Low Cost FM Radio LNA using BFR340F

Mobile Phone Applications

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RF and Protection Devices

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1 Introduction

FM Radio has a long history to its credit starting from its development in 1933. Today, FM radio is an integral part of almost all mobile phones, including the ultra low cost phones. FM Radio broadcast today is not just used to listen to songs and news, but also used for RDS (Radio Data System) to receive various services including TMC (Traffic Message Channel) which gives traffic information for navigation purposes. In addition, some handsets are being equipped with FM Radio transimission capability to send voice signals to car audio systems or Hi-Fi systems.

Therefore, FM system design in a phone is getting more and more complex. Till recently, the headset served as the antenna for FM Radio reception, wherein the antenna size is a bit relaxed and the antenna performance is satisfactory. A new trend has emerged to be able to use FM radio also without the headset, wherein the antenna embedded into the phone. But in this case, the space constraint poses a challenge on the antenna design. Shrinking the size of the antenna reduces antenna gain and bandwidth, which introduces a high loss into the system which deteriorates the receiver performance, namely the receiver sensitivity. This application note presents Infineon solution to the aforementioned challenges leading to the design of a high performance RF front end with the lowest power consumption.

A general topology for the RF front-end of FM Radio is as shown in **Figure 1**. Variations of the given application schematic are possible based on the complete system design and concept. These may include systems with only external headset antenna, only internal embedded antenna or both antennas co-existing. Infineon offers the complete chain of RF front-end parts between the antenna and the receiver IC for FM Radio, which include ESD protection devices, RF switches and LNAs. The focus of this application note is Low Noise Amplifier for FMR.

A ESD protection circuit is needed at the antenna to protect the front-end system from ESD strikes, as the antenna is susceptible to ESD events. More details and Infineon solutions for ESD protection can be found in **Appendix 1**.

A Single Pole Double Throw or SPDT RF switch is used to toggle between the headset and embedded antenna. The switch being in front of the LNA and in the vicinity of strong cellular signals should introduce minimal loss to the system and offer high linearity. To know more about Infineon solutions for RF Switches, please refer to Reference [2].

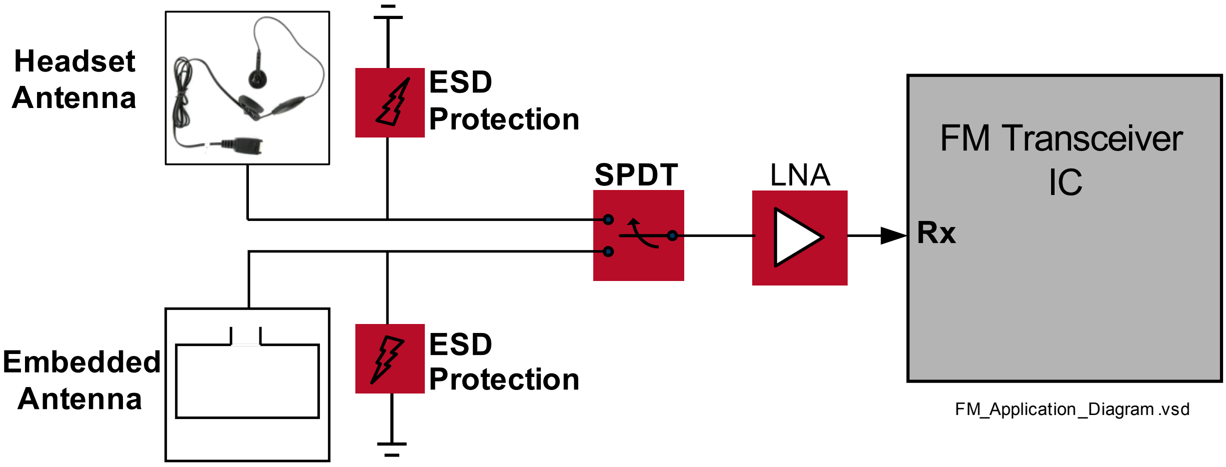

Figure 1 FM Radio RF Front-End schematic

A Low Noise Amplifier or LNA follows the switch, which significantly reduces the noise figure of the whole receiver chain, thereby improving the receiver sensitivity. However, there are a few challenges in the design of the LNA for this purpose. Using it in a hand held device demands low current consumption and high linearity due to the co-existence of cellular bands. In a system with internal antenna, due to the very small size, the antenna impedance is very high and thus the LNA has to be matched to this high impedance and in addition offer a low noise figure.

