figure 1, Figure 2 and Figure 3), one with a printed monopole antenna and one with an SMA connector.

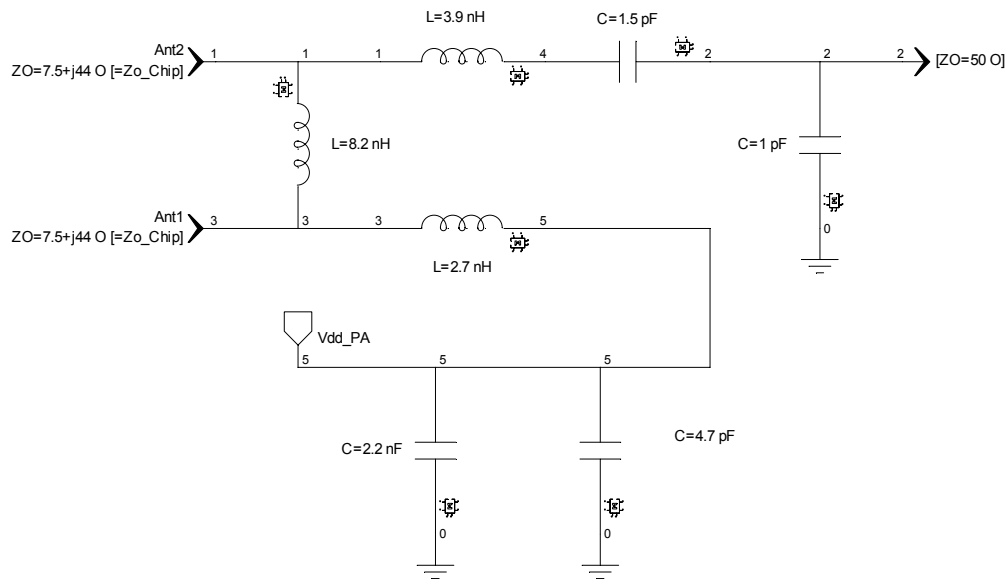


Figure 1: Nordic Semiconductors matching network schematic

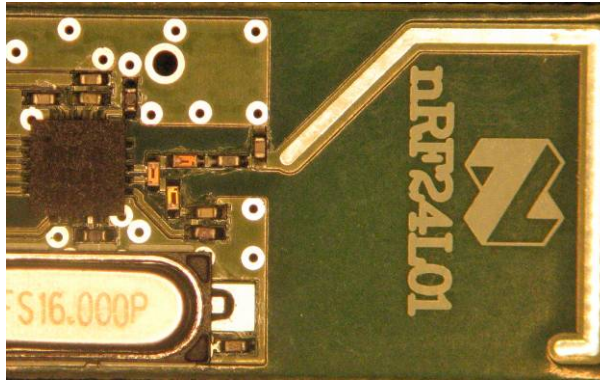


Figure 2: Nordic Evaluation Board with Microstrip Antenna

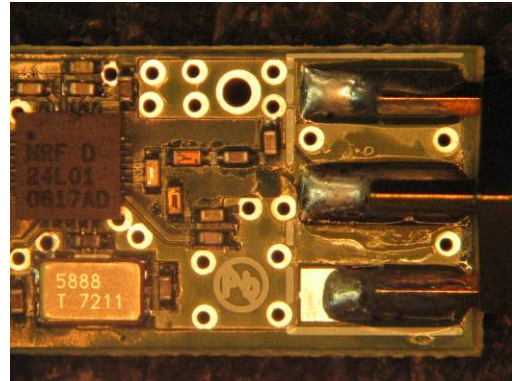


Figure 3: Nordic Evaluation Board with SMA Connector

Anaren Balun Matching Network

The Anaren solution includes an Anaren 0404 multilayer balun transformer with a chip inductor in series from the single ended port (pin 2) of the balun as shown in Figure 4. The power amplifiers are biased through the ac ground pin (pin 1) of the balun. The chip capacitors, C3 and C4, are included with the Anaren balun matching design to bias the power amplifier while providing adequate RF ground. Two designs were created the first based around 0402 inductor and capacitors, the second using an 0201 inductor and capacitors, as shown in a CAD drawing in Figure 5 and Figure 7. Images of the daughterboards are shown in Figure 6 and Figure 8.

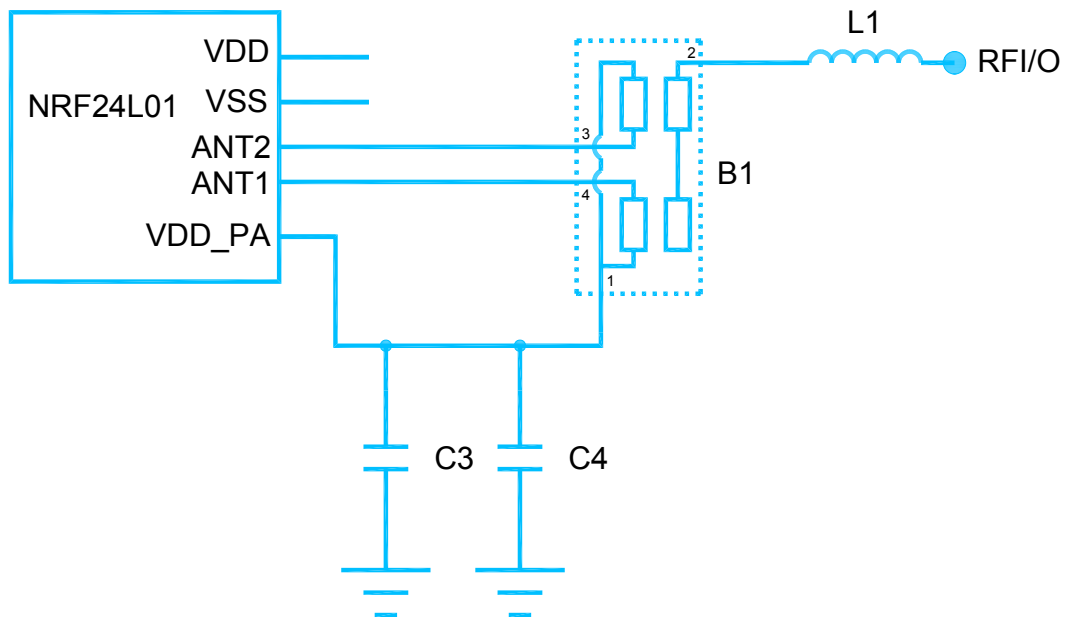


Figure 4: Anaren Solution Schematic

0402 Solution

The CAD layout, picture and bill of materials for the Anaren solution using an Anaren 0404 Balun combined with 0402 matching components and an SMA connectorized output are shown below.

