

USING NEC BJT(NESG270034 AND NESG250134) POWER AMPLIFIER WITH Si446X

1. Introduction

Silicon Laboratories' Si446x devices are high-performance, low-current transceivers covering the sub-GHz frequency bands from 142 to 1050 MHz. The Si4464/63 offers exceptional output power of up to +20 dBm with outstanding TX efficiency. The Si4464/63 can achieve up to +27 dBm output power with built-in ramping control of a low-cost, external power device (BJT, LDMOS, or even a PA block). The high output power increases link budget allowing extended ranges and highly robust communication links.

In this application note, the NESG270034 and NESG250134 NPN SiGe type power BJTs from NEC are used as an external power device. The NESG270034 is the NPN SiGe RF transistor for medium output power (2 W) amplification with a 6 V power supply. The NESG250134 is the NPN SiGe RF transistor for medium output power (800 mW) amplification with a 3.3 V power supply.

The purpose of this application note is to provide a description of the PA matching and filter circuit when using NEC BJTs with the Si446x family of RFICs at 169, 434, 470, and 868 MHz bands.

Measurements were performed on the Si4463-B0 chip but are applicable to other 20 dBm output members of the Si446x family of chips.

2. BJT Power Amplifier (PA) and Match Circuit

Figure 1 shows the diagram of the RF circuits when using an external PA with the Si446x. The PA is inserted between the Si446x match circuit and harmonics filter. GPIO0 and GPIO2 are used to control the RF switch between the transmitter and receiver. Filters are used to attenuate the harmonics to meet applicable regulatory standards.

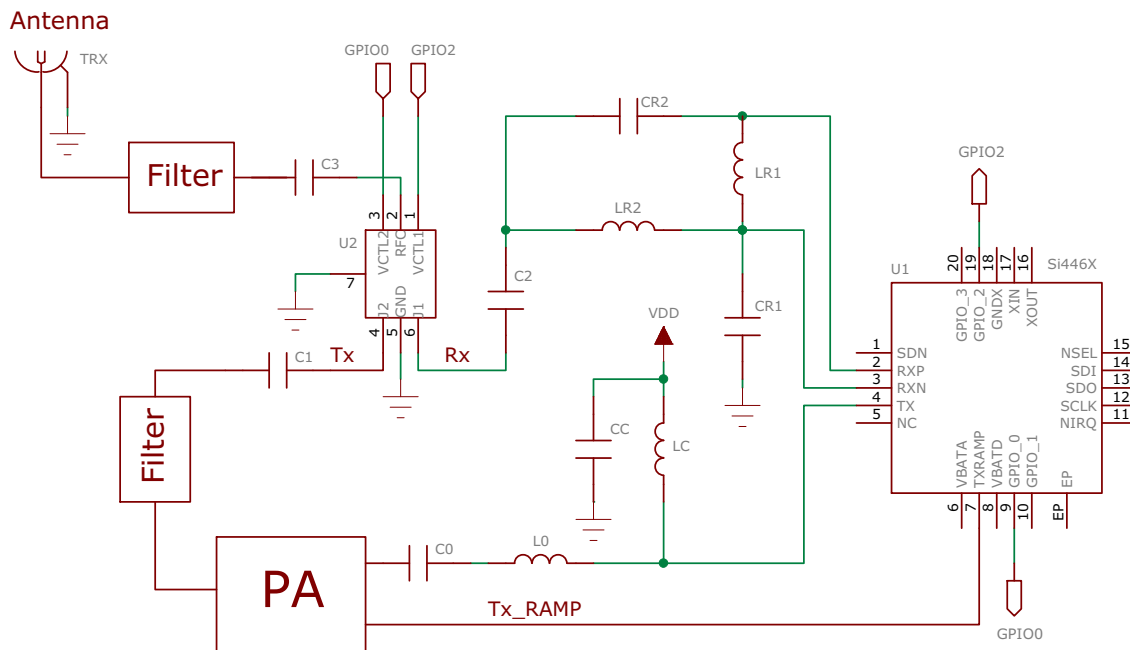


Figure 1. BJT PA Working with the Si446x

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2.1. Match Network Design of NESG270034 (6 V Power Supply)

Figure 2 shows the theoretical diagram of the NESG270034 application circuits.

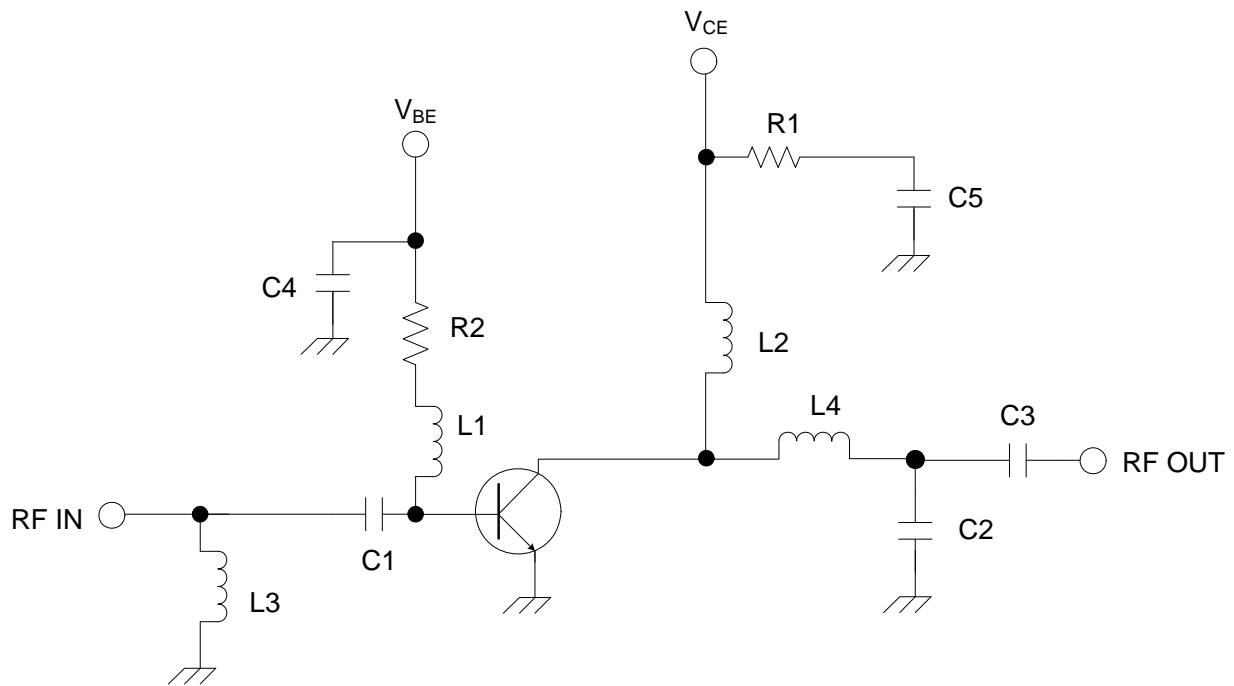


Figure 2. NESG270034 Application Circuits

In the circuit, V_{CE} is 6 V, V_{BE} is about 0.7 V. C1 and C3 are used as dc block and RF matching. L3 and L4 are used as input and output RF matching separately. L1 and L2 are used as RF block and RF matching. R1 and R2 can improve stability.

The practical circuit of the NESG270034 needs to be modified according to the frequency band and input/output matching requirements.

2.1.1. Match Design for NESG270034 at 169 MHz Band

Figure 3 shows the circuit for the NESG270034 BJT PA part at 169 MHz. In the circuit, LM0 and C1 are used for RF matching in the input circuit. R6, R3, and R8 form the bias circuit for PA. R9 is used for stability.