2 Infineon Solution

Infineon offers its LNA solution using a ultra low cost discrete transistor BFR340F, which fulfills all these performance criteria. The LNA is designed for worldwide FM band (76-108 MHz). The LNA finds its application in all kinds of mobile devices like mobile phones, PDAs, portable FM radio, MP3 players etc.

The following table gives a quick overview on the performance of the FM Antenna LNA described in this application note.

Table 1 Electrical characteristics at T_A = 25°C, V_{CC} = 1.8V, ICC_q =2.9 mA, f = 100MHz All measurements done in a 50 Ohm system

Parameter	Symbol	Values			Unit
		Min.	Typ.	Max.	
Insertion power gain	$\|S_{21}\|^2$		15.5		dB
Input return loss[1)]	RL_{IN}		1.0		dB
Output return loss	RL_{OUT}		24.7		dB
Isolation	ISO		42		dB
Noise figure (Z_s=50Ohm)[2)]	$F50ohm$		1.45		dB
Input 1dB gain compression point	$P_{-1dB,in}$		-27		dBm
Output 1dB gain compression point	$P_{-1dB,out}$		-12.2		dBm
Input 3rd Order Intercept Point[3)]	*IIP3*		-16		dBm
Output 3rd Order Intercept Point[4)]	*OIP3*		-1.2		dBm

1) LNA presents a high input impedance match over the 76-108 MHz FM radio band.
2) Does not include PCB and SMA connector losses
3) IP3 value depends on termination of all intermodulation frequency components. Termination used for the measurement is 50 Ω from 0.1 to 6 GHz
4) IP3 value depends on termination of all intermodulation frequency components. Termination used for the measurement is 50 Ω from 0.1 to 6 GHz

3 Application Circuit

The FM Radio application schematic for the BFR340F is shown in **Figure 2** and the function of each component is explained in **Table 2**.