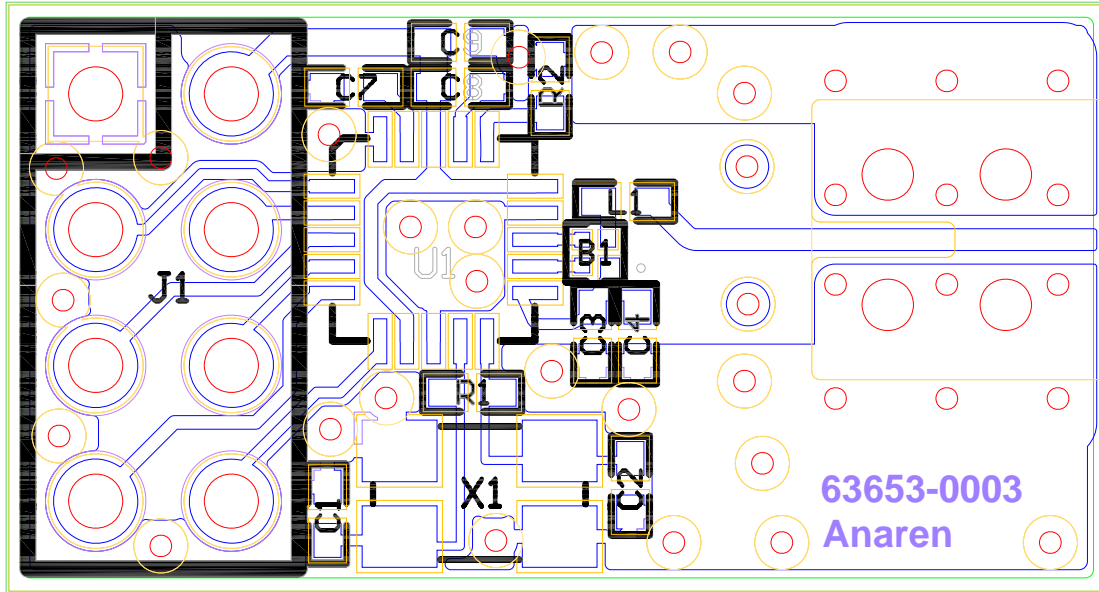


Figure 5: Anaren Solution with 0402 Matching Network Layout



Figure 6: Anaren Solution with 0402 Matching Network

Table 1: 0402 Solution Bill of Materials

Des.	Description	Value	Manufacturer
B1	BD2425NnRF05		Anaren
C1	0402, NPO, <u>+2%</u> , 50 V	22 pF	Johanson
C2	0402, NPO, <u>+2%</u> , 50 V	22 pF	Johanson
C3	0402, X7R, <u>+10%</u> , 50V	2.2 nF	Johanson
C4	0402, NPO, <u>+0.25 pF</u> , 50V	4.7 pF	Johanson
C7	0402, X7R, <u>+10%</u> , 50V	33 nF	Murata
C8	0402, X7R, <u>+10%</u> , 50V	1 nF	Johanson
C9	0402, X7R, <u>+10%</u> , 50V	10 nF	Johanson
J1	TSW-120-26-L-D		Samtec
L1	MLK Series <u>+5%</u>	3.9 nH	TDK
R1	0402, <u>+10%</u>	1M	Vishay
R2	0402, <u>+ 1%</u>	22k	Vishay
U1	nRF24L01/nRF24L01+		Nordic Semiconductor
X1	<u>+60 ppm</u> , CI = 12 pF		RF Digital

0201 Solution

The CAD layout, picture and bill of materials for the Anaren solution with the Anaren 0404 balun and 0201 matching components are shown below.

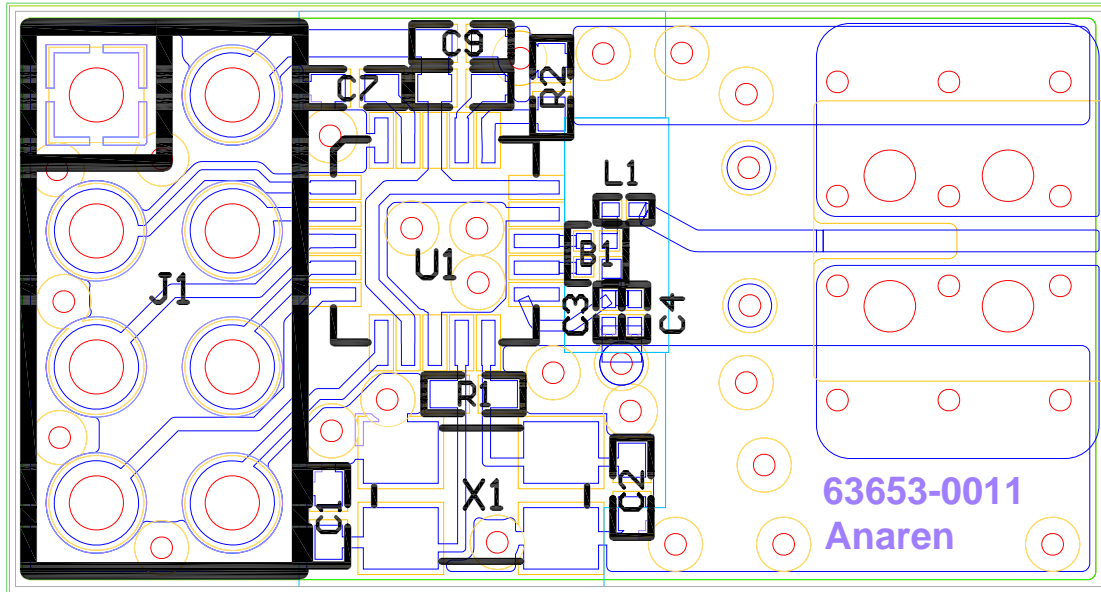


Figure 7: Anaren Solution with 0201 Components Layout

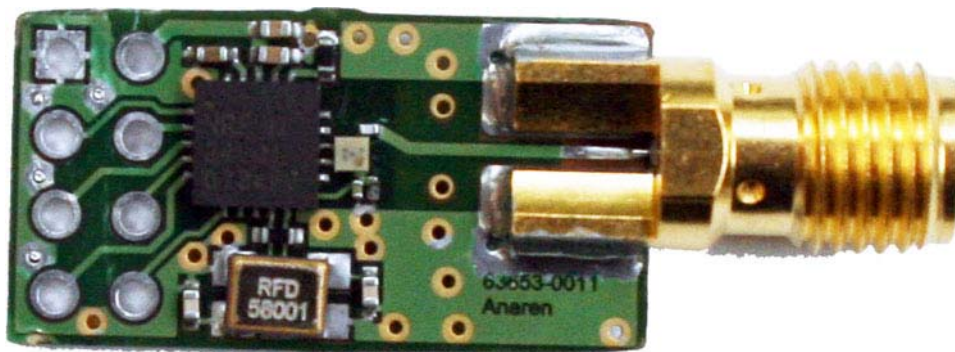


Figure 8: Anaren Solution with 0201 Components

Table 2: 0201 solution bill of materials

Des.	Description	Value	Manufacturer
B1	BD2425NnRF05		Anaren
C1	0402, NPO, +2%, 50 V	22 pF	Johanson
C2	0402, NPO, +2%, 50 V	22 pF	Johanson
C3	0201, X7R, +10%, 50V	2.2 nF	AVX
C4	0201, NPO, +0.25 pF, 50V	4.7 pF	AVX
C7	0402, X7R, +10%, 50V	33 nF	Johanson
C8	0402, X7R, +10%, 50V	1 nF	Johanson
C9	0402, X7R, +10%, 50V	10 nF	Johanson
J1	TSW-120-26-L-D		Samtec
L1	0201 MLK Series +5%	3.9 nH	TDK
R1	0402, +10%	1M	Vishay
R2	0402, + 1%	22k	Vishay
U1	nRF24L01/nRF24L01+		Nordic Semiconductor
X1	+60 ppm, CI = 12 pF		RF Digital

A comparison to the current PCB layout and the two recommended Anaren solutions are shown in Table 3. The reduction from the Nordic seven component solution, three inductors, four capacitors (a), to the four component Anaren solutions, (b) and (c), one balun, one inductor and two capacitors are shown in Figure 9. The Anaren 0402 and 0201 reduces the PCB real estate by 46% and 77% respectively, as illustrated by the black outline of each matching network in Figure 9.