The design goals are as follows according to ETSI EN300220-1's requirement on harmonics:

- The 2nd harmonics should be below -36 dBm.
- The 3rd, 4th, and 5th harmonics should be below -54 dBm.
- Other higher harmonics should be below -30 dBm.

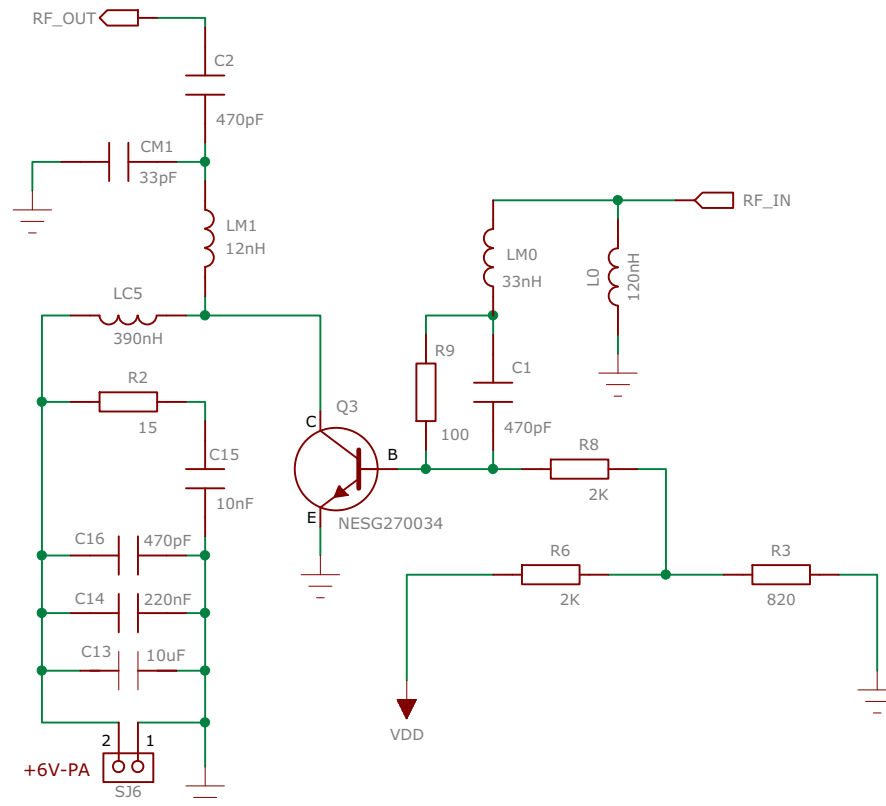


Figure 3. PA Match Circuit for NESG270034 at 169 MHz Band

2.1.2. Match Design for NESG270034 at 434 MHz Band

Figure 4 shows the circuit for the NESG270034 BJT PA part at 434 MHz. In the circuit, LM0 and C1 are used for RF matching in the input circuit. LM1 and CM1 are used for RF matching in the output circuit. R6, R3, and LC4 form the bias circuit for PA. R9 is used for stability.

The design goals are as follows according to ETSI EN300220-1's requirement on harmonics:

- The 2nd harmonics should be below -36 dBm.
- Other higher harmonics should be below -30 dBm.

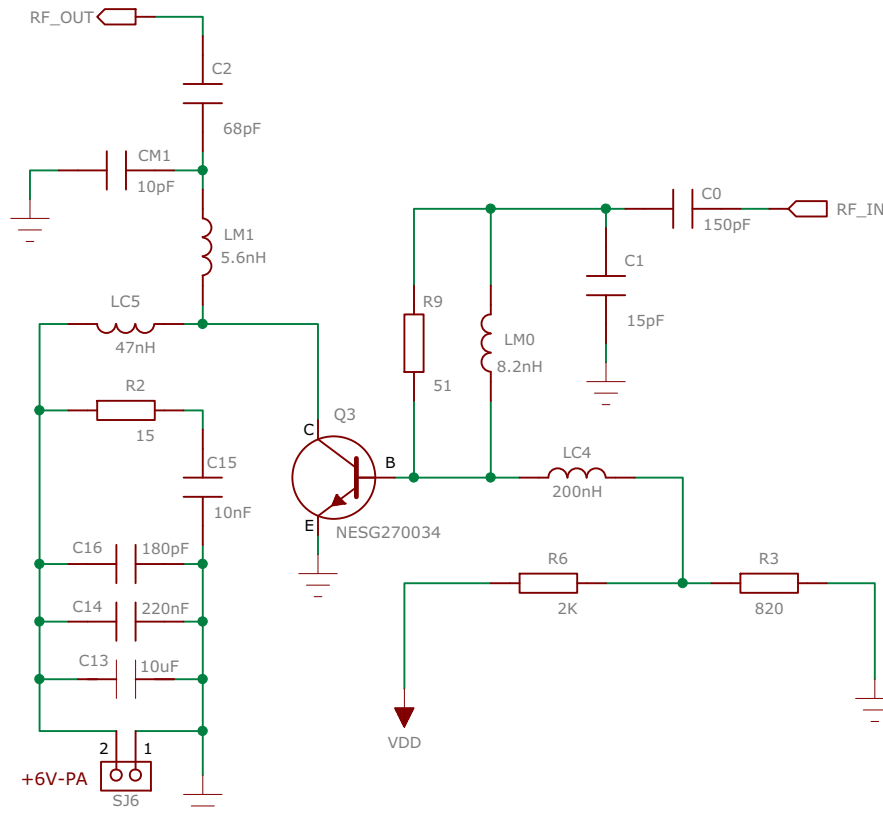


Figure 4. PA Match Circuit for NESG270034 at 434 MHz Band

2.1.3. Match Design for NESG270034 at 470 MHz Band

Figure 5 shows the circuit for the NESG270034 BJT PA part at 470 MHz. In the circuit, LM0 and C1 are used for RF matching in the input circuit. R6, R3, and LC4 form the bias circuit for PA.

The design goals are as follows similar to ETSI EN300220-1's requirement on harmonics:

- The 2nd harmonics should be below -36 dBm.
- Other higher harmonics should be below -30 dBm.

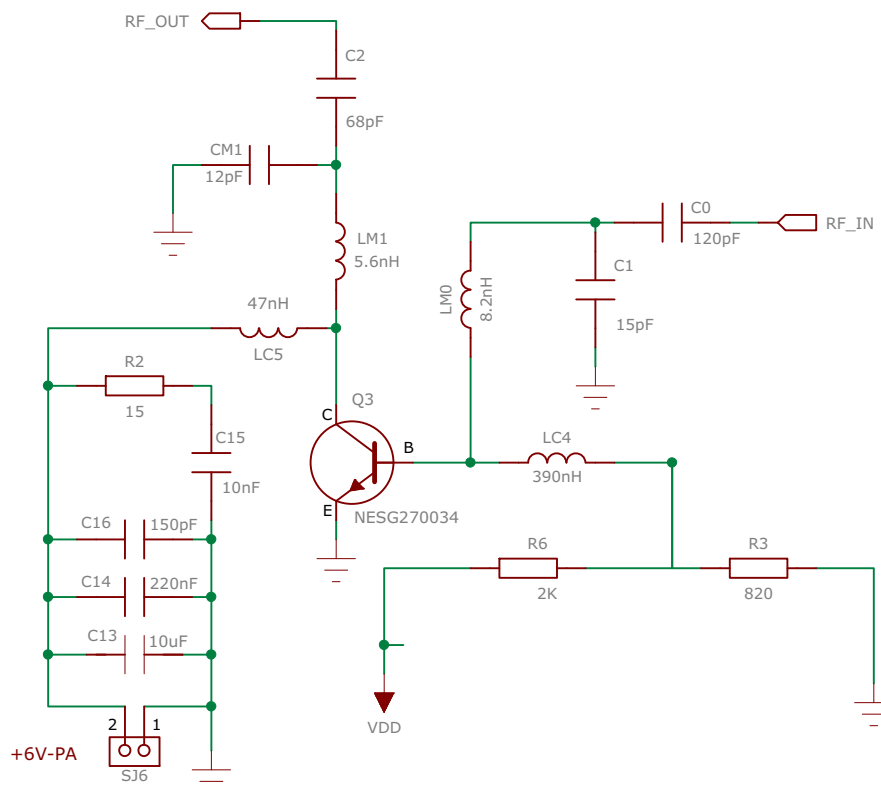


Figure 5. PA Match Circuit for NESG270034 at 470 MHz Band

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2.1.4. Match Design for NESG270034 at 868 MHz Band

Figure 6 shows the circuit for NESG270034 BJT PA part. In the circuit, C1 and LM0 are used for RF matching in the input circuit. LM1 and CM1 are used for RF matching in the output circuit. R6, R3, and LC4 form the bias circuit for PA.

