
nRF9E5 RF and antenna layout

nAN900-05

1. General

Gerber files for RF layouts have been made for Nordic Semiconductor's **nRF9E5** 433/868/915 MHz RF Transceiver with Embedded 8051 Compatible Microcontroller and 4 Input, 10 Bit ADC [1]. The RF layouts include the external EEPROM needed for the **nRF9E5** program code. A loop antenna for 433MHz has also been made available.

The Gerber files for each layout are compressed into the Zip archive format. The Zip archive files includes a file named **readme.wri** that must be read before importing the Gerber files into the PCB editor.

All described layouts should be fabricated on standard 1.6mm double-sided FR4 printed circuit board.

2. RF layout for nRF9E5

The RF layouts include all necessary circuitry to implement the **nRF9E5** in a short-range communication system. All digital I/O signals and ADC inputs are available at the perimeter of the RF layout and should be connected to the peripheral part of a customer's application.

The serial EEPROM needed for the **nRF9E5** program code is included on the layout. The EEPROM is of a standard 2XX320 SPI type, and the footprint used is SO-8.

Supply voltage and GND are also available at the perimeter of the layout. The supply voltage for this part of the application circuit should be filtered separately from the supply voltages of any high current peripheral circuitry. Star routing is strictly recommended from the voltage supply source to the different parts of the application circuitry.

All RF layouts presented below are equal except for the antenna connection circuitry. Solutions for differential connection to a differential antenna and single ended connection to a 50Ω antenna are presented.

2.1. Differential connection to a differential antenna

Figure 1 shows the schematics for RF layout with differential connection to a differential antenna. The PCB layout is shown in Figure 2. The loop antenna layout described in chapter 3 can easily be placed together with this RF layout. The connection points numbered 1, 2 and 3 on the loop antenna layout must be connected exactly to the corresponding connection points numbered 1, 2 and 3 on the RF layout.

The Gerber files Zip archive filename is **PCB_nRF9E5_diff_0603_2-0.zip**.

The recommended external components are as given in Table 1 for all frequency bands.