Comparison of PWB Layouts

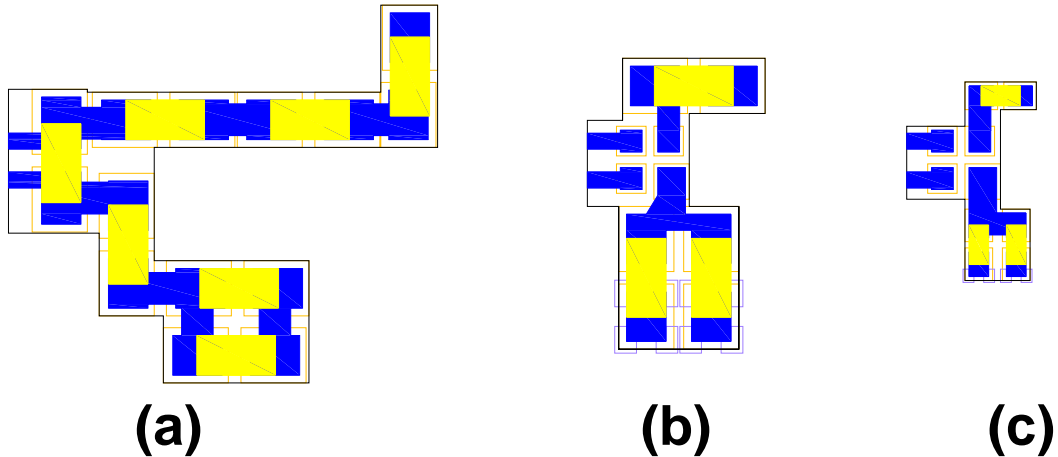


Figure 9: Size Comparison Nordic Semiconductor (a), Anaren w/ 0402 (b), Anaren w/ 0201 (c)

Performance Verification

The Nordic and Anaren solutions were measured for performance as follows

- Transmit Power
- Harmonic suppression
- Receive sensitivity
- LO Leakage

In addition the matching network is measured to establish the impedance.

Transmit Power

The output power measured at the fundamental frequency in transmit mode for both the 0402 design and the 0201 design versus frequency and shown in dBm.

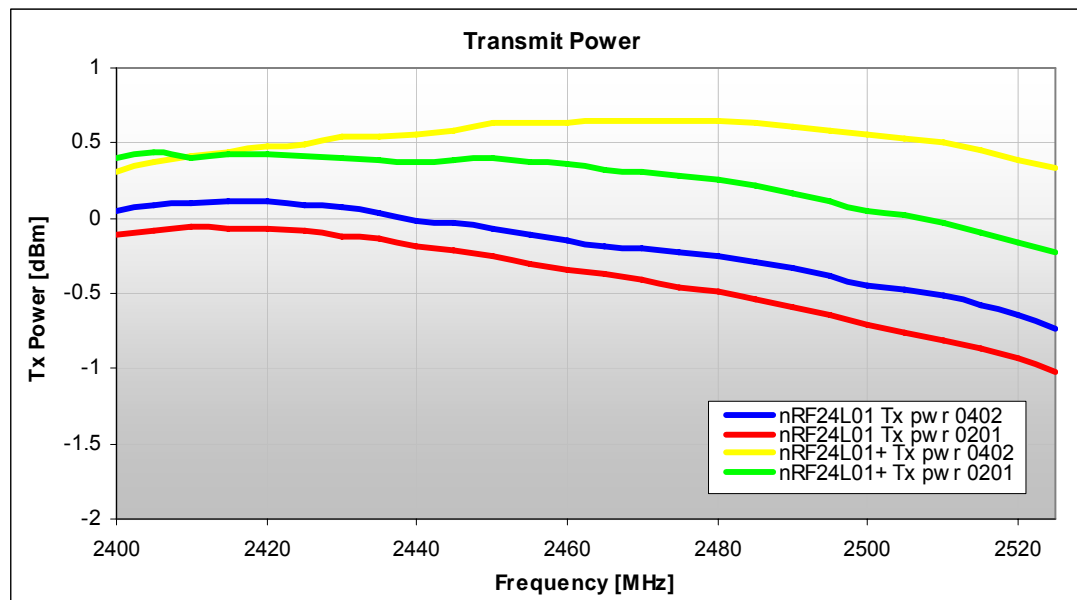


Figure 10: Transmit power as a function of transmit frequency for nRF24L01 chip, 0402 solution (blue) and 0201 solution (red) and nRF24L01+ chip, 0402 solution (yellow) and 0201 solution (green)

Harmonic Rejection

The level of signal present at the harmonic frequencies of the transmit frequency is measured and presented relative to the transmitted power (dBc).

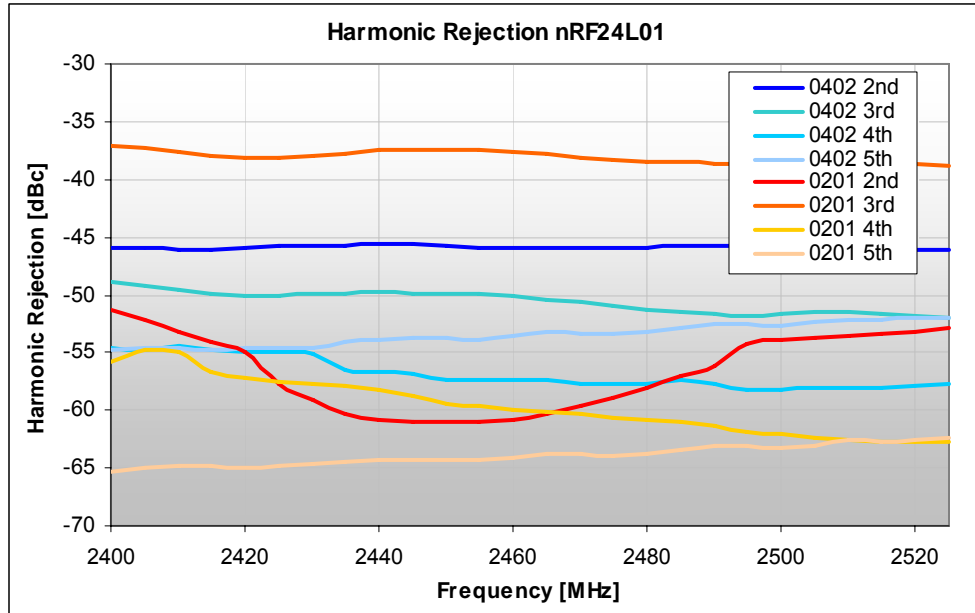


Figure 11: Harmonic rejection as a function of fundamental transmit frequency for nRF24L01 chip, 0402 solution (blue colors) and 0201 solution (reddish colors)

