# Low-Frequency RFID in a Nutshell

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## ABSTRACT

This application report describes the principles of Texas Instruments low-frequency RFID products, how to choose the right components, and shows best practices for a good PCB layout.

This application report can be used as a guideline for designing a system with the TMS37157 PaLFI chip.

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# 1 Introduction

RF design is often perceived as being very difficult and hard to understand. This application report guides you from the principles of the low-frequency (LF) RF communication to the right passive components and finally to a good layout.

The transmit frequency of the TI low-frequency RF products is 134.2 kHz. The communication range for passive devices (powered by the magnetic field of a RFID reader) is typically up to 10 cm.

# 2 Low-Frequency RF Communication

Texas Instruments offers different types of low-frequency RFID devices. All passive TI RFID devices require a charge phase in which a capacitor is charged (TI half duplex (HDX) principle). Read-only devices then send their information (typically 96 bits). Read/write devices need to receive a command to perform a desired action and answer to the downlink command. Active 3D devices (for example, for passive entry or passive start devices) use the downlink channel to receive a command via LF and wake a microcontroller if the right wake pattern is received. The uplink is usually transmitted via UHF.

This application report describes the complete communication (downlink and uplink) that is valid for all types of transponders.

Low-frequency RF communication can be used for short distances even in challenging environments. The direction of the antenna matters. Always use the antenna in its preferred direction. This should be kept in mind while designing a RFID system. Figure 1 shows how to position a stick antenna near an RFID base station antenna.

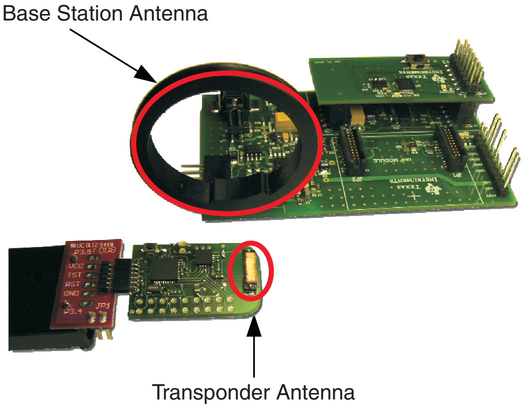


**Figure 1. Correct Placement of a RFID Stick Antenna Near a Base Station**

## 2.1 *Downlink - From the RFID Base Station to the RFID Transponder*

An RFID communication is always initiated by the base station. The RFID transponder usually has no local voltage supply and needs the LF field, which is sent by the base station, to function.

A typical communication consists of a charge phase of 25 ms to 50 ms,which is followed by the command phase. A read and a program command are shown in Figure 2 and Figure 3, respectively. In both cases the transponder sends its response after it detects a loss of the LF field.

Figure 2 to Figure 4 show a complete communication exchange between a base station and an RFID transponder. All signals are measured at the transponder and have the following meaning:

**Table 1. Signal Overview of Scope Print Outs for Figure 2 to Figure 4**

| NO. | NAME | COLOR | UNIT | MEANING |
|---|---|---|---|---|
| 1 | RF | Yellow | 5 V/div | RF voltage at the transponder antenna |
| 2 | VCL | Blue | 2 V/div | Voltage at the VCL charge capacitor |
| 3 | EOB | Magenta | 1 V/div | End of burst detector output of transponder |

The RF voltage is the voltage that is generated by the magnetic field of the RFID base station at the transponder antenna. The RF voltage is limited by the internal RF limiter of the transponder. The RF voltage is used to charge the VCL capacitor (typically 220 nF); VCL is the operating voltage for the transponder and is limited to approximately 6 V. For proper operation, make sure that the VCL limit is reached before the end of charging. The required charging time is a function of distance, antenna size, inductance, Q factor, and base station field strength.

After the charge phase, data is transmitted using On/Off Keying (see Table 2 for timings). The transponder decodes the received data. The EOB output of the transponder shows the detection of the bits. If the time between two rising edges of EOB is longer than $t_{bitH}$ (see Table 2) a high bit is detected; otherwise, a low bit is detected.

For a program page command, a 2-byte BCC is transmitted together with the data. Additionally, a second power burst (Power Burst 2, see Figure 3) is needed for programming the EEPROM. If the received BCC (needed for program and lock commands) is wrong or if the VCL level does not reach the VCL checker limit, the transponder performs a discharge without responding (see Figure 4 for a program command with a wrong BCC).