The design goals are as follows according to ETSI EN300220-1's requirement on harmonics:

- The harmonics should be below -30 dBm.

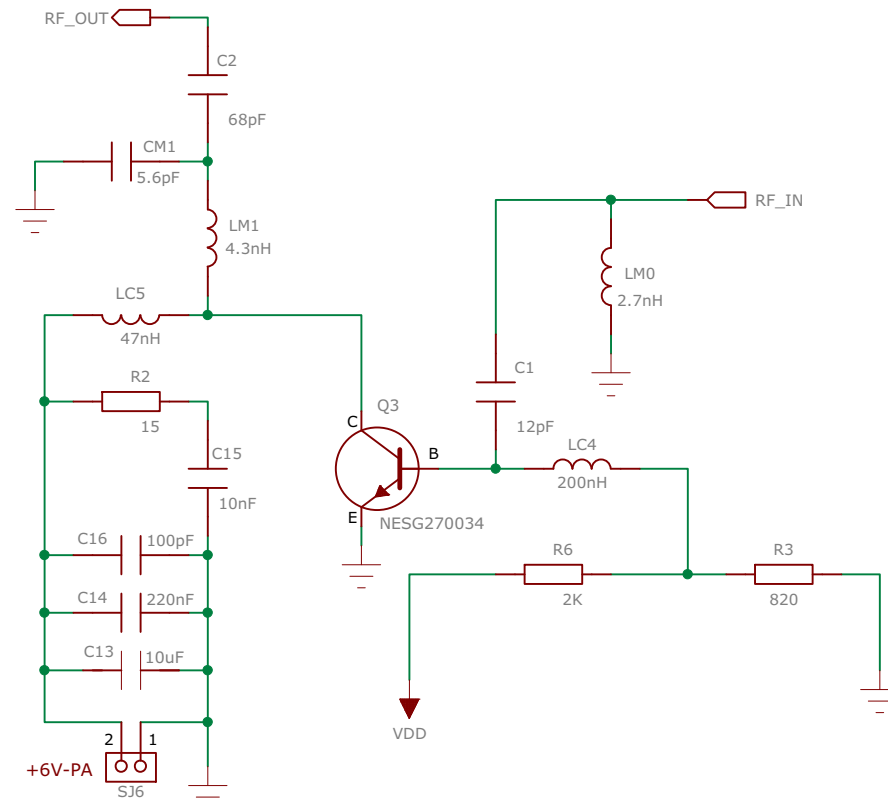


Figure 6. PA Match Circuit for NESG270034 at 868 MHz Band

2.2. Match Network Design for NESG250134 (3.3 V Power Supply)

NESG250134 is very similar to NESG270034, so the same topology shown in Figure 2 can be used for matching the NESG250134; however, V_{CE} must be changed to 3.3 V.

The practical circuit of the NESG250134 needs to be modified according to the frequency band and input/output matching requirements.

2.2.1. Match Design for NESG250134 at 169 MHz Band

Figure 7 shows the circuit for NESG250134 BJT PA part at 169 MHz. In the circuit, LM0, L0, and C1 are used for RF matching in the input circuit. LM1 and CM1 are used for RF matching in the output circuit. R6, R3, and R8 form the bias circuit for PA. R9 is used for stability.

The design goals are as follows according to ETSI EN300220-1's requirement on harmonics:

- The 2nd harmonics should be below -36 dBm.
- The 3rd, 4th, and 5th harmonics should be below -54 dBm.
- Other, higher harmonics should be below -30 dBm.

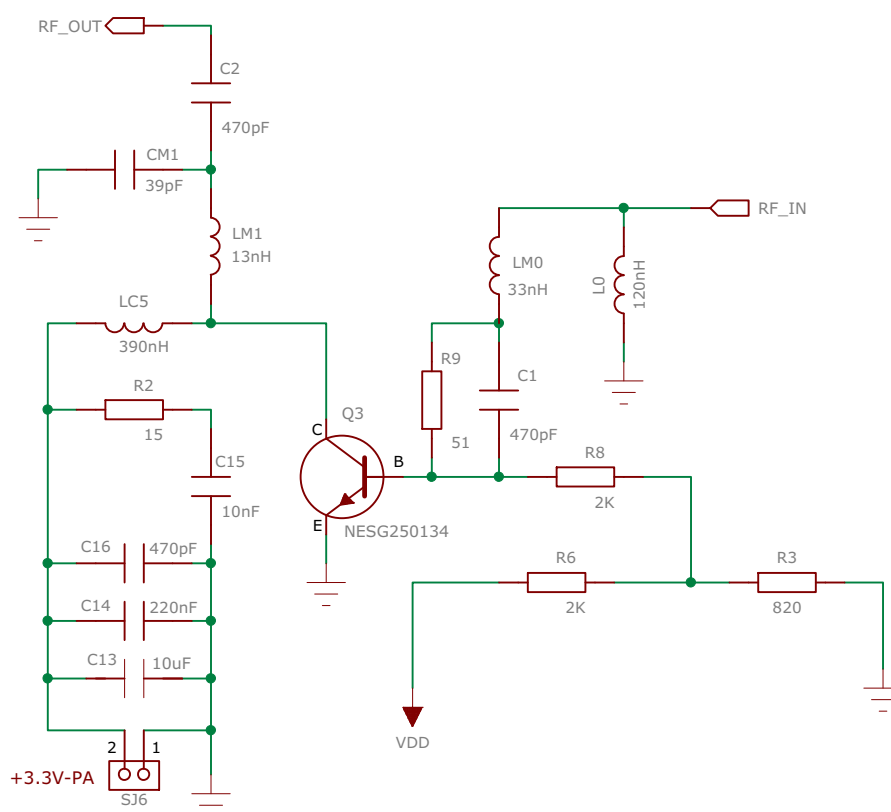


Figure 7. PA Match Circuit for NESG250134 at 169 MHz Band

2.2.2. Match Design for NESG250134 at 868 MHz Band

Figure 8 shows the circuit for the NESG250134 BJT PA part. In the circuit, C1 and LM0 are used for RF matching in the input circuit. LM1 and CM1 are used for RF matching in the output circuit. R6, R3, and LC4 form the bias circuit for PA.

The design goals are as follows according to ETSI EN300220-1's requirement on harmonics:

- The harmonics should be below -30 dBm.