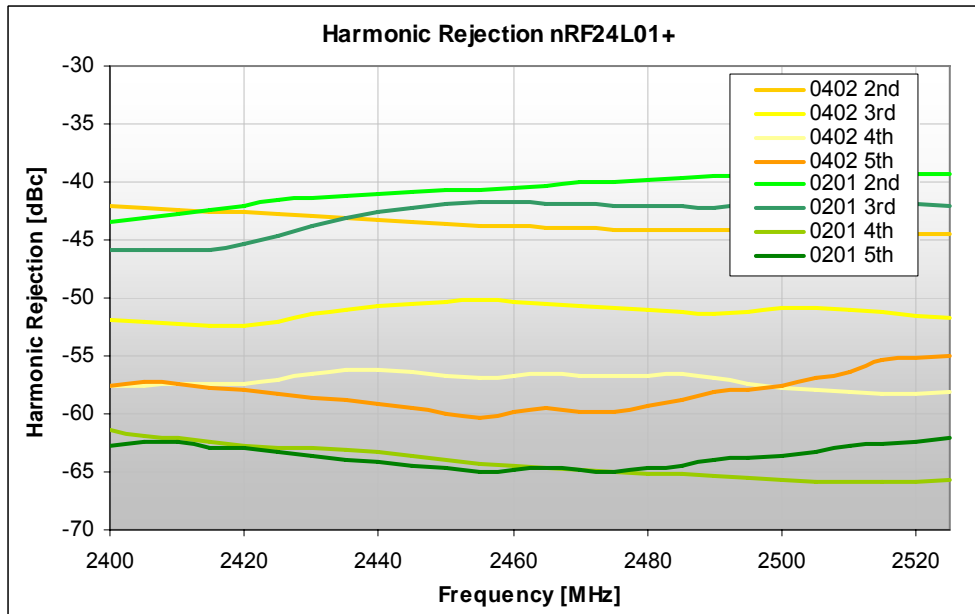


Figure 12: Harmonic rejection as a function of fundamental transmit frequency for nRF24L01+ chip, 0402 solution (yellowish colors) and 0201 solution (greenish colors)

Receive Sensitivity

The receive sensitivity performance was determined by the amount of attenuation required to reach a threshold of 50% byte error rate or 50% packet error rate. The receive sensitivity performance for the Anaren 0402 and Anaren 0201 solutions shown in Figure 13. This

measurement was done with the Nordic RF evaluation board as the transmitter and the Anaren solutions as receivers.

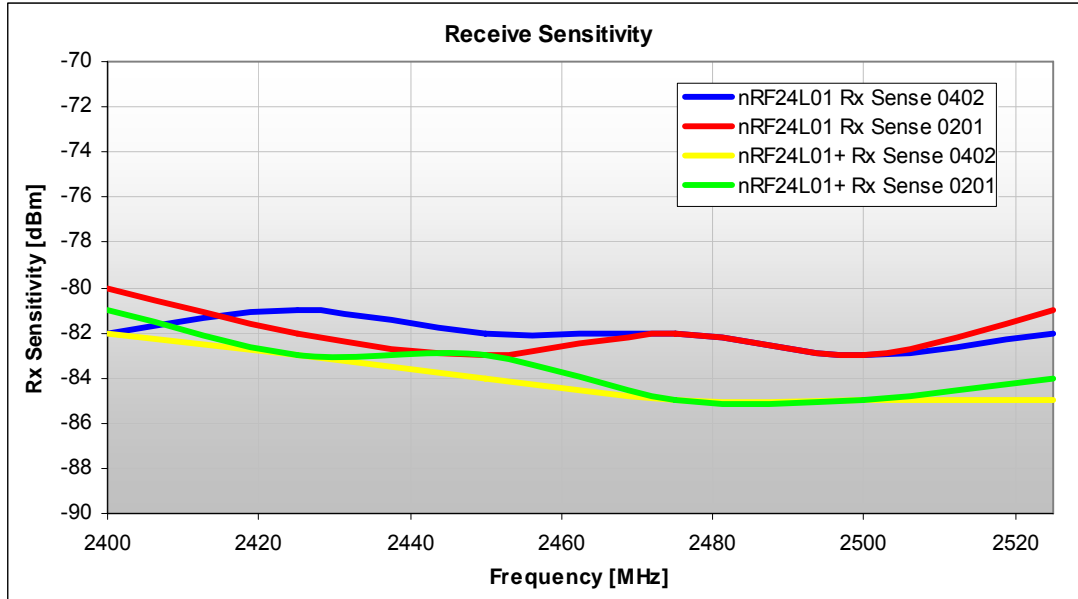
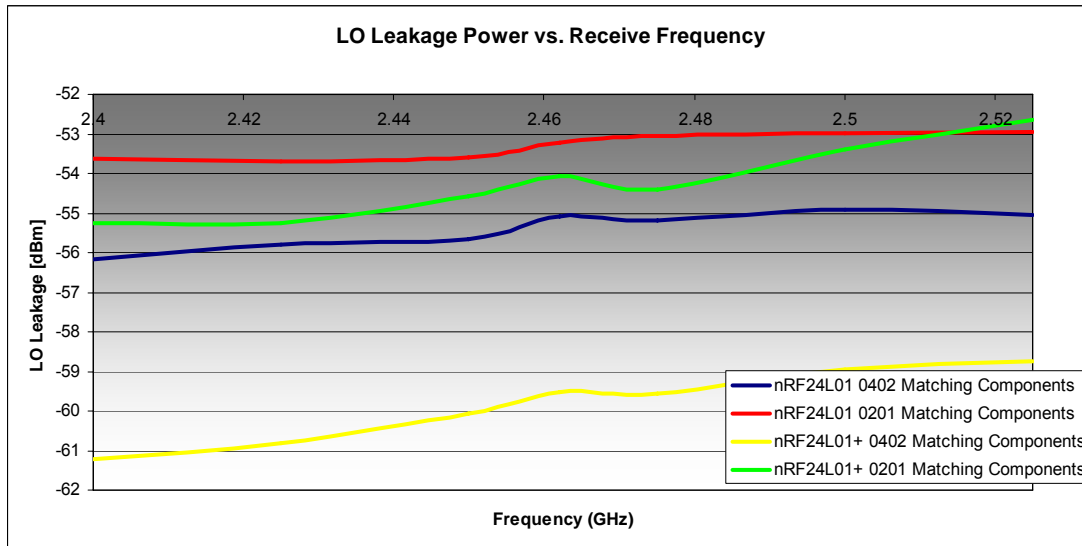


Figure 13: Receive sensitivity as a function of communication frequency for nRF24L01 0402 solution (blue) and 0201 solution (red),

LO Leakage

The LO leakage is measured by placing the module in receive and measuring the power seen from the module at the receive power.



Over Temperature Performance

The Anaren solution was tested over temperature to ensure stability. The transmit and harmonic component measurements are repeated at -40 °C, 23 °C and 85 °C, for the 0402 component solution. As expected, the loss increases with increased temperature, but there is

no detuning of the matching circuitry.