nRF9E5 RF and antenna layout

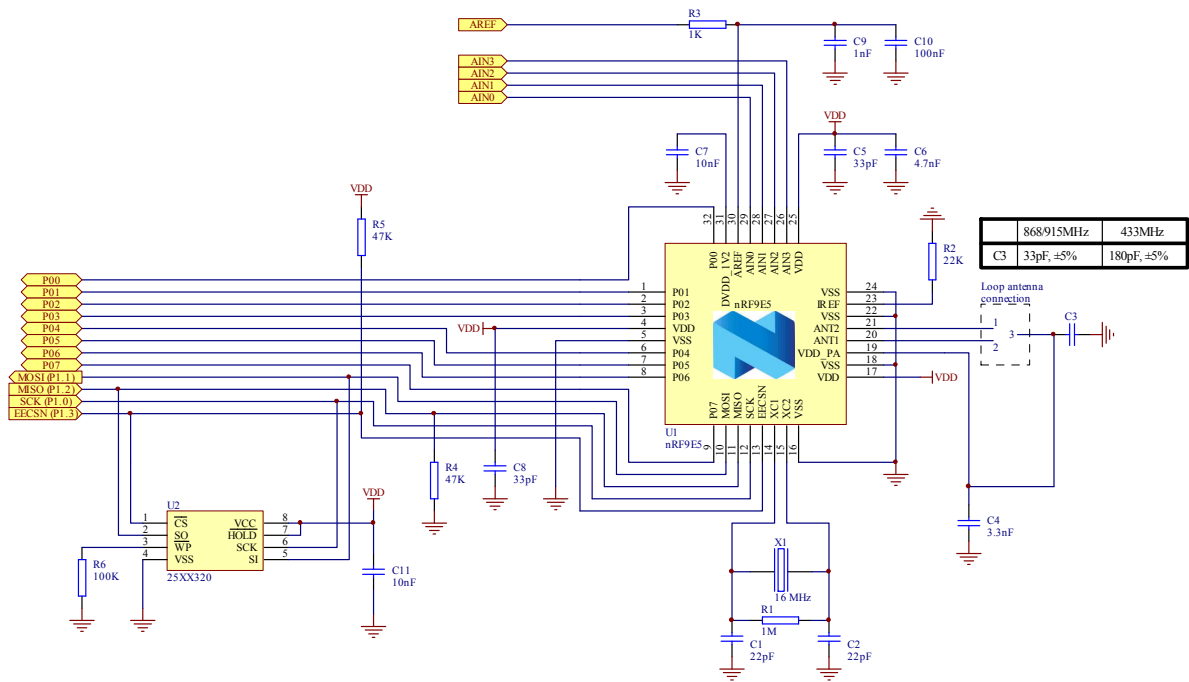


Figure 1. nRF9E5 schematics for RF layout with differential connection to a differential antenna

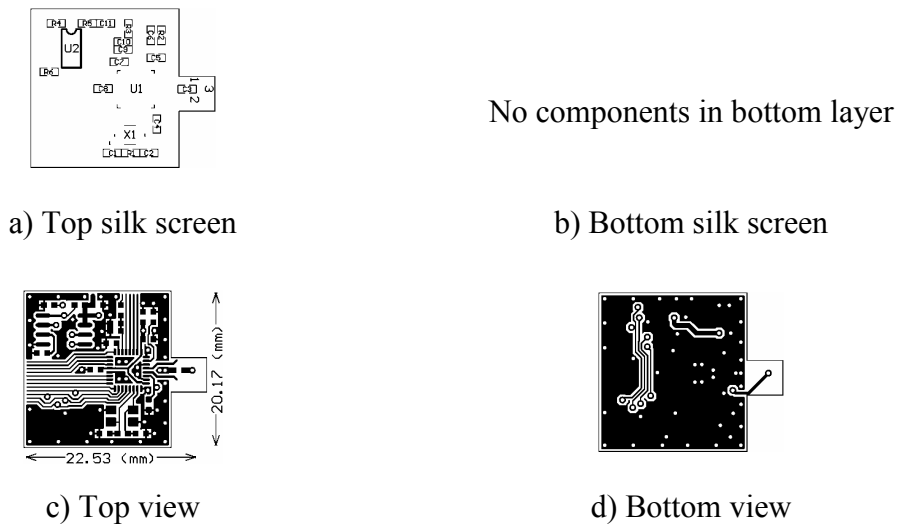


Figure 2. nRF9E5 RF layout with differential connection to a differential antenna, all frequency bands