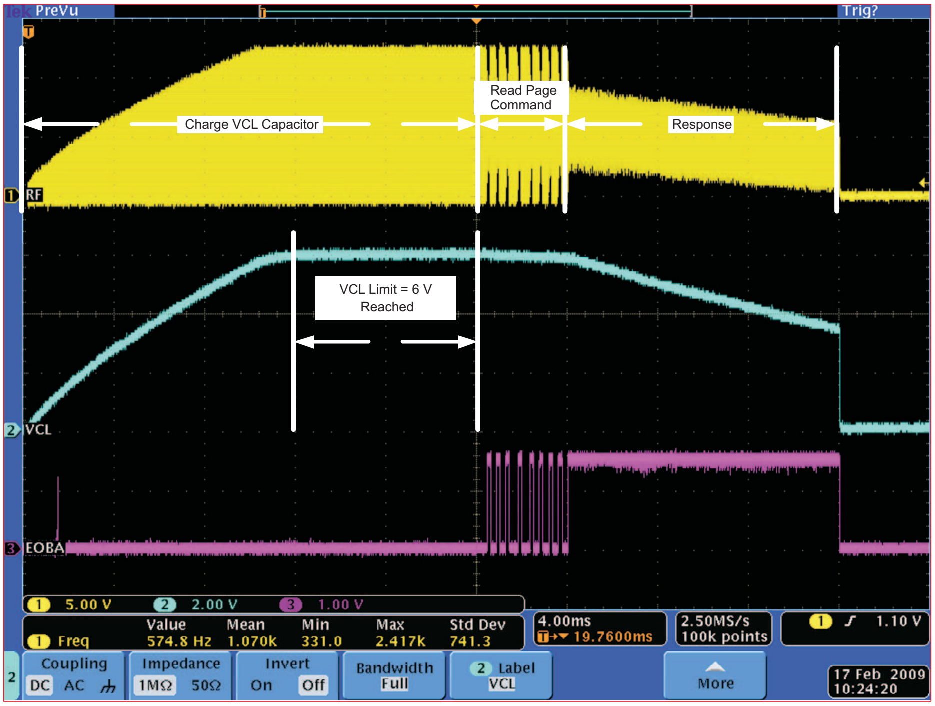


Figure 2. Read Page Command With Response (4 ms/div)

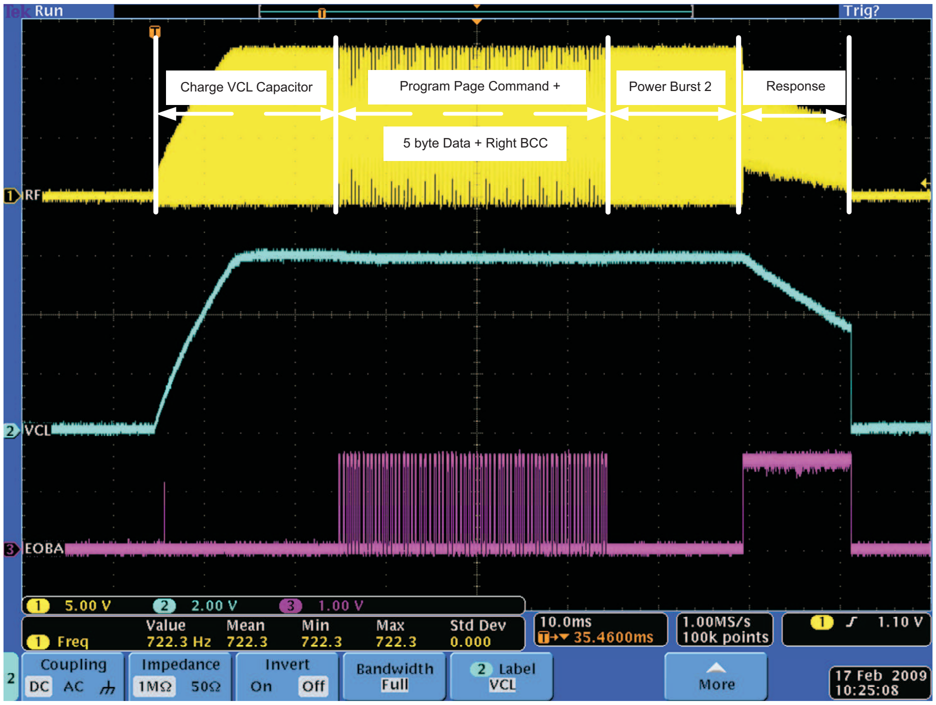


Figure 3. Program Page Command With Correct BCC and Response (10 ms/div)