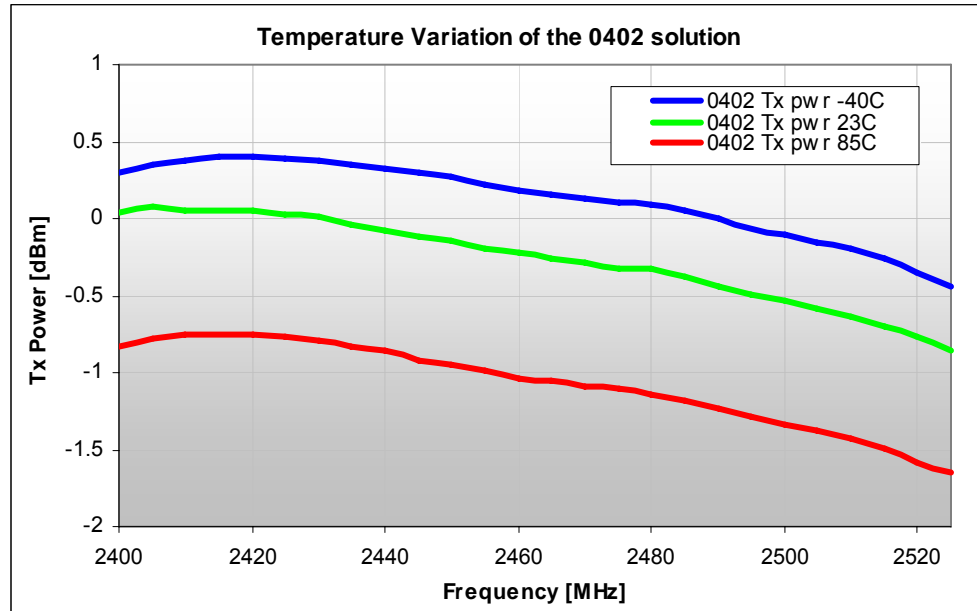


Figure 14: Temperature variation of the nRF24L01 0402 solution

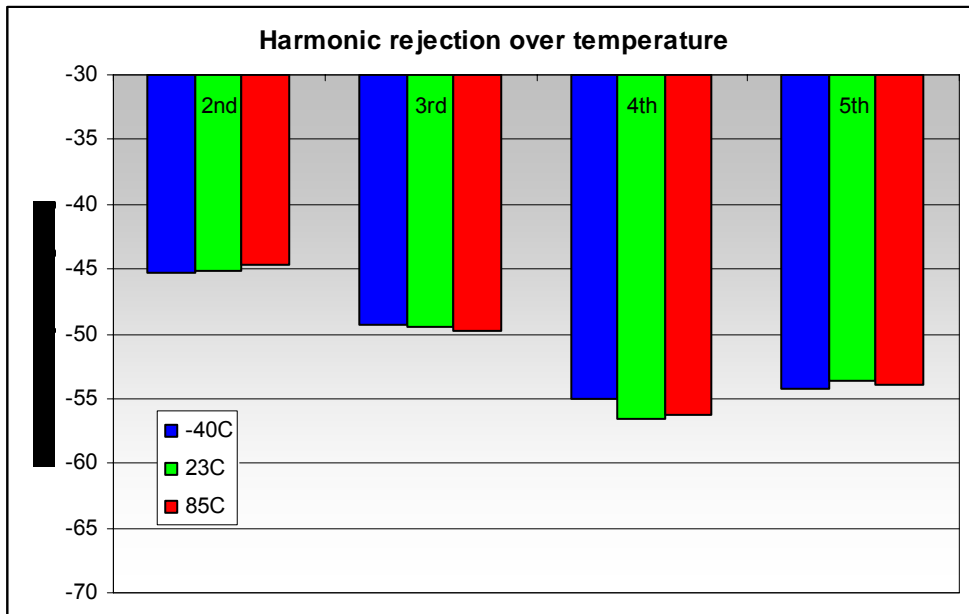


Figure 15: Harmonic rejection (averaged over frequency) versus temperature

Load Impedance

To verify the Anaren solution matches the $15 + j88 \Omega$ chip impedance the three port test board was measured and the results are compared to the Nordic RF solution. The results are plotted on the Smith chart to see the impedance presented to the chip.

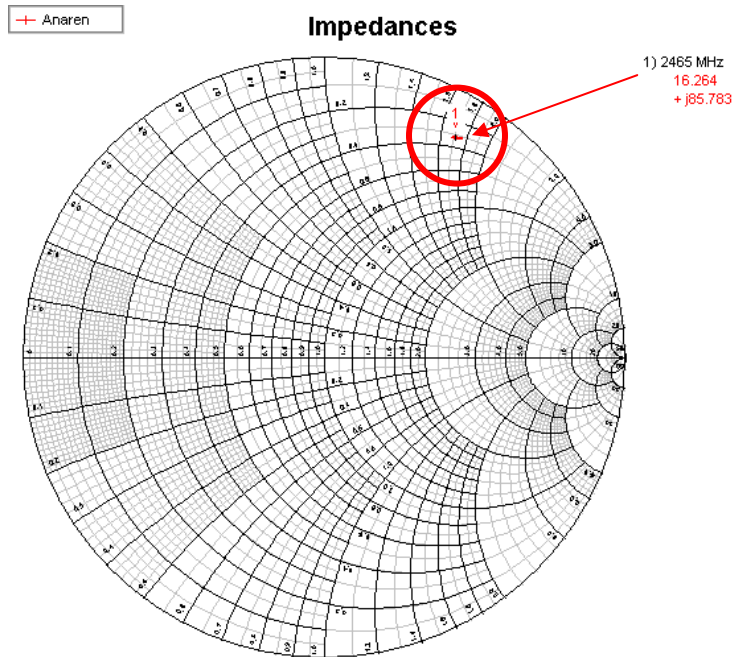


Figure 16: Load Impedance of the 0402 Solution

Performance Summary

The Anaren 0402 and 0201 solutions using the BD2425NnRF balun perform similar to the Nordic Semiconductor lumped element design in all aspects.

Size Comparison

The Anaren balun solutions offer significant savings in both size and number of components. In terms of square area occupied by the matching components alone the Anaren solution offers a savings of approximately 47% of the board space for the 0402 matching components and approximately 77% for the 0201 matching components. In terms of distance from the chip the Anaren 0402 and 0201 solutions are approximately 59% and 70% closer to the chip than the current reference design.

Table 3: Layout Size Comparison

	Nordic Semiconductor	Anaren 0402	Anaren 0201
Number of Components	4 Capacitors, 3 inductors	1 Anaren 0404 Balun, 1 Inductor, 2 Capacitors	1 Anaren 0404 Balun, 1 Inductor, 2 Capacitors
Area Occupied	0.0165 in ² (10.65 mm ²)	0.0088 in ² (5.68 mm ²)	0.0037 in ² (2.39 mm ²)
Distance from chip	0.2177 in (5.53 mm)	0.0902 in (2.29 mm)	0.0658 in (1.67 mm)

Design Optimization

Although the optimum design is application specific, some applications may call for the cheapest implementation possible, others may have physical constraints and some may need the longest range or lowest battery power consumption.

The Anaren solution addresses most of these concerns, but there are still a few things to consider when implementing the Anaren matching solution, as with any implementation.

Component Placement

Although the Anaren matching solution is very compact it may still be required to move components around a little to fit a specific form factor. The following is a guideline to what can be done safely and where to be cautious.

- The distance between the 'Ant' pins of the nRF24L01 (U1) and the BD2425NnRF (B1) balun is critical and should not be changed.
- The RF shunting capacitor C4 is critical for harmonic suppression and it is critical to have it located as close to the BD2425NnRF balun as possible and to have a good and equally close GND via connection to the other end of C4.
- The DC-decoupling (bias voltage stabilizer) C3 on the other hand is not critical to the RF match and can be relocated harmlessly.
- The inductor (L1) in series with the Anaren balun should be kept close to the balun. However it can be moved some distance away if a high impedance (inductive) transmission line is used. The value of the inductor should then be compensated for this added inductance.
- When connecting the matching network to a connector or antenna, the connecting line should either be 50Ω, in which case no compensation has to be done, or it can be inductive in which case the series inductor (L1) should be compensated for this additional inductance.

Antenna matching

Any 50Ω antenna will match directly into Anaren's solution as it will with the Nordic Semiconductor reference design. When it is desired to use a short monopole antenna (<1/4 wavelength) then the inductor value can be increased some to compensate for the capacitive nature of the antenna. However, short monopoles are only useful for very short range communication as the radiation efficiency decreases dramatically.

Vendor Component Variations

Due to manufacturing differences, inductors vary from one manufacturing vendor to another. These changes will impact the performance of the matching network and may require tuning the value of the inductor and/or additional components. To illustrate this the Anaren 0402 solution with a 3.9 nH TDK inductor was selected, the inductor was changed to show the effects of vendors components on the transmit power and harmonic components.