nRF9E5 RF and antenna layout

| Component | Description | Size | Value | Tolerance | Units |
|-----------|---|--|---------------|--|-------|
| C1 | Capacitor ceramic, 50V, NP0, (Crystal oscillator) | 0603 | 22 | ±5% | pF |
| C2 | Capacitor ceramic, 50V, NP0, (Crystal oscillator) | 0603 | 22 | ±5% | pF |
| C3 | Capacitor ceramic, 50V, NP0, (PA supply decoupling) @ 433MHz @ 868/915MHz | 0603 | 180pF 33pF | ±5% | pF |
| C4 | Capacitor ceramic, 50V, X7R, (PA supply decoupling) | 0603 | 3.3 | ±10% | nF |
| C5 | Capacitor ceramic, 50V, NP0, (Supply decoupling) | 0603 | 33 | ±5% | pF |
| C6 | Capacitor ceramic, 50V, X7R, (Supply decoupling) | 0603 | 4.7 | ±10% | nF |
| C7 | Capacitor ceramic, 50V, X7R, (Supply decoupling) | 0603 | 10 | ±10% | nF |
| C8 | Capacitor ceramic, 50V, NP0, (Supply decoupling) | 0603 | 33 | ±5% | pF |
| C9 | Capacitor ceramic, 50V, X7R, (AREF filtering) | 0603 | 1 | ±10% | nF |
| C10 | Capacitor ceramic, 50V, X7R, (AREF filtering) | 0603 | 100 | ±10% | nF |
| C11 | Capacitor ceramic, 50V, X7R | 0603 | 10 | ±10% | nF |
| R1 | Resistor, 0.1W, (Crystal oscillator bias) | 0603 | 1 | ±5% | MΩ |
| R2 | Resistor, 0.1W, (Reference bias) | 0603 | 22 | ±1% | kΩ |
| R3 | Resistor, 0.1W | 0603 | 1 | ±10% | kΩ |
| R4 | Resistor, 0.1W, (MISO pull-down) | 0603 | 47 | ±10% | kΩ |
| R5 | Resistor, 0.1W, (EECSN pull-up) | 0603 | 47 | ±10% | kΩ |
| R6 | Resistor, 0.1W | 0603 | 100 | ±10% | kΩ |
| U1 | nRF9E5 RF Transceiver | QFN32L/5x5 | | | |
| U2 | 4 kbyte serial EEPROM with SPI interface | SO8 | 2XX320 | | |
| X1 | Crystal, $C_L = 12\text{pF}$, $\text{ESR} < 100\Omega$, $C_0 < 7.0\text{pF}$ | $L_x \times W \times H =$ 4.0x2.5x0.8mm | $16^{1)}$ | < +/- 30 ppm (frequency tolerance at 25°C + temperature drift) | MHz |

Table 1. nRF9E5 recommended external components for all frequency bands

¹⁾ nRF9E5 can operate at several crystal frequencies, please refer to [1].



2.2. Single ended connection to 50Ω antenna by using a differential to single ended matching network

Figure 3 shows the schematics for **nRF9E5** with single ended connection to 50Ω antenna by using a differential to single ended matching network when operating at 433MHz. The PCB layout is shown in Figure 4. Figure 5 shows the schematics for **nRF9E5** with single ended connection to 50Ω antenna by using a differential to single ended matching network when operating at 868/915MHz. The PCB layout is shown in Figure 6.

The antenna connection point should be as close as possible to the output of the matching network. If this is not possible of practical reasons, the PCB track between the output of the matching network and the antenna connection should be carried out as a 50Ω microstrip line. In such a case, the length of the microstrip line is limited to a few centimeters. For a standard FR4 printed circuit board with 1.54mm substrate thickness and relative dielectric constant $\epsilon_r \approx 4.45-4.25$ at 433MHz-915MHz, the width of the microstrip line should be 3mm.

For 433MHz operating **nRF9E5**, the Gerber files Zip archive filename is **PCB_nRF905_single_netw_0603_433_2-0.zip**.

For 868/915MHz operating **nRF905**, the Gerber files Zip archive filename is **PCB_nRF905_single_netw_0603_868-915_2-0.zip**.

The recommended external components are as given in Table 1, with addition of the components in the differential to single ended matching network as given in Table 2.



nRF9E5 RF and antenna layout

| Component | Description | Size | Value | Tolerance | Units |
|-----------|---|------|------------------------------------|----------------------------------|-------|
| C12 | Capacitor ceramic, 50V, NP0, (Impedance matching) @ 433MHz @ 868/915MHz | 0603 | 18 5.6 | ³⁾ ±5% <±0.25pF | pF |
| C13 | Capacitor ceramic, 50V, NP0, (Impedance matching) @ 433MHz @ 868/915MHz | 0603 | 18 5.6 | ³⁾ ±5% <±0.25pF | pF |
| C14 | Capacitor ceramic, 50V, NP0, (Impedance matching) @ 433MHz @ 868/915MHz | 0603 | optional ⁴⁾ Not used | ±0.25% | pF |
| C15 | Capacitor ceramic, 50V, NP0, (Impedance matching) @ 433MHz @ 868/915MHz | 0603 | 6.8 22 | ±5% ±5% | pF |
| C16 | Capacitor ceramic, 50V, NP0, (Impedance matching) @ 433MHz @ 868/915MHz | 0603 | optional ⁵⁾ 4.7 | ³⁾ ±5% <±0.25pF | pF |
| L1 | Chip inductor, (Impedance matching) @ 433MHz: SRF>433MHz @ 868/915MHz: SRF>915MHz | 0603 | 12 12 | ³⁾ ±5% ±5% | nH |
| L2 | Chip inductor, (Impedance matching) @ 433MHz: SRF>433MHz @ 868/915MHz: SRF>915MHz | 0603 | 39 10 | ³⁾ ±5% ±5% | nH |
| L3 | Chip inductor, (Impedance matching) @ 433MHz: SRF>433MHz @ 868/915MHz: SRF>915MHz | 0603 | 39 12 | ³⁾ ±5% ±5% | nH |