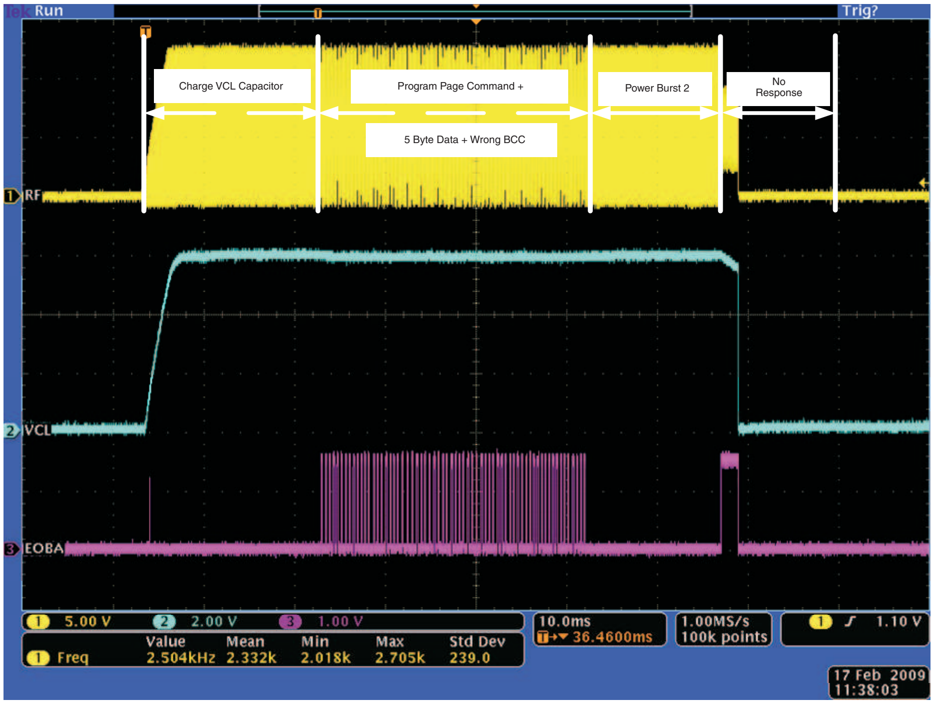


Figure 4. Program Page With Incorrect BCC and No Response (10 ms/div)

The downlink uses On/Off Keying for transmitting the data from the base station to the transponder. The base station switches the 134.2 kHz LF field on and off to modulate the data.

The bits are modulated with Pulse Position Modulation (PPM). Figure 5 shows the PPM timing for a read page command; Figure 6 shows the timing for a program page command. The program page command needs one additional transmitter off phase and a power phase. See the device-specific data sheet for the correct timings. For TMS37157 the recommend timings are shown in Table 2.

**Table 2. Example Timings for the TMS37157 PaLFI Device**

| SIGN | TIME | UNIT | NODE |
|---|---|---|---|
| $t_{tx}$ | 25 | ms | Charge time to charge VCL capacitor |
| $t_{offi}$ | 170 | µs | Initial off time |
| $t_{off}$ | 170 | µs | Standard off time |
| $t_{onH}$ | 350 | µs | Transmitter on time for a high bit |
| $t_{bitH}$ | 520 | µs | Period for a high bit |
| $t_{onL}$ | 230 | µs | Transmiter on time for a low bit |
| $t_{bitL}$ | 400 | µs | Period for a low bit |
| $t_{prg}$ | 15 | ms | Program time necessary for programming the EEPROM |
| $t_{Hdet}$ | 510 | µs | High bit period must be 210 µs (minimum) to 1730 µs (maximum) |