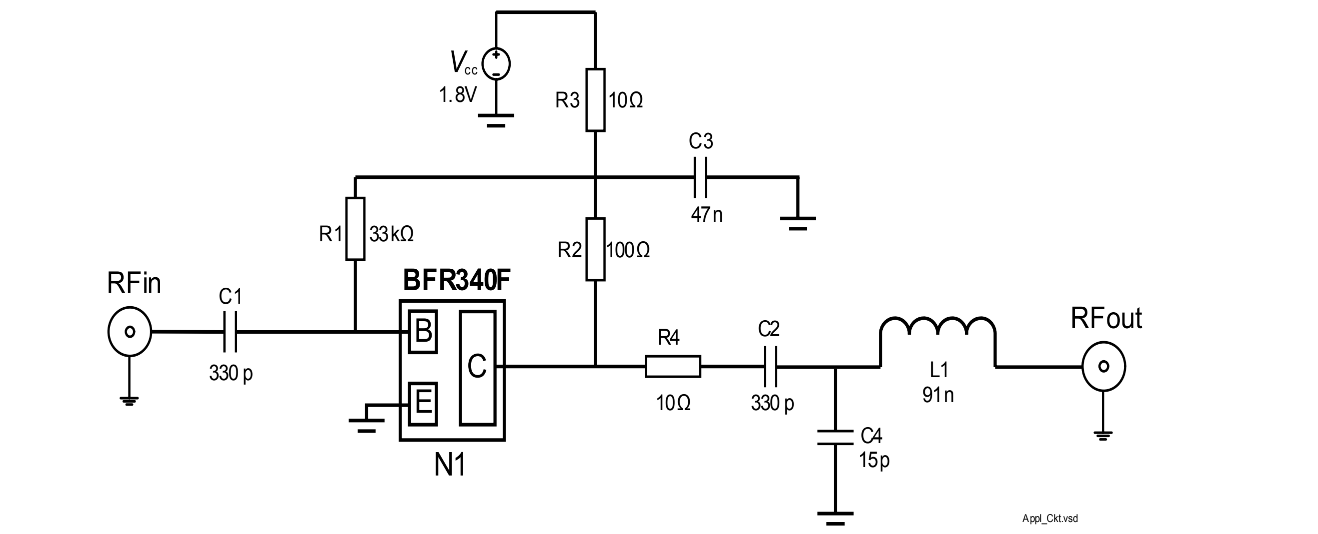

Figure 2 Application schematic for FM Radio

Table 2 Bill of material

Component	Value	Manufacturer / Type	Function
N1	BFR340F Transistor	Infineon Technologies / TSFP-3	LNA Active device
C_1	330 pF	Various / 0402	DC blocking
C_2	330 pF	Various / 0402	DC blocking
C_3	47 nF	Various / 0402	DC stabilization
C_4	15 pF	Various / 0402	Narrow-band output matching for FMR
R_1	33 kOhm	Various / 0402	Biasing
R_2	100 Ohm	Various / 0402	Biasing, Matching, Stability
R_3	10 Ohm	Various / 0402	Biasing and DC operating point stabilization over temperature & transistor h_{fe}variation
R_4	10 Ohm	Various / 0402	RF Stability
L_1	91 nH	Wirewound / 0402	Narrow-band output matching for FMR

4 Evaluation Board

To enable a fast and stand alone evaluation of the Application circuit described in this document, Infineon offers an application board, which is as shown in the **Figure 3**.

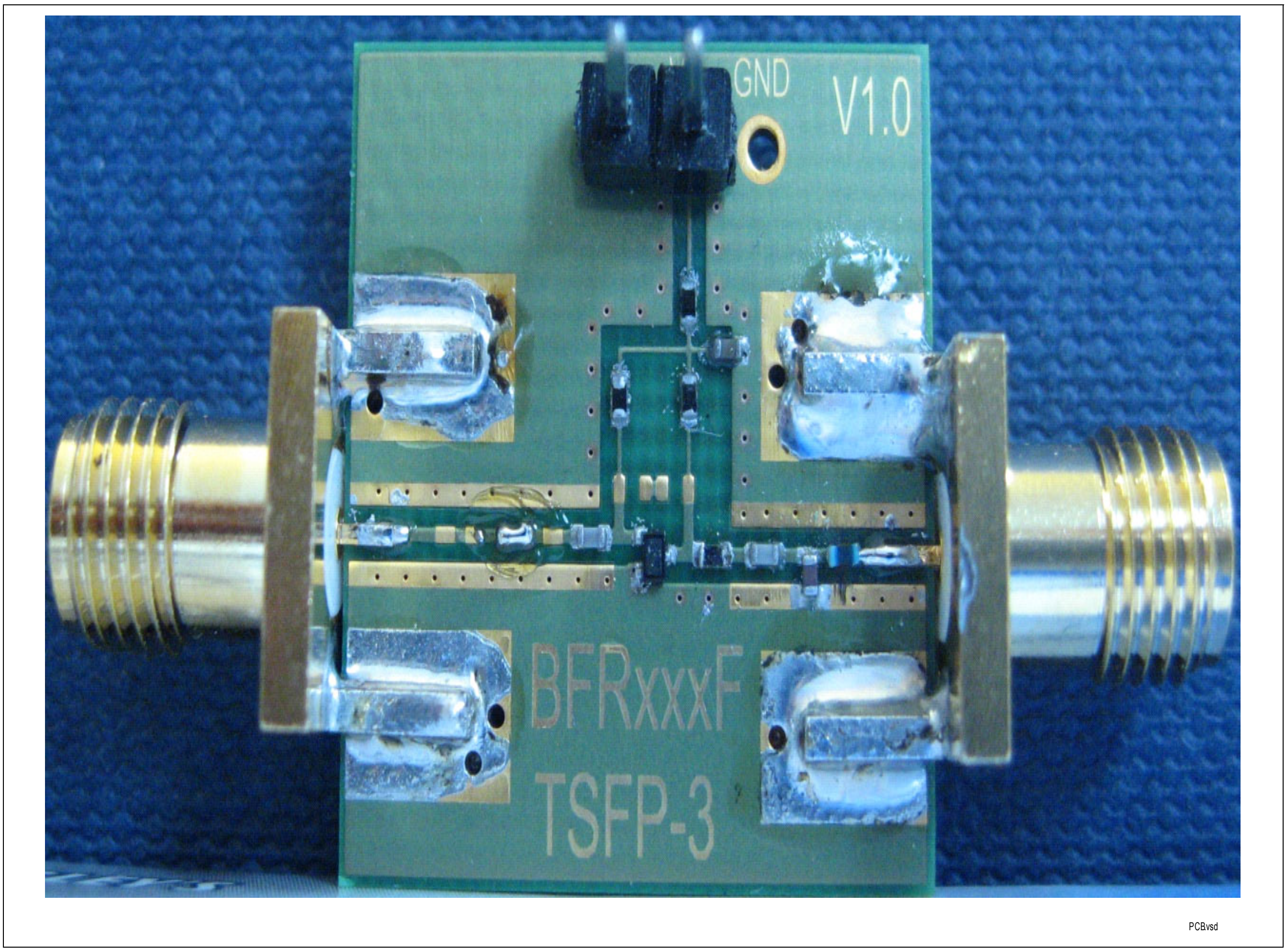

Figure 3 Evaluation Board

The PCB cross-section of the evaluation board is shown in **Figure 4**.