Table 2. nRF9E5 recommended components in the differential to single ended matching network, all frequency bands

³⁾ To achieve more reproducible values of matching network insertion loss in mass production and hence less variation in output power and sensitivity, components with tighter tolerances can be utilized.

⁴⁾ This capacitor is optional for 433MHz operating nRF9E5 and may be needed to tune the resonance frequency of the matching network if a printed circuit board which is different from a 1.6mm, 2 layer, FR4 printed circuit board is used.

⁵⁾ This capacitor is optional for 433MHz operating nRF9E5 and may be needed in some designs to reduce harmonic emissions when measuring directly at the matching network output.



nRF9E5 RF and antenna layout

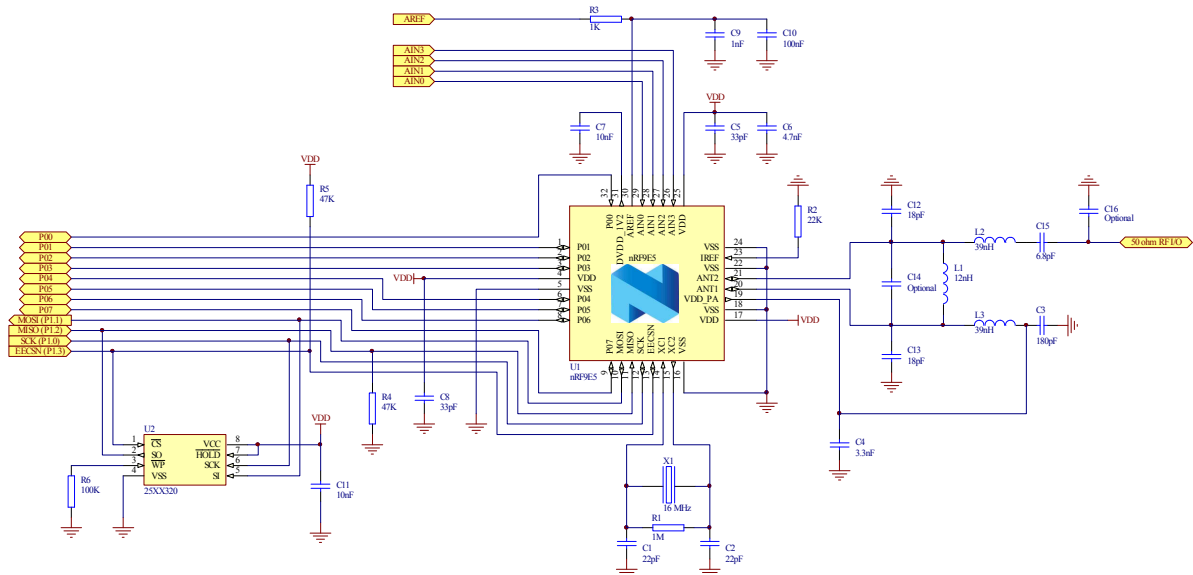
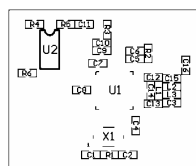