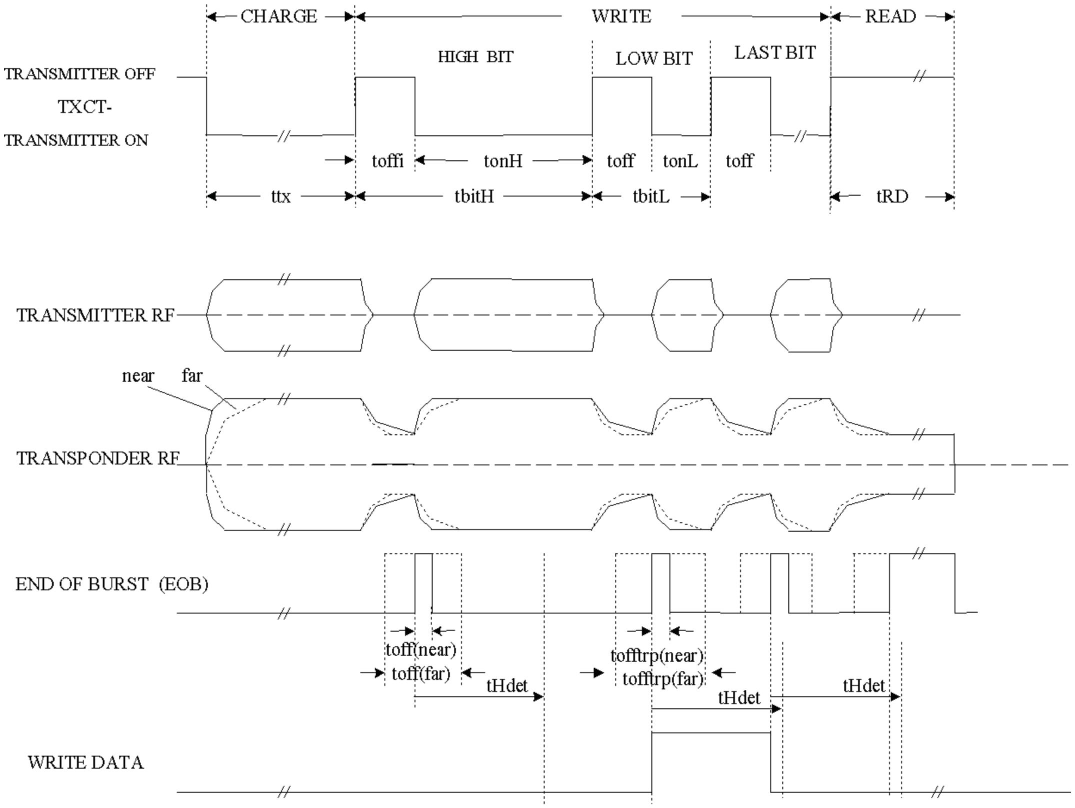


**Figure 5. PPM Timing for a Read Command**

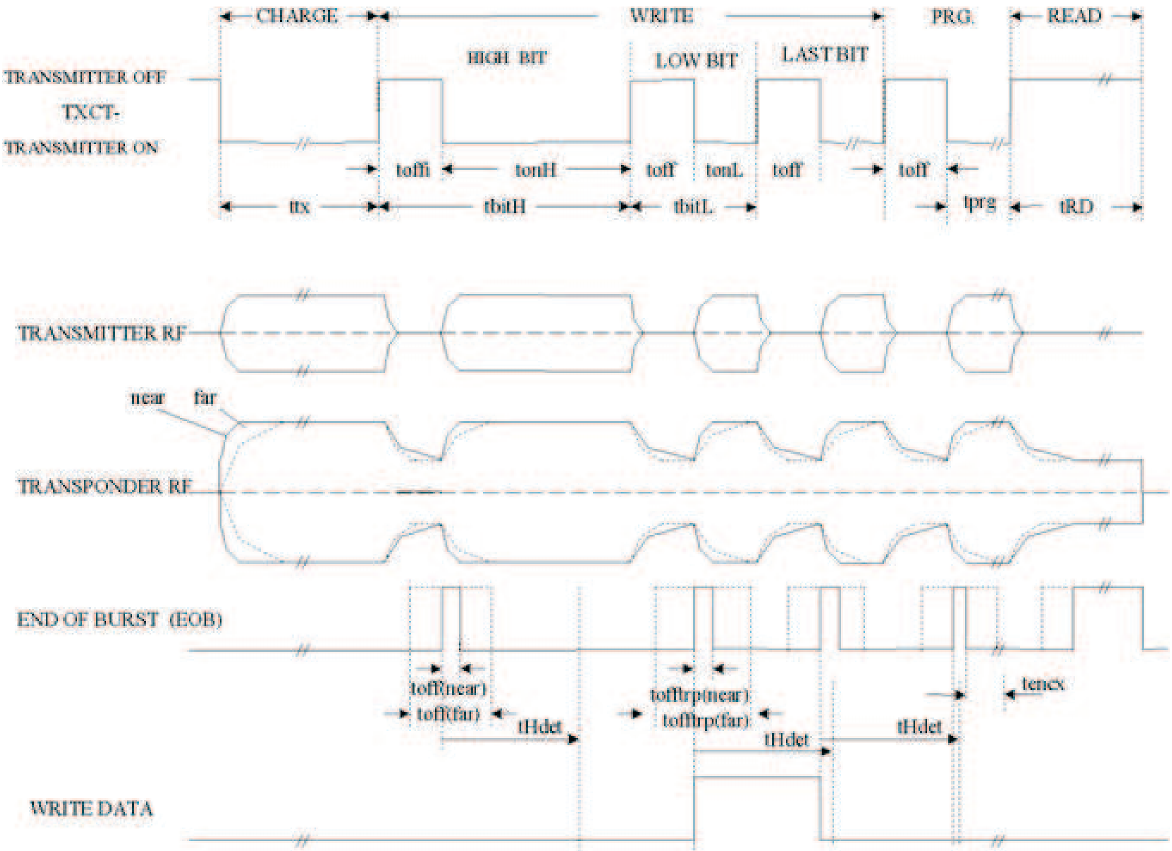


Figure 6. PPM Timing for a Program Command

## 2.2 Uplink - From the RFID Transponder to the RFID Base Station

After reception of a valid command, the transponder processes the data and sends a response. The response is always 96 bits long and has the structure shown in Figure 7; a detailed description of the fields is shown in Table 3.

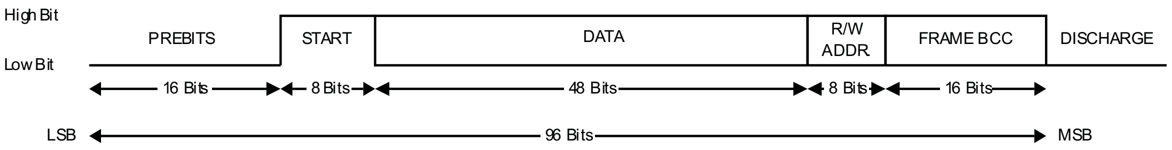


Figure 7. Response Format for a Transponder LF Command

One high bit is represented by 16 sinus oscillations with a frequency of 123.7 kHz (length: 129.3 µs). One low bit is represented by 16 sinus oscillations with a frequency of 134.7 kHz (length: 128.3 µs).

Table 3. Description of the Different Fields of a Transponder Response

| FIELD | LENGTH | NODE |
|---|---|---|
| PREBITS | 16 bits | Always 16 low bits - 0x00 00 |
| START | 8 bits | Depends on type of transponder - TMS37157 : 0x7E |
| DATA | 48 bits | Depends on the performed command |
| R/W ADDRESS | 8 bits | Depends on the performed command |
| FRAME BCC | 16 bits | Calculated from START, DATA, and R/W ADDRESS |

The response is always 96 bits long, resulting in a maximum duration for the response of approximately 12.2 ms. After transmitting the data, the transponder discharges the VCL capacitor. If the transponder receives an invalid command, it shows only the 16 pre-bits followed by discharging the VCL capacitor (see Figure 4).

## 3 How to Choose the Right Passive Components

A Texas Instruments RFID low-frequency transponder system needs only a few passive components. This application report describes the components for 1D systems using the TMS37157. The application circuit for the transponder function of the TMS37157 is shown in Figure 8.