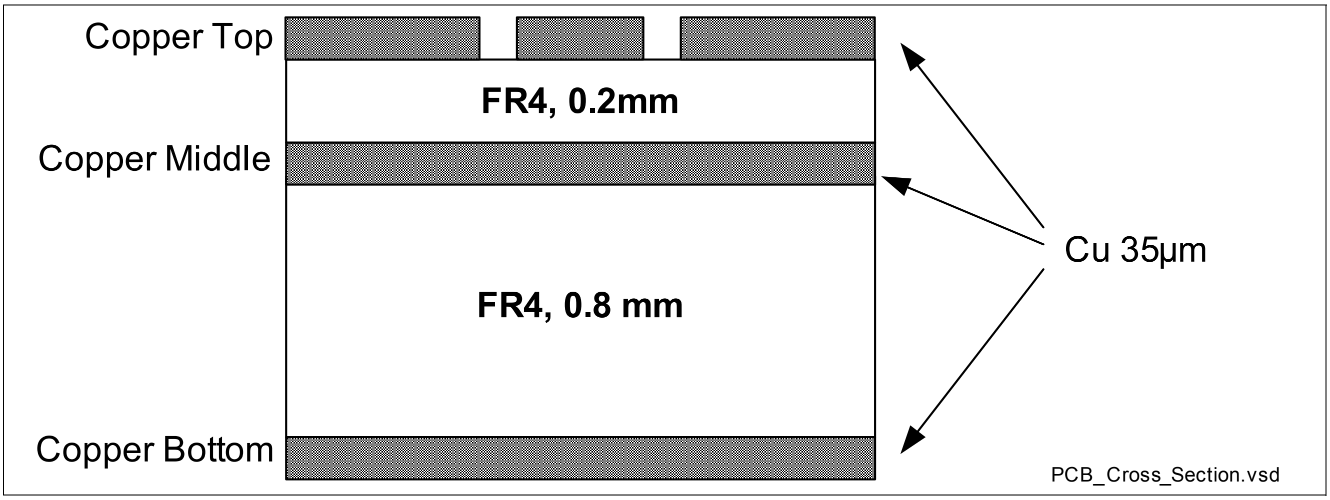

Figure 4 PCB Cross-section

5 Measurement Results

This section presents the measurement results of the aforementioned application circuit on the evaluation board. The measurements were performed at 25°C and include the losses of both SMA connectors and the PCB microstrip lines.

5.1 Narrowband Results

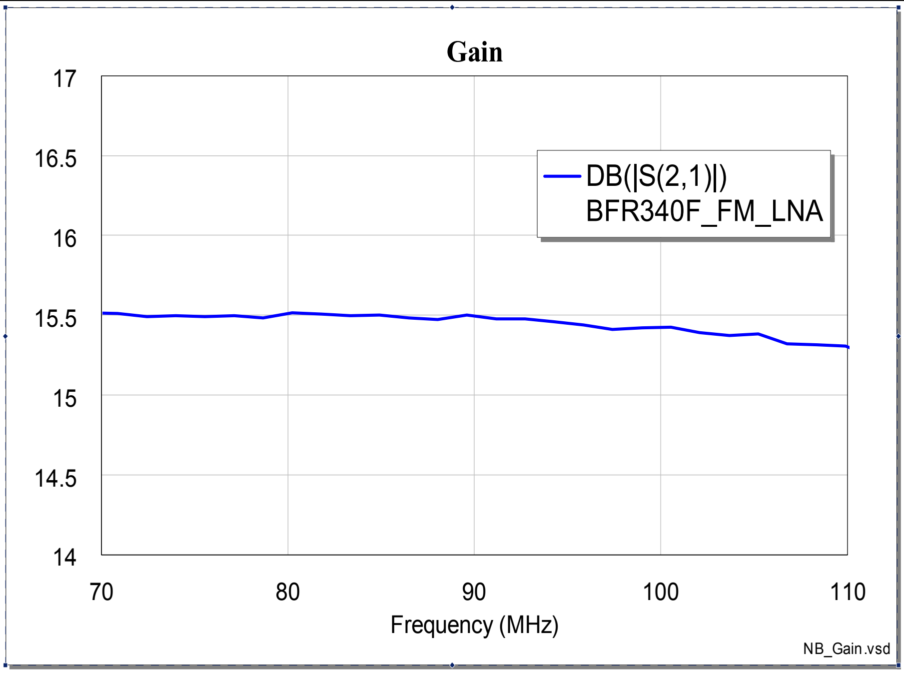

Figure 5 Power Gain (dB)