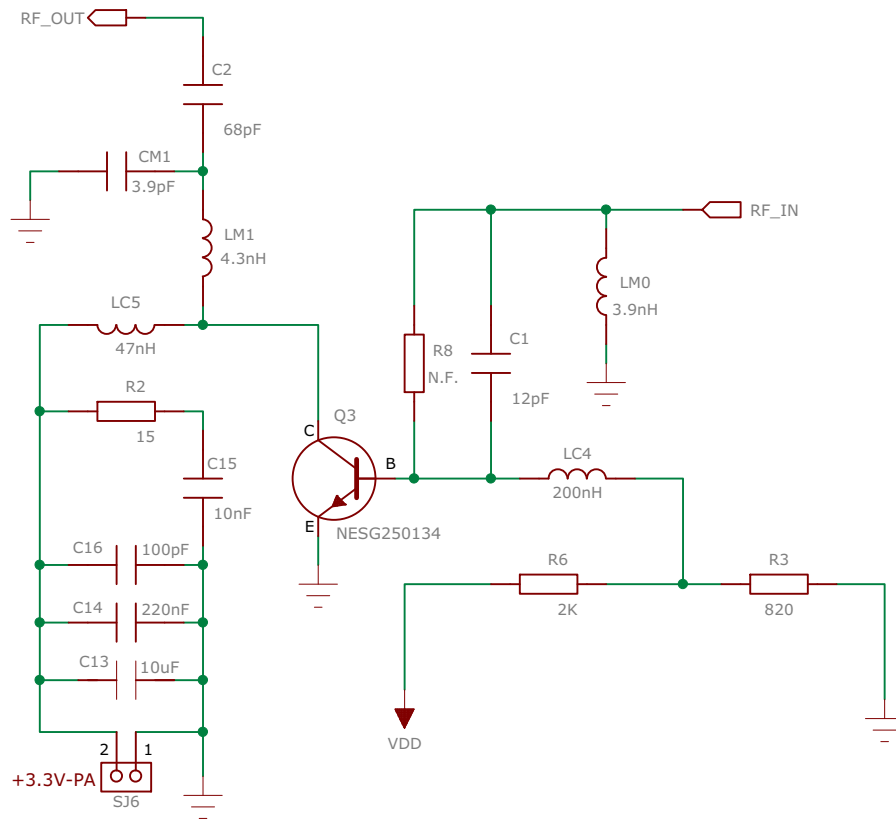


Figure 8. PA Match Circuit for NESG250134 at 868 MHz Band

2.3. Filter Design

A low-pass filter network is needed to attenuate the harmonics below the level required to meet applicable regulatory specs (e.g., FCC or ETSI).

However, the RF switch itself is not a perfectly ideal component; it will re-generate some amount of harmonic energy, regardless of the cleanliness of the input signal from the TX low-pass filter. Thus, it is necessary to place some amount of low-pass filtering after the RF switch and prior to the antenna. It is not required to increase the total order of low-pass filtering (i.e., number of filter poles); instead, it is generally sufficient to split the normal amount of low-pass filtering into two half-filter sections of approximately equal cutoff frequency. The RF switch is placed between these two half-filter sections. In this fashion, the final half-filter section cleans up any harmonic energy re-generated by the RF switch.

The initial design goals for the low-pass filter are as follows:

- Minimal insertion loss at the desired operating frequency
- Enough attenuation at the harmonics required by regulatory spec (for example, ETSI)
- Lowest filter order possible to still achieve this required harmonics attenuation

A Chebyshev low-pass filters are selected in this application note because of the acceptable filter response.

2.3.1. Filter Design at 169 MHz Band

Figure 9 shows the circuit for filters part at 169 MHz band. In the circuit, a five-order Chebyshev filter is used at the output of the RF switch and a three-order Chebyshev filter is used at the input of the RF switch.

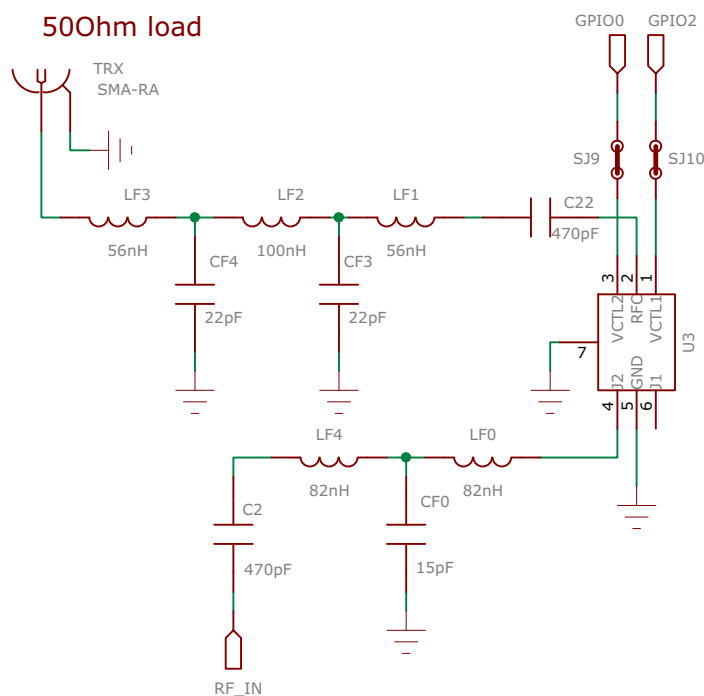


Figure 9. Filter Circuit for 169 MHz Band

2.3.2. Filter Design at 434 MHz Band

Figure 10 shows the circuit for filters part at 434 MHz band. In the circuit, a five-order Chebyshev filter is used at the output of the RF switch and a three-order Chebyshev filter is used at the input of the RF switch.

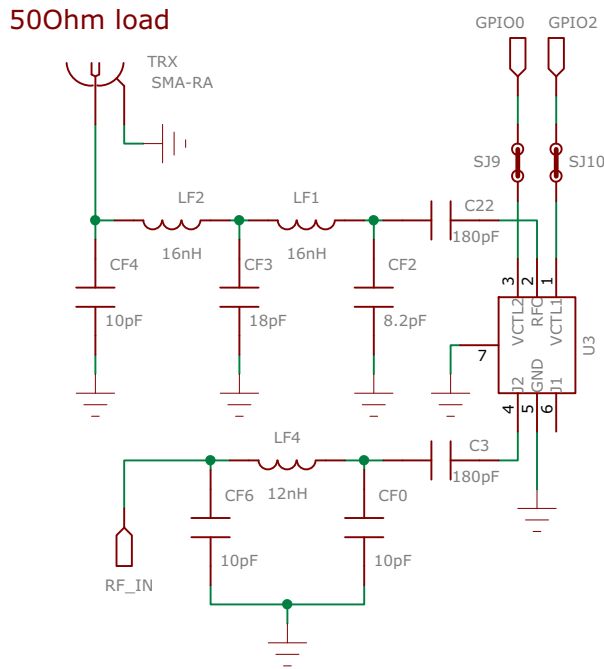


Figure 10. Filter Circuit for 434 MHz Band

2.3.3. Filter Design at 470 MHz Band

Figure 11 shows the circuit for filters part at 470 MHz band. In the circuit, a five-order Chebyshev filter is used at the output of the RF switch and a three-order Chebyshev filter is used at the input of the RF switch.