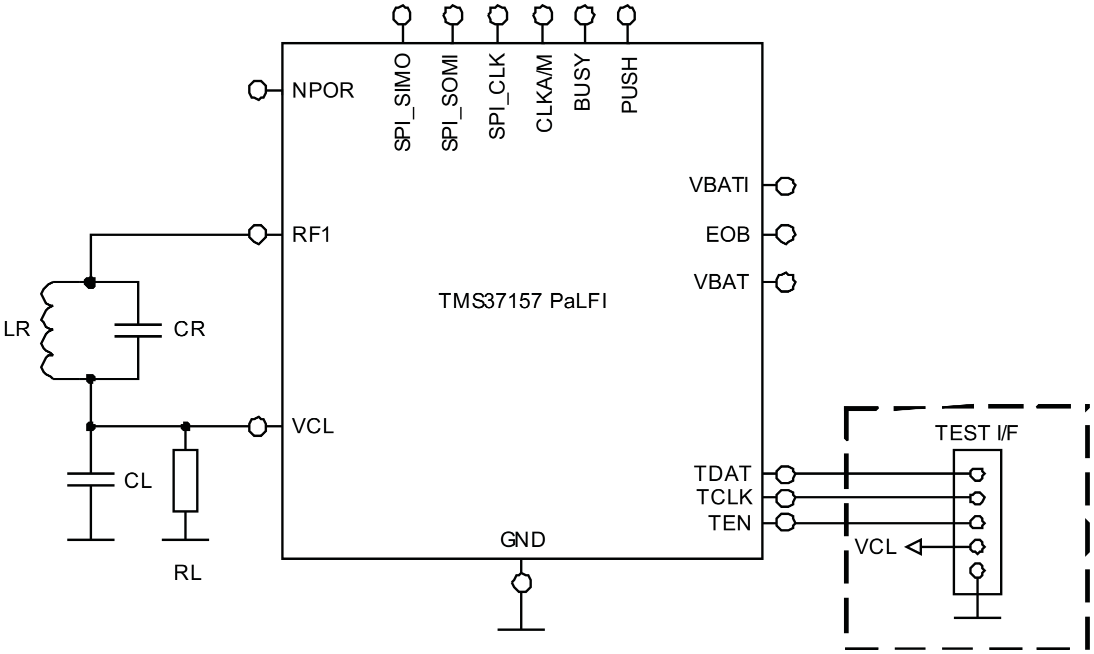


**Figure 8. Transponder Only Application Circuit TMS37157**

The components and recommended values are listed in Table 4.

**Table 4. Recommended Components for RFID Transponders Based on the TMS37157**

| SYMBOL | FUNCTION | TYPE | VALUE |
|---|---|---|---|
| LR | Antenna | Ferrite stick antenna | 2.66 mH |
| CR | Resonance capacitor | NPO | 470 pF |
| CL | VCL charge capacitor | X7R | 220 nF |
| RL | Termination resistor | Arbitrary | 1 MΩ |

### *3.1 Charge Capacitor CL and Resonance Capacitor CR*

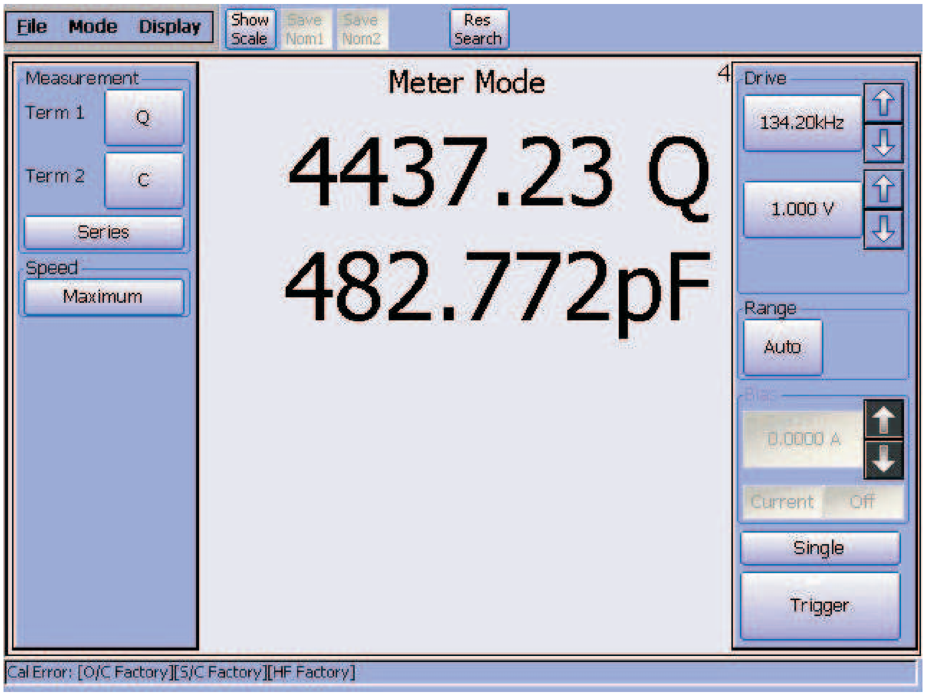
A half duplex (HDX) RFID system requires a charge capacitor to store energy for phases during which no magnetic field from the RFID base station is present. Texas Instruments recommends using a 220-nF surface mount capacitor, X7R type, with a maximum operating voltage of at least 16 V.