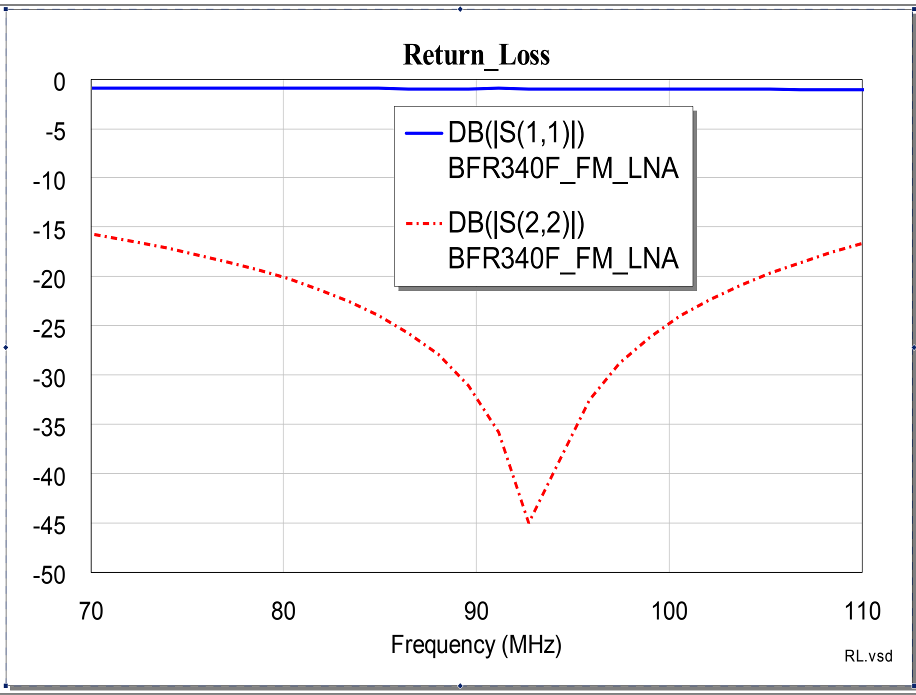

Figure 6 Input and Output Reflection Coefficient (dB)

Most of the internal antennas for FM Radio are high ohmic and vary in their impedance value based on the antenna design. Therefore, the LNA in this AN is designed to have high impedance at the input, which can be easily matched to the desired antenna. The input impedance of the LNA is shown in **Figure 7** for the FMR frequency range.