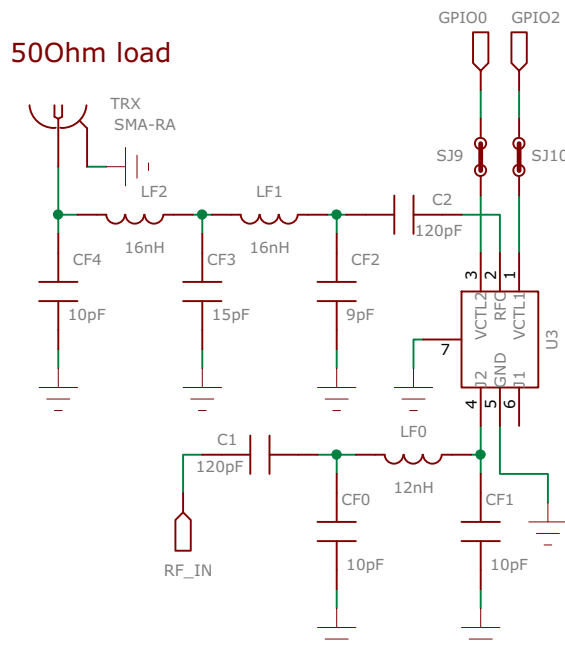


Figure 11. Filter Circuit for 470 MHz Band

2.3.4. Filter Design at 868 MHz Band

Figure 12 shows the circuit for filters part at 868 MHz band. In the circuit, a three-order Chebyshev filter is used at the output of the RF switch and a three-order Chebyshev filter is used at the input of the RF switch.

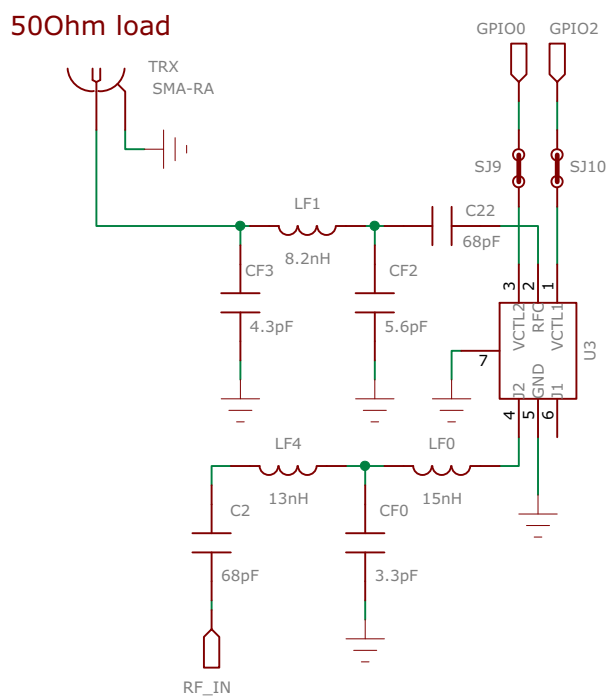


Figure 12. Filter Circuit for 868 MHz Band

3. Measurement Results for NESG270034 6 V Power Supply Solution

The measurements are done under the following parameters:

- 6.0 V power supply for BJT; 3.3 V for Si4463.
- Receiving data rate is 38.4 Kbps; frequency deviation is 20 kHz.
- Operating frequency is 169 MHz, 434 MHz, and 470 MHz separately.
- Conducted test, RX sensitivity measured at 1E-3 BER level.

3.1. Measurement Results at 169 MHz Band

In the measurement, a four-layer PCB test card (4463-TSQ27F169-6V) is used. The circuits are shown in Figure 13.

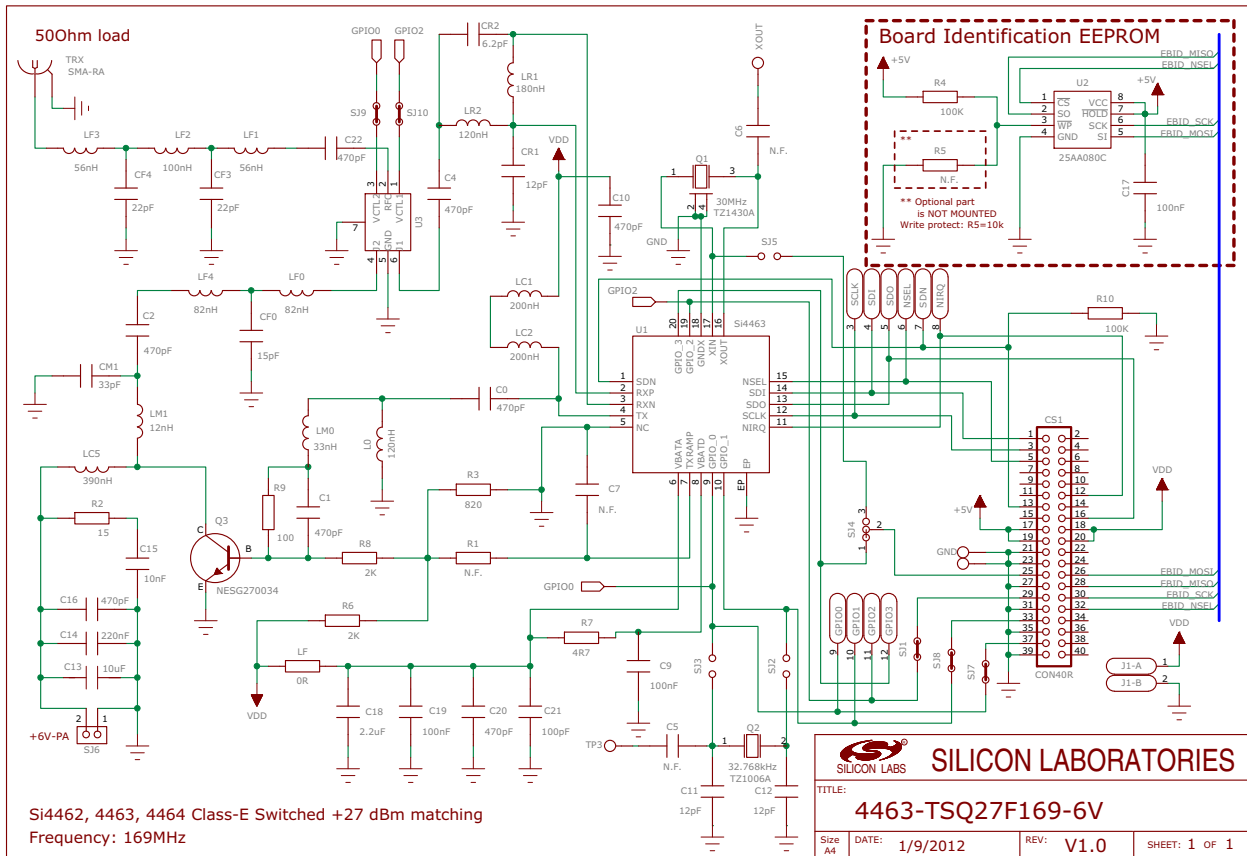


Figure 13. 4463-TSQ27F169-6V Schematic

The RF measurement results are as follows:

- Sensitivity: -108.5 dBm.
- BJT shutdown current consumption: $0.1 \mu\text{A}$
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-------|-------|-----|----|----|----|----|-----|---------------------|------------------|--------------------|
| 30.1 | -40 | -58.3 | -58.7 | -60 | — | — | — | — | — | 90 | 420 | 40% |
| 27.0 | -41.5 | — | — | — | — | — | — | — | — | 50 | 280 | 30% |

Note: — means the harmonic is below -60 dBm.

3.2. Measurement Results at 434 MHz Band

In the measurement, a four-layer PCB test card (4463-TCE27F434-6V) is used. The circuits are shown in Figure 14.