The resonance circuit of a RFID circuit is determined by the antenna and the resonance capacitor. Therefore, a resonance capacitor with a low variation in capacity and a high quality factor is required. Texas Instruments strongly recommends using a 470-pF ±2% surface-mount capacitor, NPO (CGO) type, with a maximum operating voltage of at least 20 V.

Only NPO (CGO) type capacitors have a high enough quality factor to ensure a properly working RFID system. Using another type of capacitor will likely result in a non-working system.

### 3.1.1 How to Measure the Quality Factor and Capacitance of a Capacitor

To measure the quality factor and the capacitance of a capacitor, an impedance analyzer is needed. Figure 9 shows the measurement performed with a Wayne Kerr impedance analyzer. Attach the capacitor between the two measurement pins of the impedance analyzer. The measurement frequency is 134.2 kHz (the nominal frequency of LF RFID). Be aware that the quality measurement is not precise for such high values. The quality should be above 1000.



Measurement
Term 1: Q
Term 2: C
Speed: Maximum

4437.23 Q
482.772pF

Drive: 134.20kHz, 1.000 V
Range: Auto
Bias: 0.0000 A, Current Off

Cal Error: [O/C Factory][S/C Factory][HF Factory]

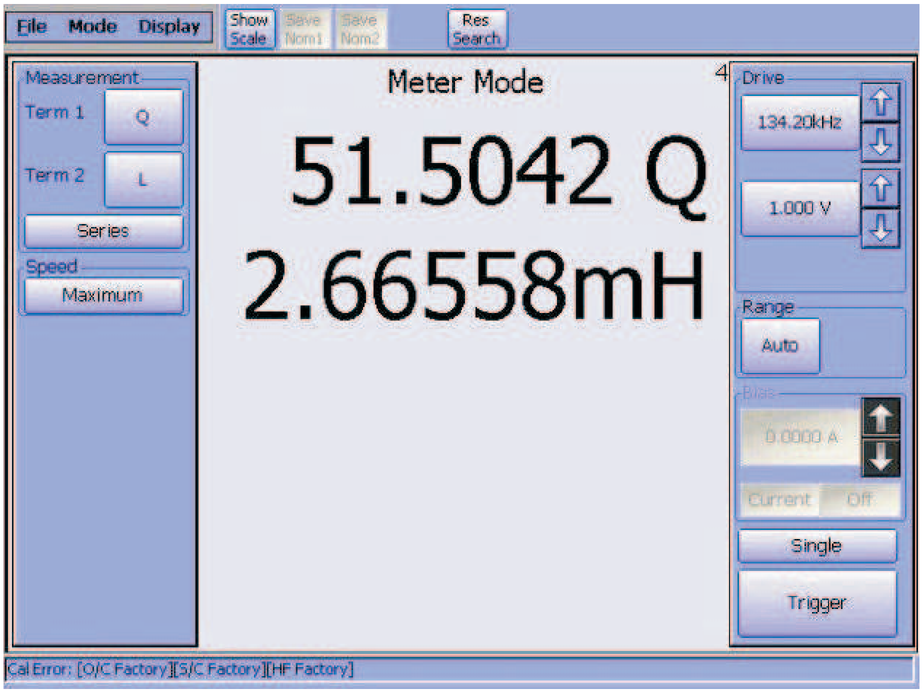
**Figure 9. Quality Factor and Capacity of a NPO Capacitor**

## *3.2 Antenna*

The quality factor of a NPO type resonance capacitor is normally above 1000. Thus, one of the most importing factors for the overall quality factor of the resonance circuit is the antenna. In combination with the TMS37157, Texas Instruments recommends using a ferrite stick antenna with an inductivity of 2.66 mH ±2.8%. To ensure an overall system quality of at least 30 (required for proper operation of the TMS37157) the quality factor of the antenna should be between 40 and 75.

### 3.2.1 How to Measure the Quality Factor and Inductivity of an Antenna

To measure the quality factor and the inductivity of an antenna, an impedance analyzer is needed. Figure 10 shows the measurement performed with a Wayne Kerr impedance analyzer. Attach the antenna between the two measurement pins of the impedance analyzer. The measurement frequency is 134.2 kHz (the nominal frequency of LF RFID).



Meter Mode

51.5042 Q

2.66558mH

Term 1: Q

Term 2: L

Speed: Maximum

Drive: 134.20kHz, 1.000 V

Range: Auto

Bias: 0.0000 A

Cal Error: [O/C Factory][S/C Factory][HF Factory]

**Figure 10. Quality Factor and Inductivity of an Antenna**

# 4 Resonance Frequency and System Quality

## *4.1 How to Calculate the Resonance Frequency of a Resonance Circuit*

The resonance frequency of a resonance circuit can be calculated with Equation 1.

$$f_{res} = \frac{1}{2\pi \sqrt{C_{res} \bullet L_{antenna}}} \tag{1}$$

Where:

- $f_{res}$ – Resonance frequency of the resonance circuit
- $C_{res}$ – Resonance capacitor
- $L_{antenna}$ – Inductivity of the antenna

The resonance frequency of the components from Figure 9 and Figure 10 is 140.44 kHz. The TMS37157 has an additional internal parasitic capacitance ($C_{int}$, see Figure 11) of approximately 30 pF, which must be added to $C_{res}$. In addition, the TMS37157 has an integrated trimming function that offers the possibility to switch on additional resonance capacitors to trim $f_{res}$ to 134.2 kHz.