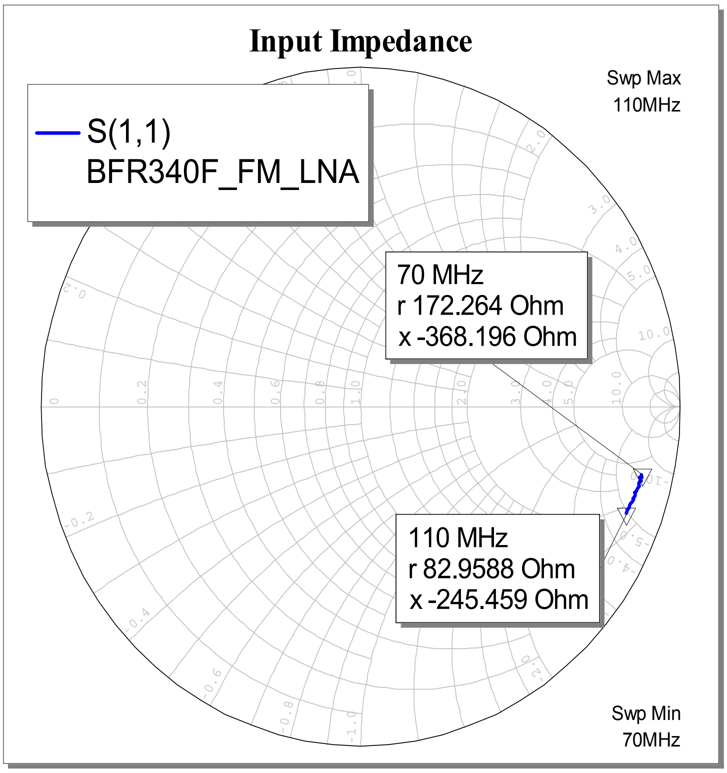

Figure 7 Input Reflection Coefficient

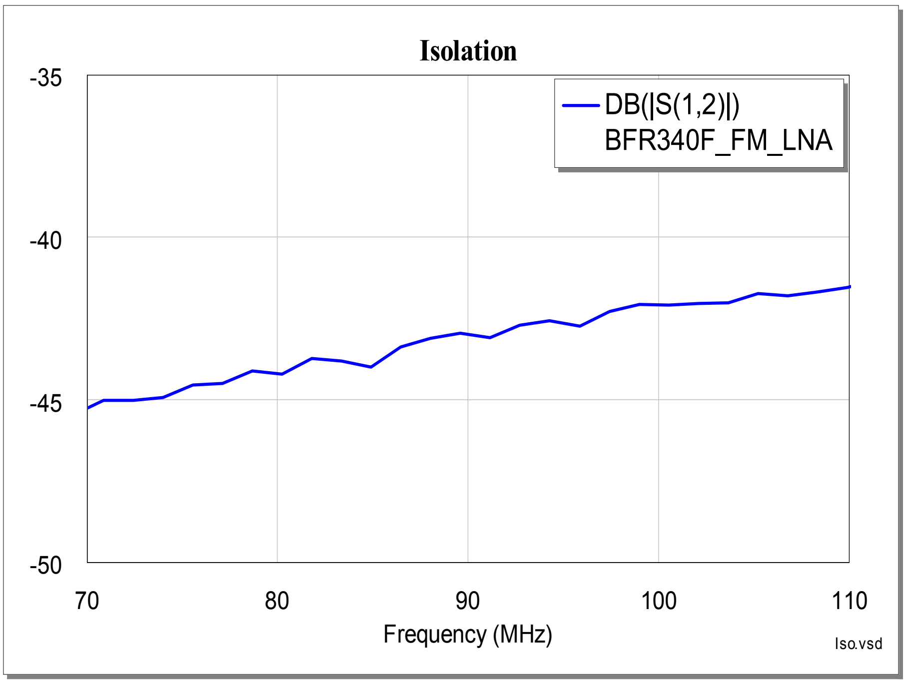

Figure 8 Input to Output Isolation (dB)

5.2 Wide-Band Results

Below is a graph depicting wide-band LNA characteristics up to 10 GHz.