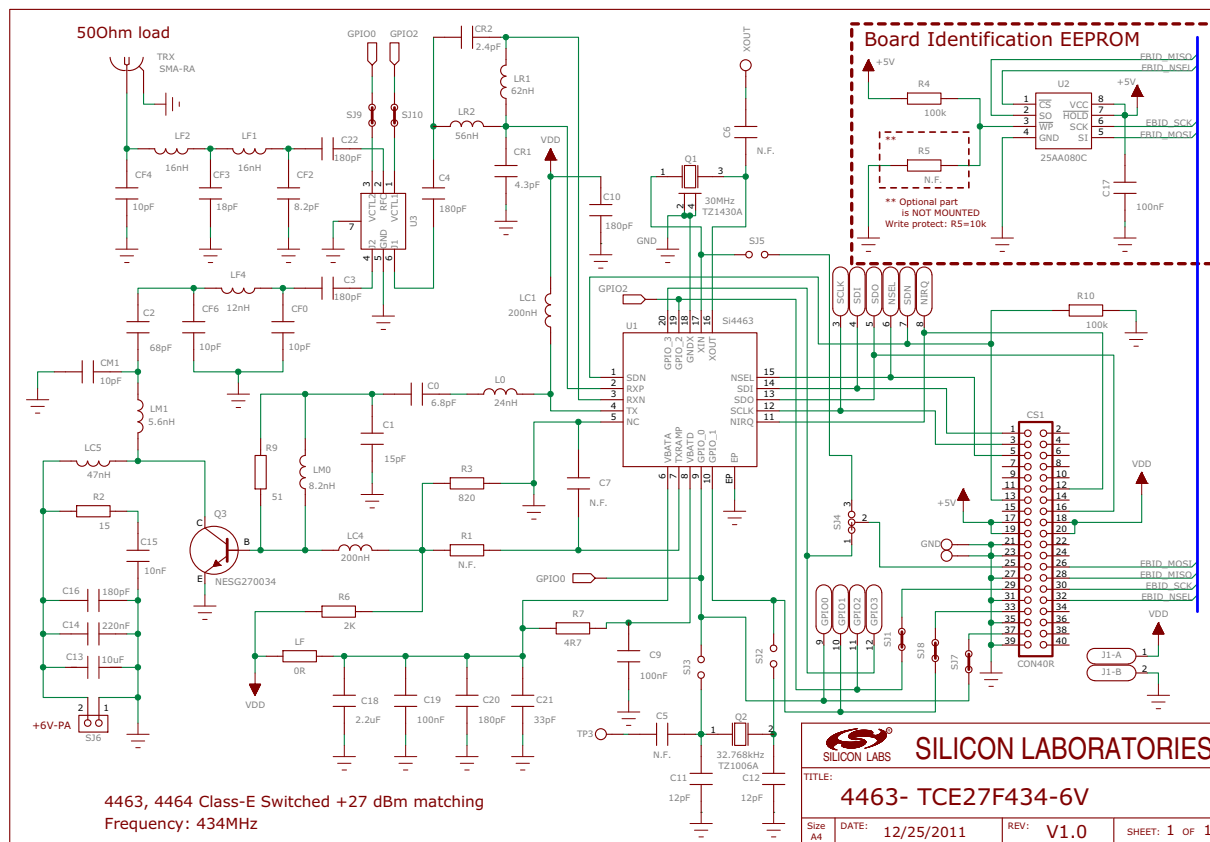


Figure 14. 434 MHz 6 V Supply Solution Schematic

The RF measurement results are as follows:

- Sensitivity: -108.5 dBm.
- BJT shutdown current consumption: 0.1 μ A.
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-------|-----|----|----|----|----|----|-----|---------------------|------------------|--------------------|
| 29.8 | -40.5 | -56.7 | -60 | — | — | — | — | — | — | 95 | 430 | 37% |
| 27.0 | -41 | -58 | — | — | — | — | — | — | — | 80 | 290 | 29% |

Note: — means the harmonic is below -60 dBm.

3.3. Measurement Results at 470 MHz Band

In the measurement, a four-layer PCB test card (4463-TCE27F434-6V) is used. The circuits are shown in Figure 15.

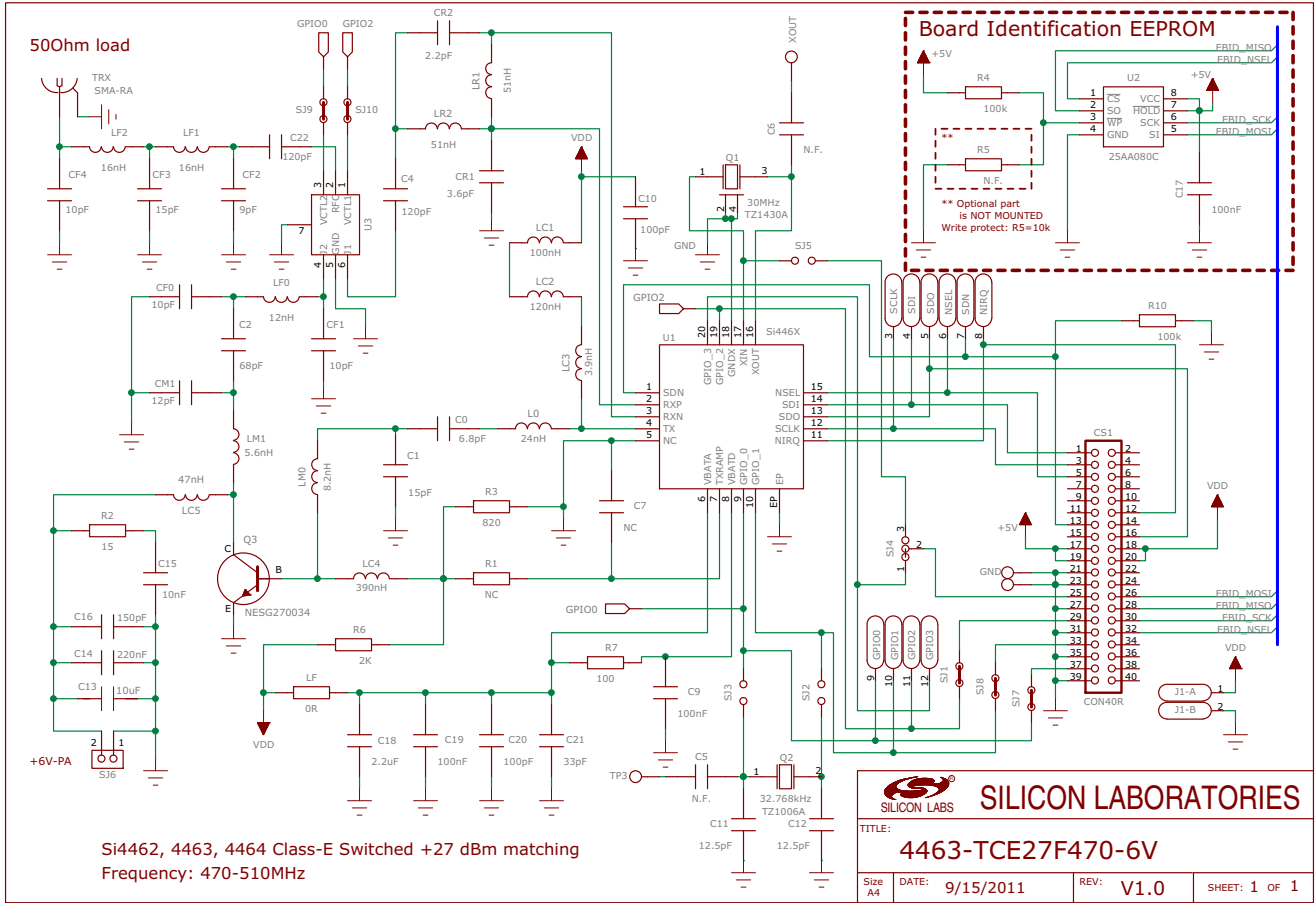


Figure 15. 470 MHz 6 V Supply Solution Schematic

The RF measurement results are as follows:

- Sensitivity: -109 dBm.
- BJT shutdown current consumption: 0.1 μ A.
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-------|-------|----|----|----|----|----|-----|---------------------|------------------|--------------------|
| 29.8 | -41.5 | -45.5 | -46.5 | — | — | — | — | — | — | 90 | 415 | 39% |
| 27.0 | -43.0 | -47.5 | -48.0 | — | — | — | — | — | — | 80 | 280 | 30% |

Note: — means the harmonic is below -50 dBm.