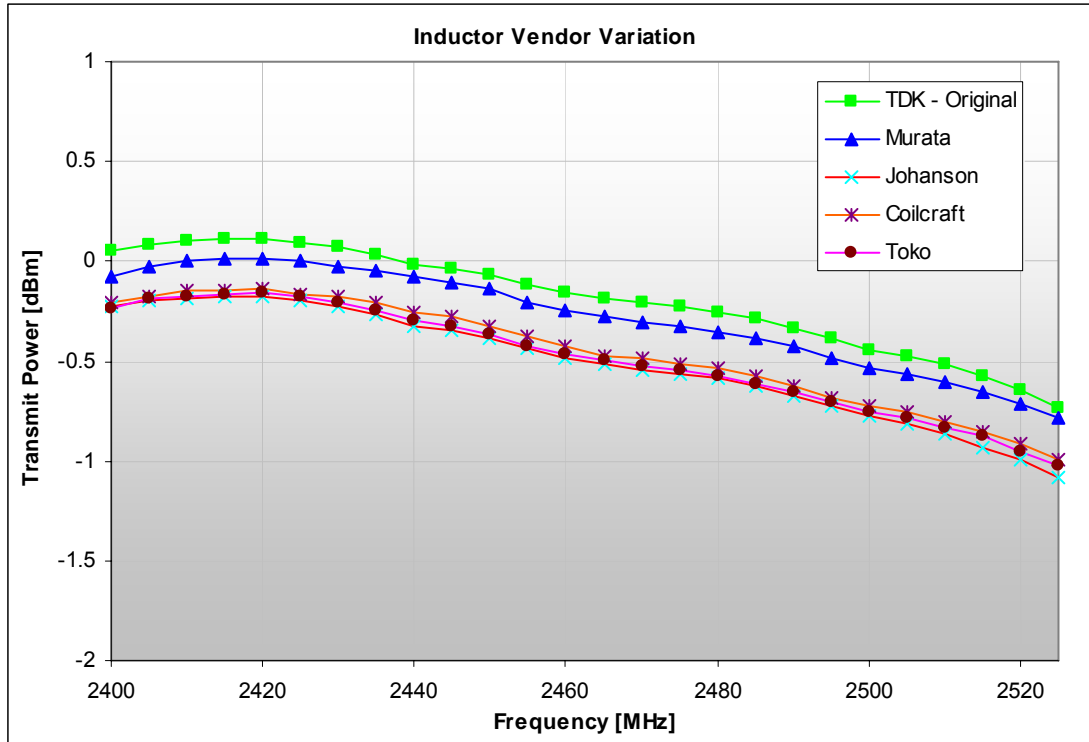


Figure 17: Transmit power variation with the L1 inductor vendor

Grounding Capacitor Value Variation

The performance of the Anaren balun is affected by changing the grounding capacitance value. Changing the capacitance may improve the common mode rejection ratio of the balun. The RF grounding capacitor, C4 is varied over a range of values to see the performance for both the 0402 designs (Figure 18 and Figure 19) as well as the 0201 designs.