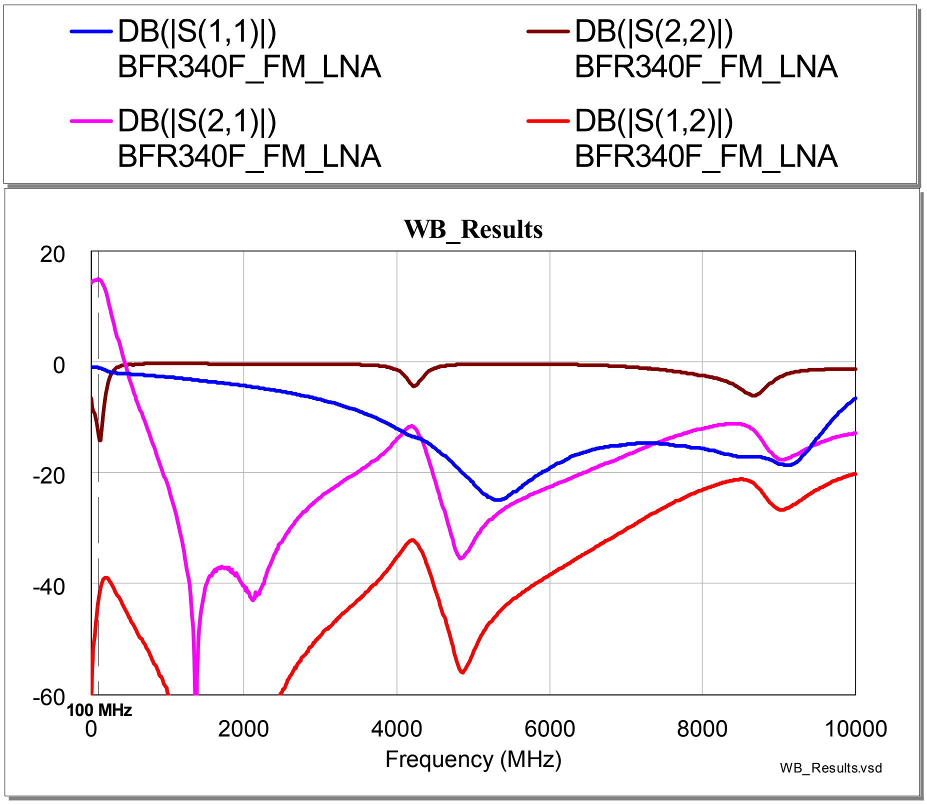

Figure 9 Wide-Band: Gain, Input/Output Matching, Isolation

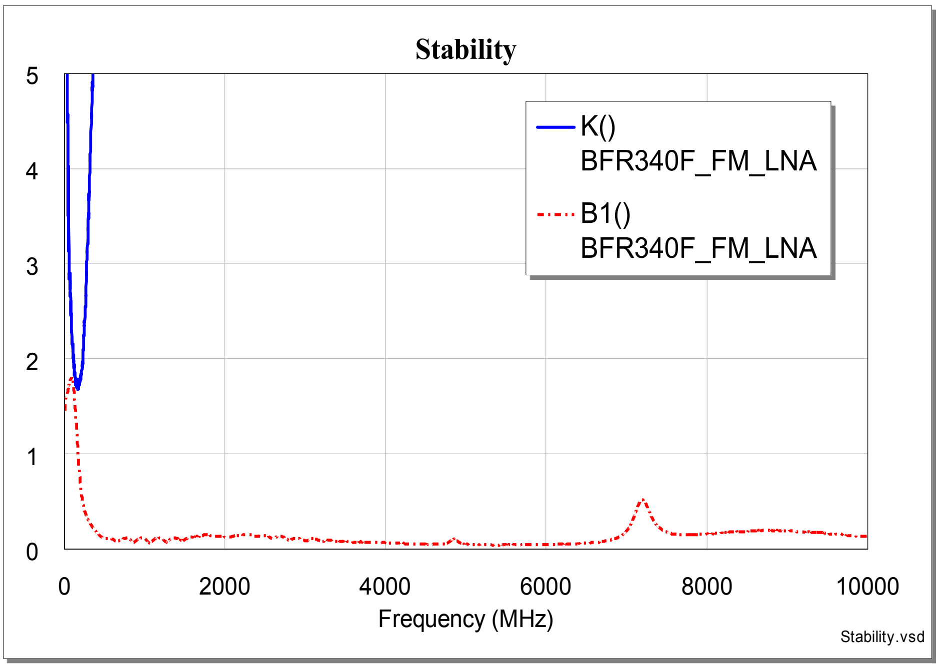

Figure 10 Stability Factor (necessary and sufficient condition for “Unconditional Stability”: k>1 & *B1*>0)

Appendix 1: ESD protection circuit for system level ESD robustness

Introduction

With the advancement in miniaturization of semiconductor structures, ESD handling capability of the devices is becoming a concern. Increasing ESD handling capability of the I/O ports costs additional chip size and affects the I/O capacitance significantly. This is very important for high frequency devices, especially when high linearity is required. Therefore, tailored and cost effective ESD protection devices can be used to build up an ESD protection circuit. To handle ESD events during assembly, devices normally have on-chip ESD protection according to the device level standards e.g. “Human Body Model” JEDEC 22-A-115. To fulfill the much more stringent system level ESD requirements according to IEC61000-4-2 as shown in **Figure 11**, the external ESD protection circuit has to handle the majority of the ESD strike. The best external ESD protection is achieved using a TVS diode assisted by additional passive components.