3.4. Measurement Results at 868 MHz Band

In the measurement, a four-layer PCB test card (4463-TCE27F868-6V) is used. The circuits are shown in Figure 16.

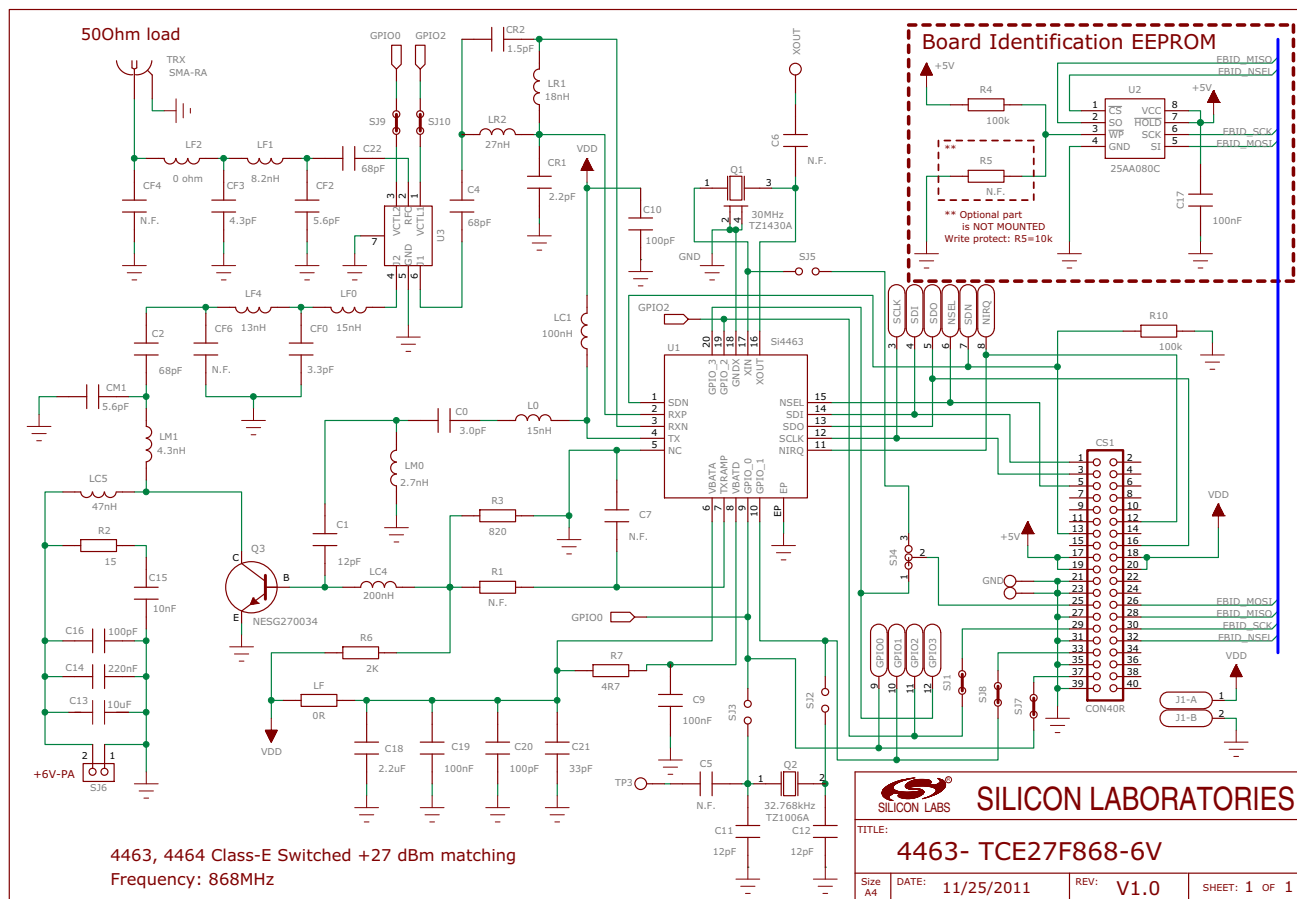


Figure 16. 868 MHz 6 V Supply Solution Schematic

The RF measurement results are as follows:

- Sensitivity: -105 dBm.
- BJT shutdown current consumption: $0.1 \mu\text{A}$.
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-------|-------|----|----|----|----|----|-----|---------------------|------------------|--------------------|
| 28.3 | -40 | -41.8 | -45 | — | — | — | — | — | — | 90 | 260 | 43% |
| 26.9 | -42.5 | -45 | -47.8 | — | — | — | — | — | — | 75 | 220 | 37% |

Note: — means the harmonic is below -50 dBm.

4. Measurement Results for NESG250134 3.3 V Power Supply Solution

The measurements are under the following parameters:

- 3.3 V power supply for BJT, 3.3 V for Si4463.
- Receiving data rate is 38.4 Kbps.
- Frequency Deviation is 20 kHz.
- Operating frequency is 169 MHz and 868 MHz separately.
- Conducted test.
- RX sensitivity measured at 1E-3 BER.

4.1. Measurement Results at 169 MHz Band

In the measurement, a four-layer PCB test card (4463-TSQ27F169) is used. The circuits are shown in Figure 17.