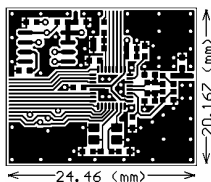
Figure 3. 433MHz operating nRF9E5 schematic, single ended connection to 50Ω antenna by using a differential to single ended matching network



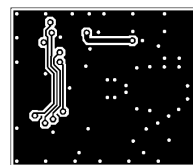
a) Top silk screen

No components in bottom layer

b) Bottom silk screen



c) Top view



d) Bottom view

Figure 4. nRF9E5 RF layout for 433MHz operation, single ended connection to 50Ω antenna by using a differential to single ended matching network, all frequency bands



nRF9E5 RF and antenna layout

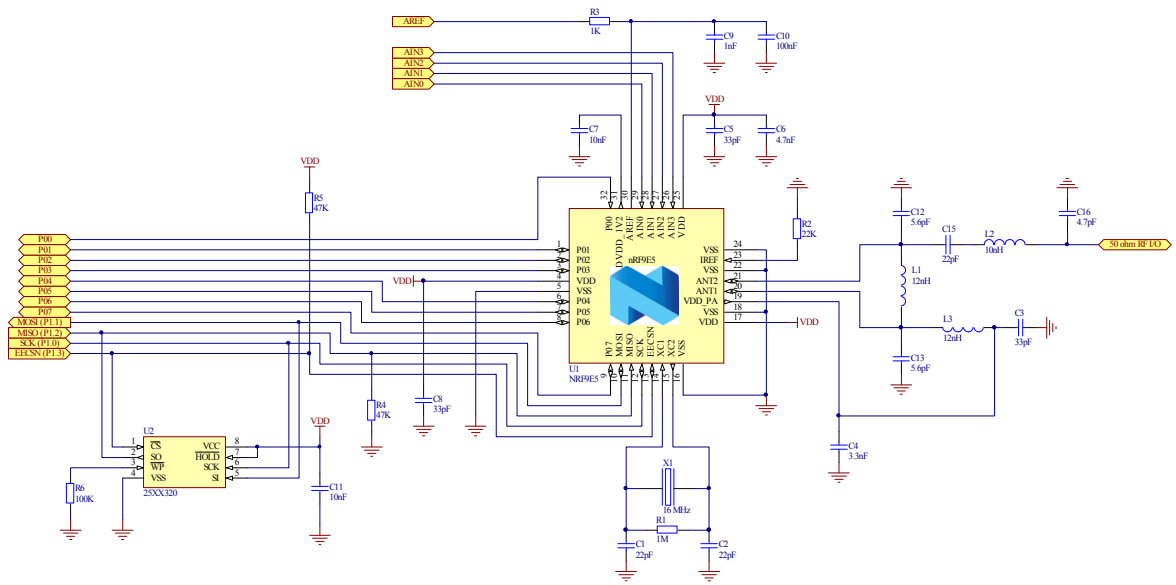
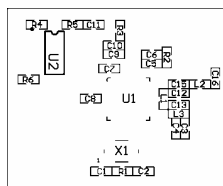


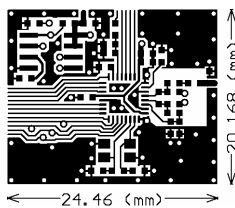
Figure 5. 868/915MHz operating **nRF9E5** schematic, single ended connection to 50Ω antenna by using a differential to single ended matching network



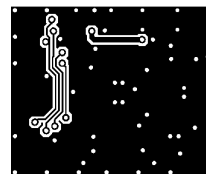
a) Top silk screen

No components in bottom layer

b) Bottom silk screen



c) Top view



d) Bottom view

Figure 6. **nRF9E5** RF layout for 868/915MHz operation, single ended connection to 50Ω antenna by using a differential to single ended matching network, all frequency bands



3. Loop antenna layouts

A loop antenna with T-match [2] is a good solution for low cost and small size radio modules. A layout solution for a small rectangular loop antenna for 433MHz operation is described below.