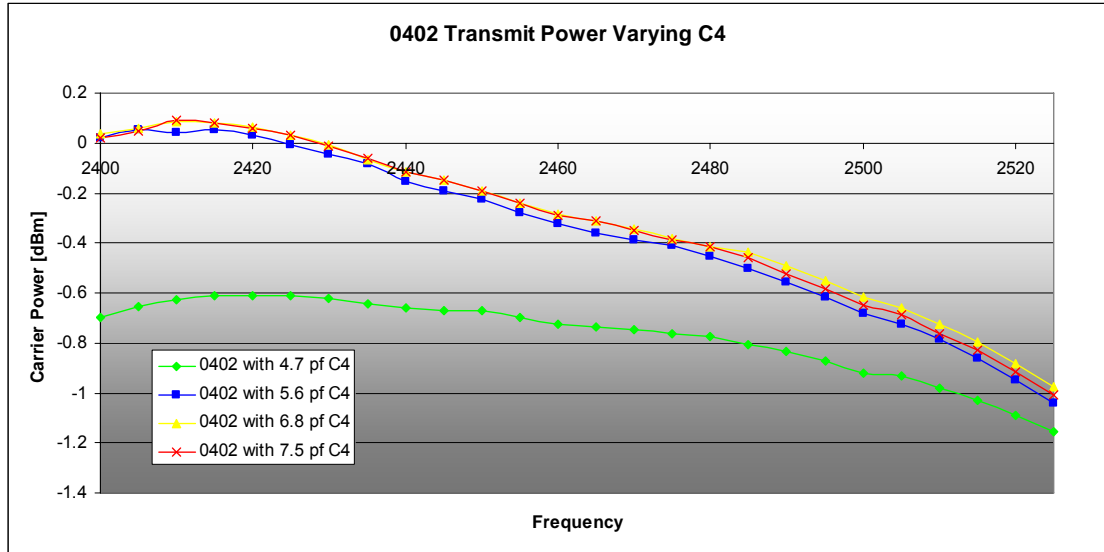


Figure 18: Transmit Power for Various Ground Capacitance Values

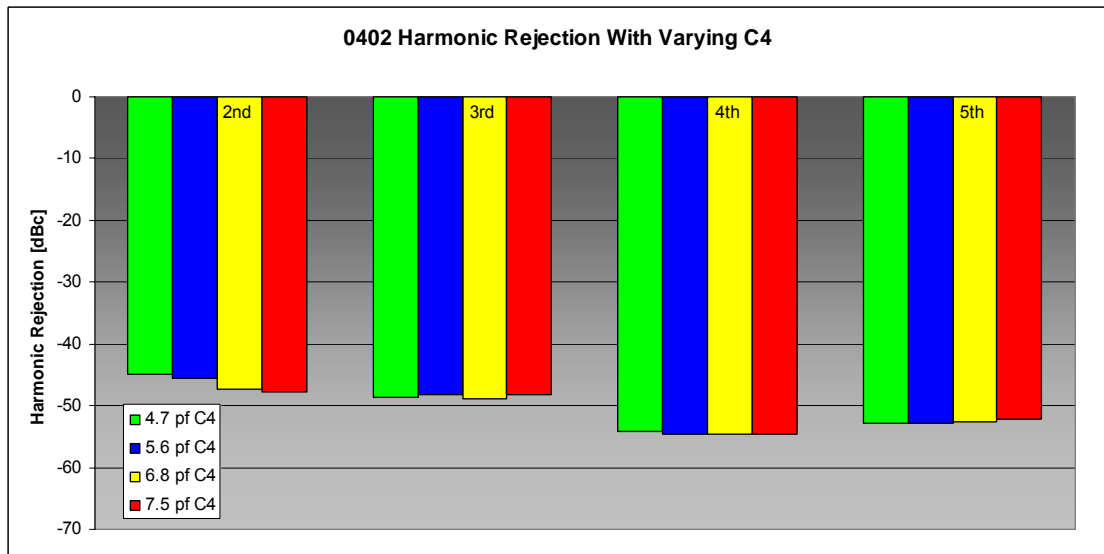


Figure 19: Average Harmonic Rejection for Various Grounding Capacitors

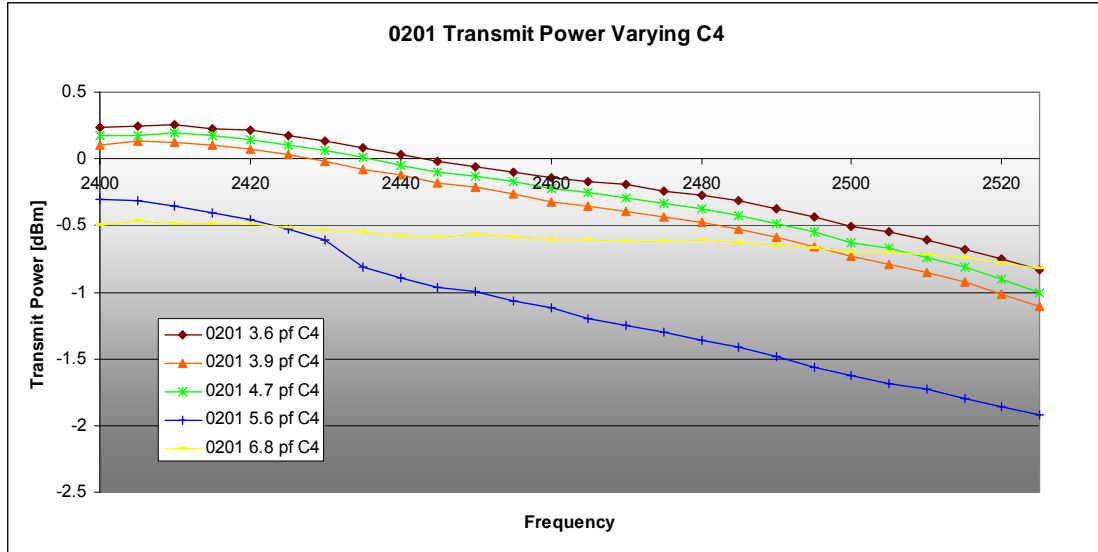


Figure 20: 0201 Design with Various Grounding Capacitors

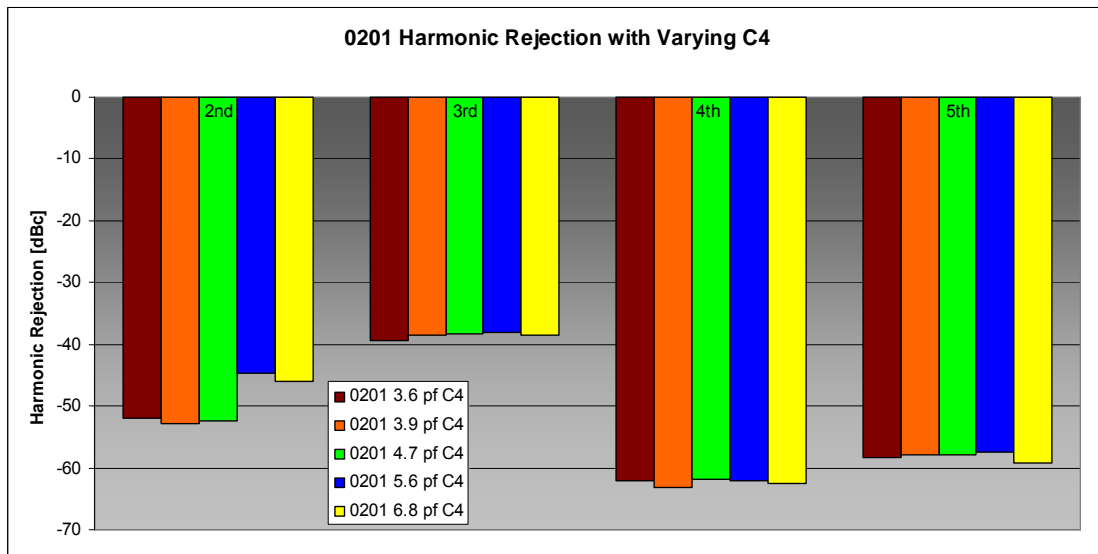
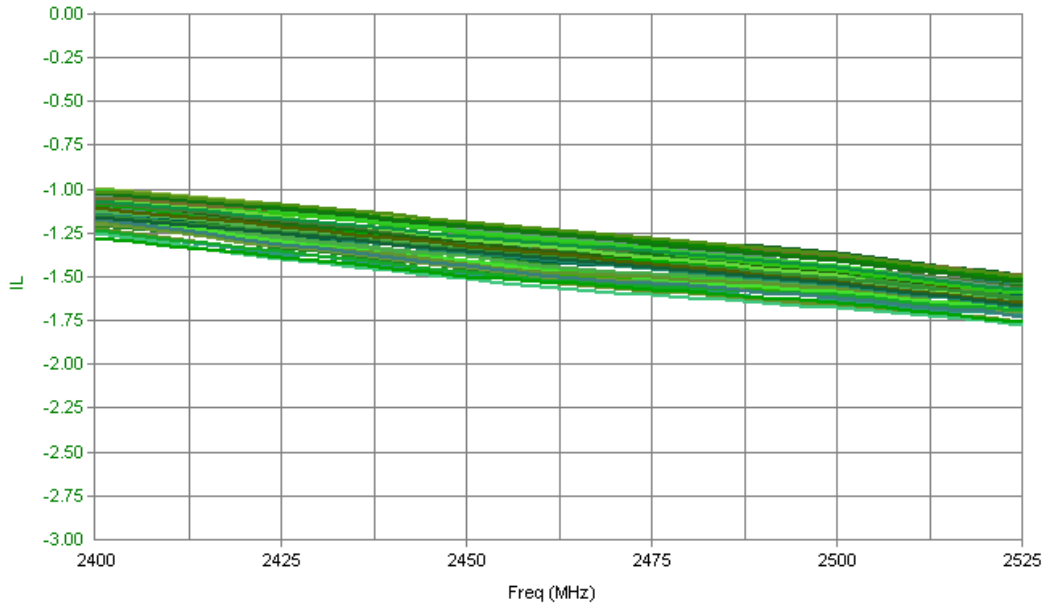


Figure 21: Average Harmonic Rejection For Various Grounding Capacitors

Balun Statistical Data

Anaren baluns are manufactured using a reliable, repeatable process which delivers a tight distribution of performance for a large number of samples. All parts are also 100% RF tested.



IL

Figure 22: Insertion Loss

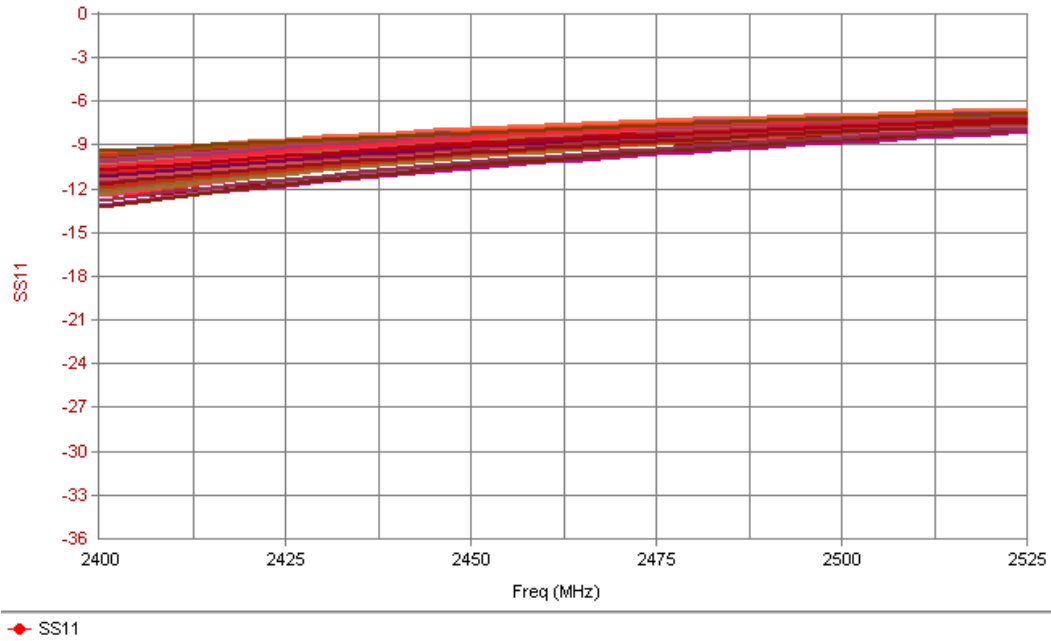
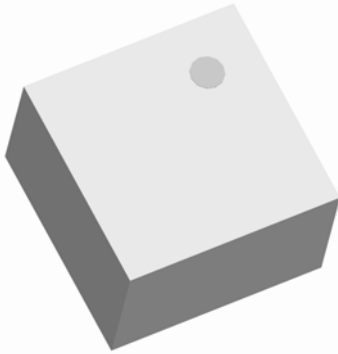