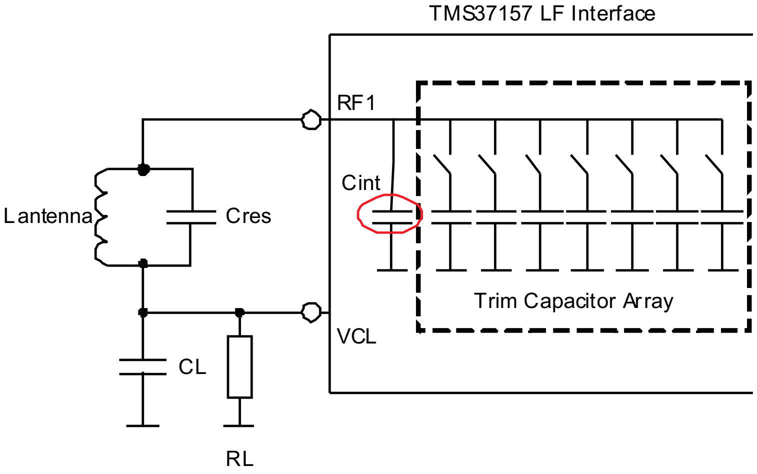


**Figure 11. Internal Capacitances of TMS37157**

### 4.2 How to Measure the Quality Factor and Resonance Frequency of an RF Circuit

For measurement of the quality and resonance frequency of an RF circuit, a spectrum analyzer is needed. Connect a send coil to the output of the spectrum analyzer and set the output power to minimum. For Texas Instruments low-frequency systems, choose a center frequency of 134.2 kHz. Connect another cable to one antenna pin and ground, the other end to the input of the spectrum analyzer. Be aware that high voltages can appear at the antenna, which can damage the input of the spectrum analyzer. It is recommended to place the RF circuit away from the send coil initially (20 cm or more), and then close the distance until a superelevation at the spectrum analyzer can be seen (see Figure 11). The peak determines the resonance frequency. The quality factor can be calculated from the resonance frequency and the 3-dB bandwidth. The 3-dB bandwidth is the difference between the two frequencies where the power is half (3 dB lower) as in resonance. The quality factor can be calculated with Equation 2.

$$Q = \frac{f_{res}}{B_{3dB}} \tag{2}$$

Where:

- Q – Quality factor of the resonance circuit
- $f_{res}$ – Resonance frequency of the resonance circuit
- $B_{3dB}$ – 3-dB bandwidth