Figure 7 shows the basic geometry of the designed rectangular loop antenna.

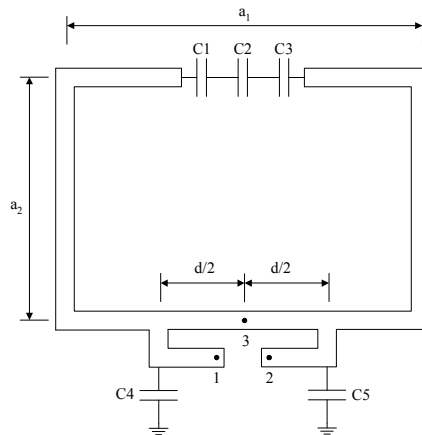


Figure 7. Geometry of rectangular loop antenna

The loop antenna physical parameters are

- a_1 = loop antenna length [mm]
- a_2 = loop antenna width [mm]
- d = feed length [mm]
- b = width of loop conductor

The antenna is tuned to a resonance frequency of 433MHz with chip capacitors $C1$, $C2$ and $C3$. Capacitors $C1$, $C2$ and $C3$ should be NP0 type and have tolerances equal to or better than $\pm 0.1\text{pF}$. Capacitors $C4$ and $C5$ should also be NP0 type and have tolerances equal to or better than $\pm 5\%$. The loop antenna is tuned to approximately 300Ω with a T-match. The width of the loop conductor is 1mm (40mil). There is no ground plane beneath the antenna.

Table 3 shows a summary of the designed loop antenna for 433MHz.

| Loop antenna $a_1 \times a_2$ [mm] | Feed length d [mm] | C1 | | C2 | | C3 | | C4, C5 [pF] | Z_0 [Ω] |
|--|----------------------------|---------------|-------------------|---------------|-------------------|---------------|-------------------|-------------------|-----------------------|
| | | Value [pF] | Tolerance [pF] | Value [pF] | Tolerance [pF] | Value [pF] | Tolerance [pF] | | |
| 35x20 | 22.5 | 3.9 | ± 0.1 | 6.8 | ± 0.1 | 4.7 | ± 0.1 | 27 | 300 |

Table 3. Summary of the loop antenna for 433MHz operation

The component values given in Table 3 are only valid when the connection points numbered 1, 2 and 3 on the loop antenna layout, as shown in Figure 8, are connected exactly to the

**nRF9E5 RF and antenna layout**

corresponding connection points numbered 1, 2 and 3 on the RF layout with differential connection. The component footprints used in the loop antenna layout are size 0603. The layout of the rest of the communication system may influence the antenna tuning and require measurement of the antenna together with the complete system in order to find the values for $C1$, $C2$ and $C3$ for your system.

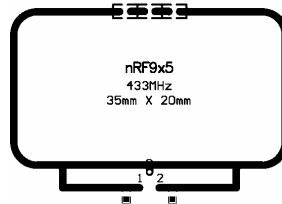


Figure 8. Loop antenna PCB layout

It is recommended that a system should not be designed with a longer communication range than the application requires. Estimations on communication range with the antenna presented in this application note and a receiver with a given sensitivity and antenna gain, can be made based on the theory given in [2]. Initial communication range tests should be carried out with the lowest RF output power setting that, based on the estimations, satisfies the range requirements. If the achieved communication range does not satisfy the requirements, the RF output power should be increased to the required level.

The Gerber files Zip archive filename for the antenna layout is **Loop_35x20mm_433MHz_nRF9x5.zip**.

Measured gain of this 35x20mm loop antenna is approximately -18dBi .



4. References

1. Product Specification **nRF9E5**, “433/868/915 MHz RF Transceiver with Embedded 8051 Compatible Microcontroller and 4 Input, 10 Bit ADC”, Nordic Semiconductor ASA.
2. Application note **nAN400-03**, “Small loop antennas”, Nordic Semiconductor ASA.



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