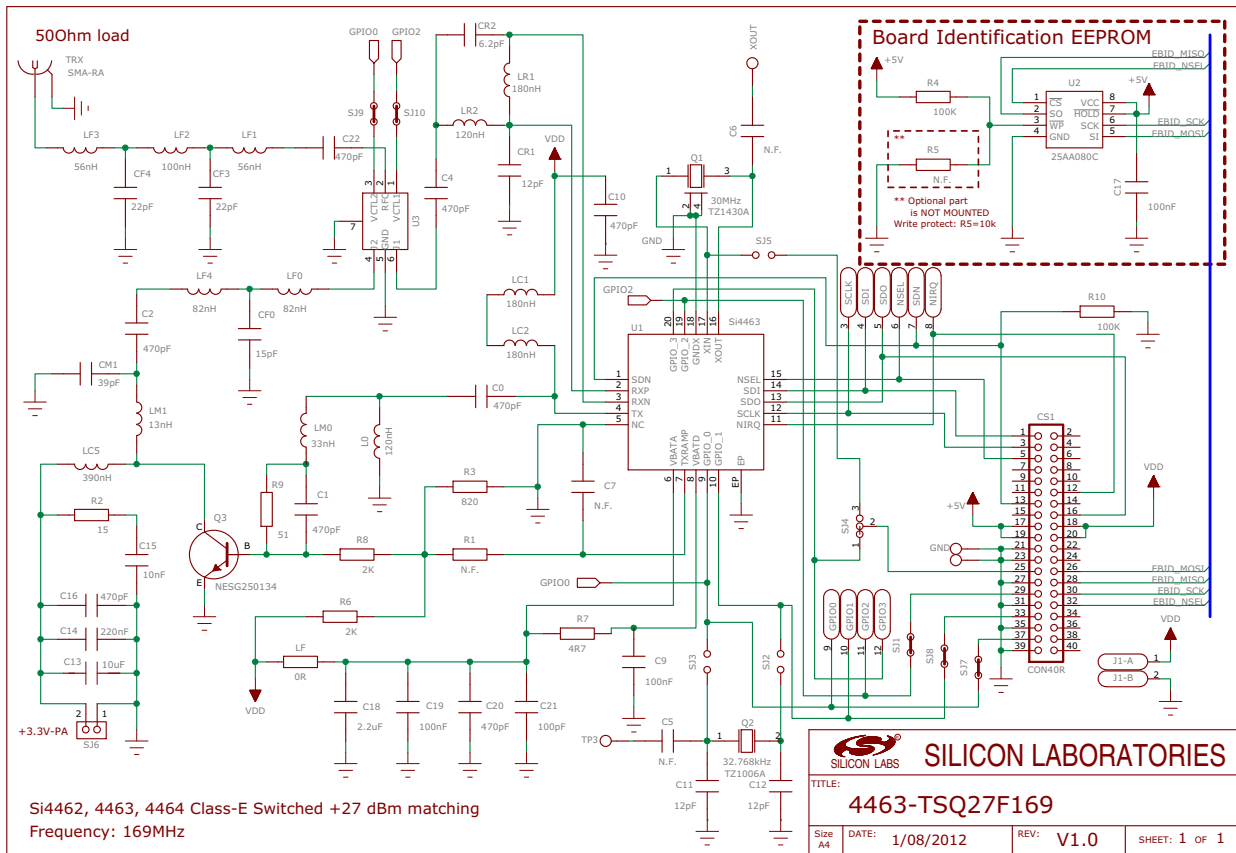


Figure 17. 4463-TSQ27F169 Schematic

The RF measurement results are as follows:

- Sensitivity: -109 dBm.
- BJT shutdown current consumption: 0.1 μ A.
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-------|-------|-------|-------|----|----|----|-----|---------------------|------------------|--------------------|
| 27 | -47.9 | -57.7 | -59.1 | -57.5 | -58.7 | — | — | — | — | 80 | 360 | 42% |

Note: — means the harmonic is below -50 dBm.

4.2. Measurement Results at 868 MHz Band

In the measurement, a four-layer PCB test card (4463-TCE27F868) is used. The circuits are shown in Figure 18.

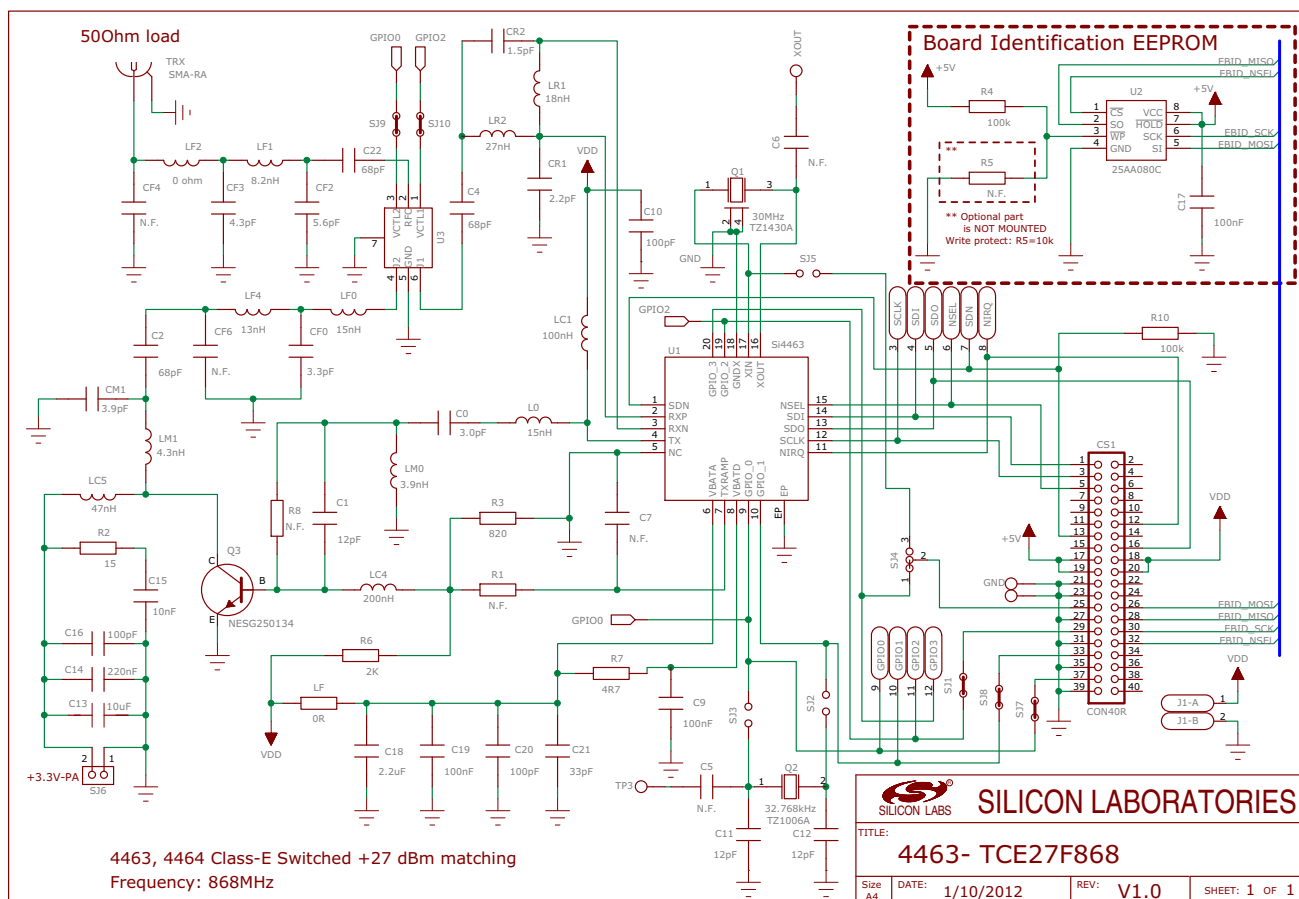


Figure 18. 4463-TCE27F868 Schematic

The RF measurement results are as follows:

- Sensitivity: -105 dBm
- BJT shutdown current consumption: 0. μ A
- Output power (dBm), harmonics (dBm), current consumption (mA) of Si4463, current consumption (mA) of BJT and total BJT efficiency at SMA connector:

| Fund. | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | I _{Si4463} | I _{BJT} | Eff _{BJT} |
|-------|-------|-----|-----|----|----|----|----|----|-----|---------------------|------------------|--------------------|
| 24.6 | -40.5 | -42 | -45 | — | — | — | — | — | — | 85 | 205 | 42.6% |

Note: — means the harmonic is below -45 dBm.

5. Layout Requirement

To obtain a high level of RF performance and reliability, follow the common RF circuit layout guideline that is used in the EZRadioPRO layout. In addition, use the following suggestions to achieve optimum performance:

- The TX and RX path layouts are separated and isolated by a GND metal on the top layer as much as possible to minimize the mutual coupling effects.
- The control signals (GPIO0 and GPIO2) for RF switch should be placed in the inner layer of the PCB to avoid interference from the high power transmitted signal.
- All of the circuit lines in the PA matching and filters should be 50 Ω microstrip line.
- Exposed pad footprint of the PA BJT should use more vias to connect to GND to achieve optimal grounding and best thermal coupling.
- In the filter layout, the two capacitors should be placed on a different side of the circuit line.
- The shield can be used to get good radiation performance.

DOCUMENT CHANGE LIST

Revision 0.1 to Revision 0.2

- Include all 6 V power supply NESG270034 BJT designs (169 MHz, 434 MHz, 470 MHz, and 868 MHz)
- Add 3.3 V power supply NESG250134 BJT designs (at 169 MHz and 868 MHz)
- Include detailed test data
- Correct the relative information of the BJTs, NOT FETs



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