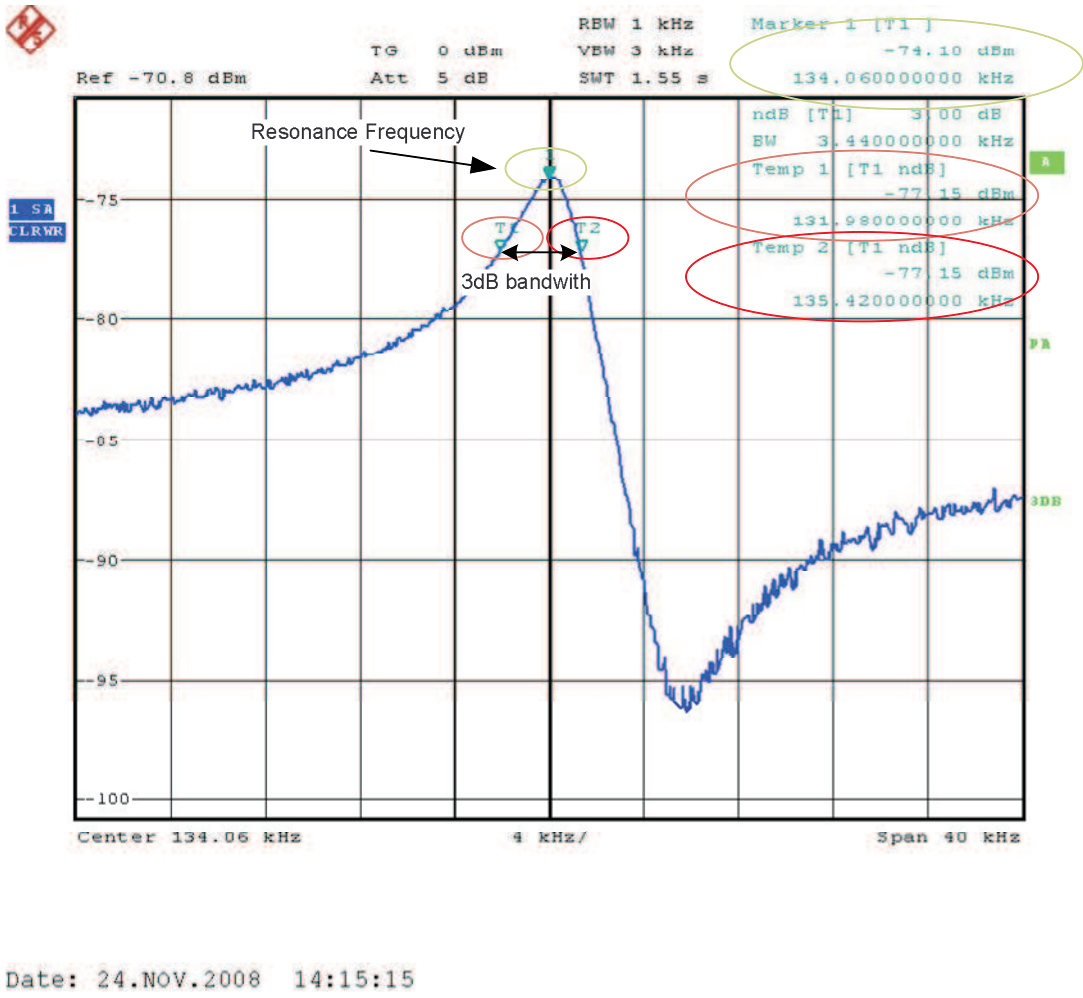


Figure 12. Resonance Curve of an RFID System

The quality factor of the RFID system measured in Figure 12 is calculated with Equation 3.

$$Q = \frac{f_{res}}{B_{3dB}} = \frac{134.06kHz}{3.440kHz} = 39 \tag{3}$$

## 4.3 Influence of Resonance Frequency and System Quality on an RFID System

The TMS37157 requires a quality factor of at least 30 to work properly. The quality factor of the resonance circuit is determined by different factors:

- Antenna should have a high Q (52 to 60)
- Resonance capacitor must be NPO (CGO) type
- In the PCB design, no metal layer should be underneath or around the antenna
- No signal routing under the antenna
- Keep PCB traces to the antenna short, straight, and thin
- Keep antenna pads as small as possible
- Quality factor and resonance frequency change with temperature

An RFID system is described by the parts of the resonance circuit (antenna, capacitor) but also by the RFID chip and the other active and passive parts mounted on the PCB. The last step during production of an RFID system is to trim the circuit. Because of component tolerances, every RFID system must be trimmed—this can be easily achieved with the integrated trim function of the TMS37157.

A low quality factor and untrimmed resonance circuit decrease the performance of the whole RFID system. Inadequate energy is induced into the RF circuit of the transponder, resulting in a low voltage at the antenna (RF pin) and a poorly charged VCL capacitor. Metal under the resonance circuit detunes the resonance circuit and lowers the quality factor immensely; this should be considered while designing a mount-on-metal system.

### *4.4 Recommended PCB Layout*

For a good PCB layout, keep in mind the factors which determine the system quality, mentioned in Section 4.3 . An example for a recommended PCB layout is shown in Figure 13, where the L1 antenna and the C11 resonance capacitor are shown. The PCB traces to the antenna are straight, thin, and short and are not routed under the antenna. The antenna pads are as small as possible, and no metal layer is under or around the antenna.

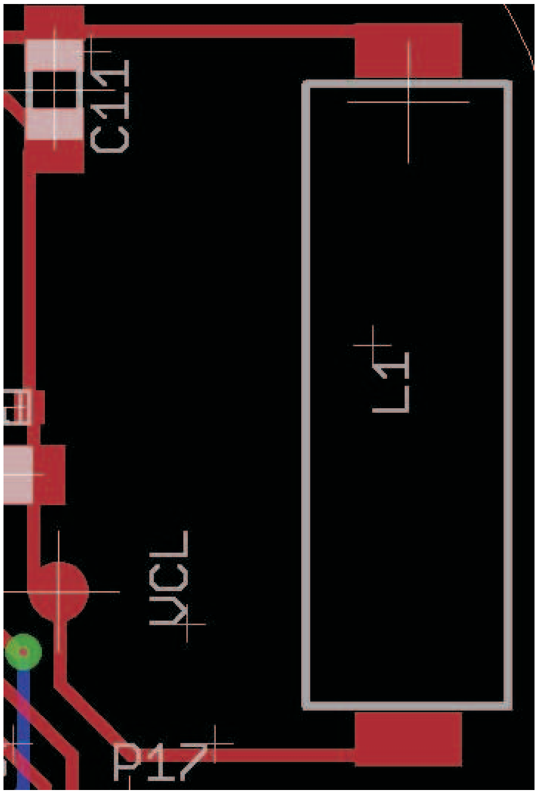


**Figure 13. Recommended PCB Layout for an Antenna**

## 5 Summary

This application report gives a short introduction about low-frequency RFID from Texas Instruments. The reader is introduced to LF RFID principles, is advised how to choose the right passive components, and should be aware of the influence of resonance frequency and system quality in an RFID transponder system.

## 6 References

1. *TMS37157 Passive Low-Frequency Interface (PaLFI) Device With EEPROM and 134.2-kHz Transponder* data sheet (SWRS083)
2. *eZ430-TMS37157 Development Tool User's Guide* (SLAU281)
3. *Communicating With the RFID Base Station* (SWRA283)

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