Figure 23: Single Ended Return Loss



Ultra Low Profile 0404 Balun For nRF24L01 and nRF24L01+

(Anaren Application Note Ann-3001)



Description

The BD2425NnRF is a low cost, low profile sub-miniature unbalanced to balanced transformer designed for differential inputs and output, tuned to provide optimal performance in tandem with the Nordic Semiconductor nRF24L01 and nRF24L01+. The BD2425NnRF is ideal for high volume manufacturing and delivers higher performance than a discrete implementation. The BD2425NnRF has an unbalanced port impedance of 50Ω and matched balanced port impedance when used in the specified matching network, which is the conjugate match of the nRF24L01 and nRF24L01+ devices. This transformation enables single ended signals to be applied to differential ports on the nRF24L01 and nRF24L01+. The BD2425NnRF is available on tape and reel for pick and place high volume manufacturing.

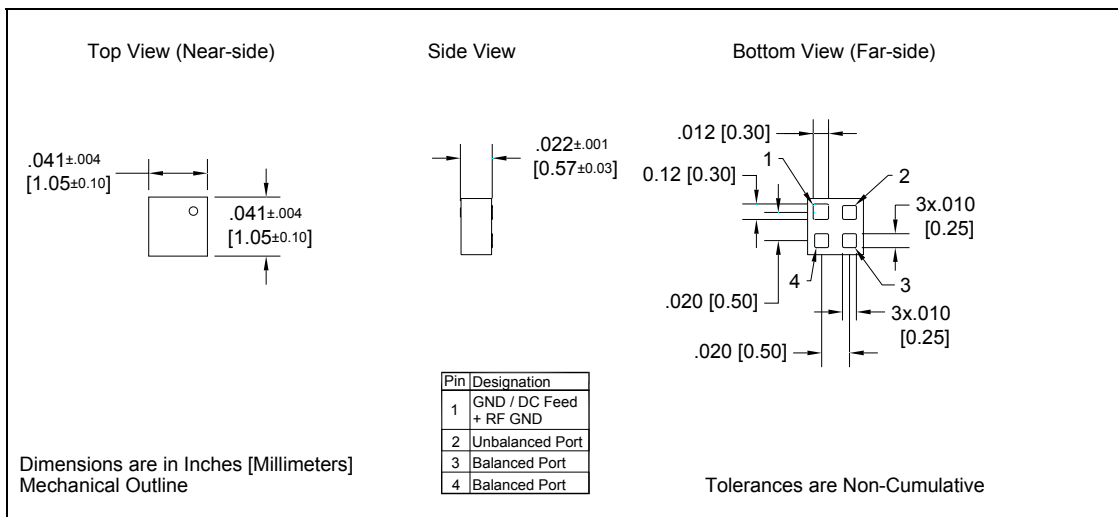
Detailed Electrical Specifications: Specifications subject to change without notice.

Features:	Parameter	ROOM (25°C)			Unit	
		Min.	Tvp.	Max		
<ul style="list-style-type: none"> • 2400 – 2525 MHz • 0.57 mm Height Profile • Matched to Nordic Semiconductor nRF24L01 and nRF24L01+ • Low Insertion Loss • Surface Mountable • Tape & Reel • Non-conductive Surface • RoHS Compliant 	Frequency	2400		2525	MHz	
	Unbalanced Port Impedance**		50		Ω	
	Balanced Port Impedance**		Matched		Ω	
	Return Loss**			10.2		dB
	Insertion Loss* **			1.25		dB
	Power Handling				1	Watts
	Operating Temperature		-55		+85	°C

* Insertion Loss stated at room temperature (Insertion Loss is approximately 0.1 dB higher at +85 °C)

** Stated performance assumes proper matching network found in application note: Ann-3001

Outline Drawing

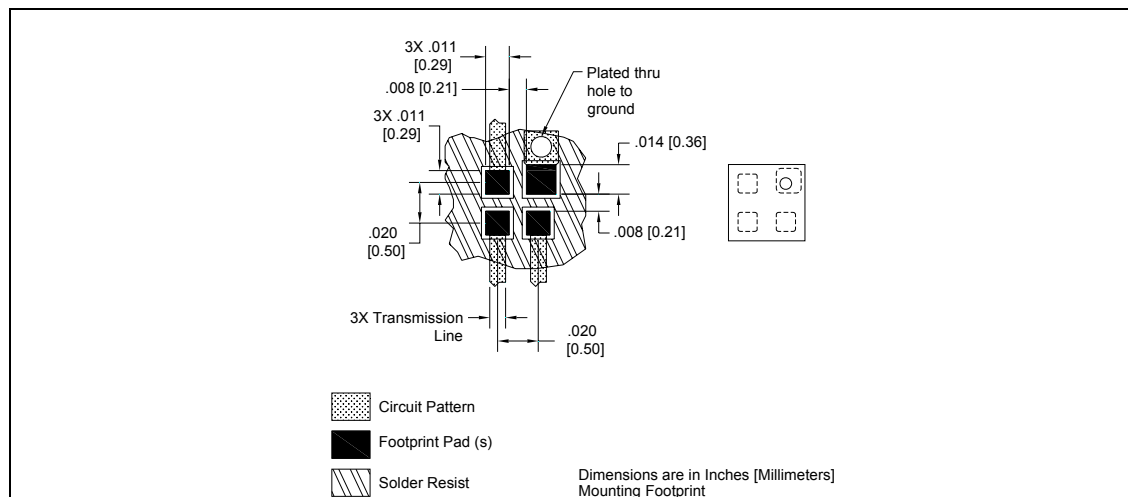


Mounting Configuration

In order for Xinger surface mount components to work optimally, the proper impedance transmission lines must be used to connect to the RF ports. If this condition is not satisfied, insertion loss, Isolation and VSWR may not meet published specifications.

All of the Xinger components are constructed from ceramic filled PTFE composites which possess excellent electrical and mechanical stability having X and Y thermal coefficient of expansion (CTE) of 17 ppm/°C.

An example of the PCB footprint used in the testing of these parts is shown below. An example of a non-DC-biased footprint is also shown below. In specific designs, the transmission line widths need to be adjusted to the unique dielectric coefficients and thicknesses as well as varying pick and place equipment tolerances



Note: For specific matching layout for nRF24L01 and nRF24L01+ please see Anaren application note ANN-3001

Packaging and Ordering Information

Parts are available in reel and are packaged per EIA 481-2. Parts are oriented in tape and reel as shown below. Minimum order quantities are 4000 per reel. See Model Numbers below for further ordering information.