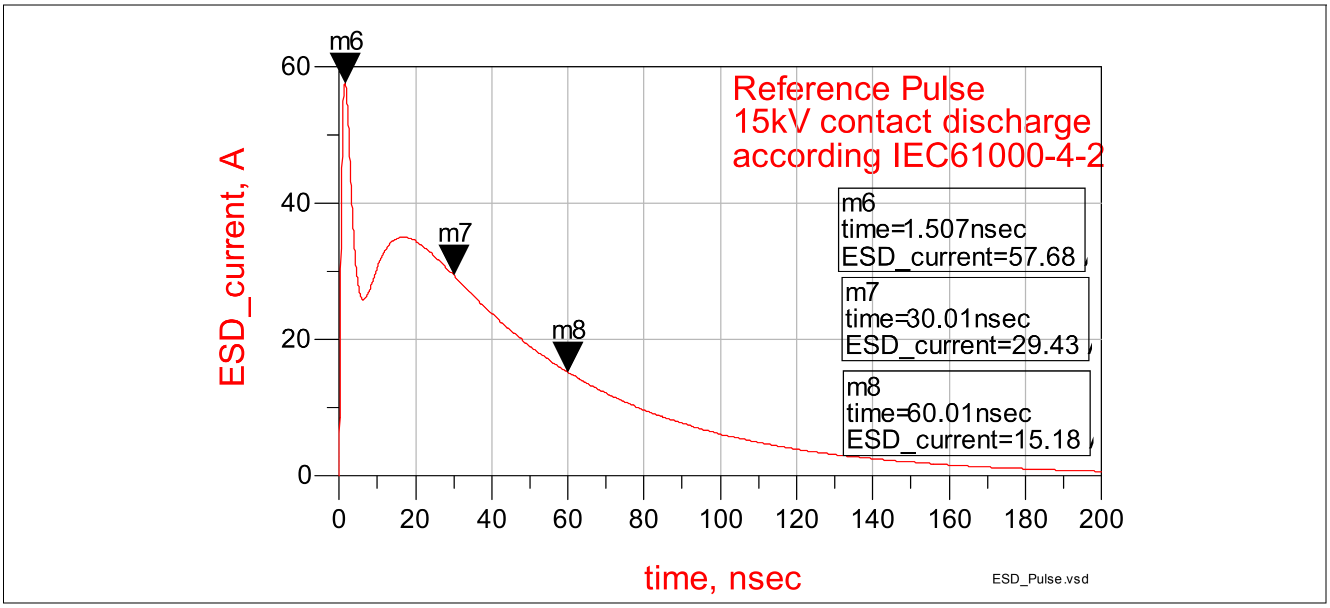

Figure 11 ESD test pulse according to system level specification IEC61000-4-2 – Contact Discharge 15kV

Some examples of RF applications addressed by the Infineon ESD protection proposal are given below:

- FM Radio (76 MHz -110 MHz)
- WLAN 802.11b/g/n (2.4 GHz, Tx ~ +20 dBm)
- Bluetooth (2.4 GHz, Tx ~ +20 dBm)
- Automatic Meter Reading, AMR (900 MHz, TX ~ +20 dBm)
- Remote Keyless Entry, RKE (315 MHz - 434 MHz - 868 MHz - 915 MHz, Tx~13 dBm)
- GPS (1575 MHz, Rx only but can be affected by RF interferer)

For an ESD protection device tailored for medium power RF signals (=< +20 dBm), following requirements are essential:

1. RF requirements
   a) Bidirectional characteristic to handle DC free signals without clipping / signal distortion
   b) A highly symmetrical behavior of the ESD device for positive and negative voltage swings is mandatory to keep the power level of even Harmonics low
   c) Breakdown voltage of 5 V-10V, to avoid signal distortion at high RF voltage swing applied at the TVS diode, located close to the antenna
   d) High linearity
   e) Low leakage current and stable diode capacitance vs. RF voltage swing
   f) Ultra low diode capacitance is mandatory

2. ESD requirements:
   a) Lowest dynamic resistance R_{dyn} to offer best protection for the RFIC; R_{dyn} is characterized by Transmission Line Pulse (TLP) measurement
   b) Very fast switch-on time (<<1nsec) to ground the initial peak of an ESD strike according to IEC61000-4-2
   c) No performance degradation over a large number of ESD zaps (>1000

Two-step ESD Protection approach

General structure for a 2-step ESD approach according to **Figure 12** enables to split the entire ESD current between the internal and external ESD protection device. The external device is much more robust and handles the majority of the ESD current. To avoid any impact on the RF behavior of the system and to minimize non linearity effects, the TVS diode should possess an ultra low device capacitance.

Therefore the bi-directional (symmetrical) Infineon TVS Diode ESD0P2RF is well suited, which provides a diode capacitance as low as 0.2 pF and a Rdyn of only 1 Ohm. The additional insertion loss in the 50 Ohm environment caused by the ESD0p2RF is less than 0.05dB up to 3Ghz.

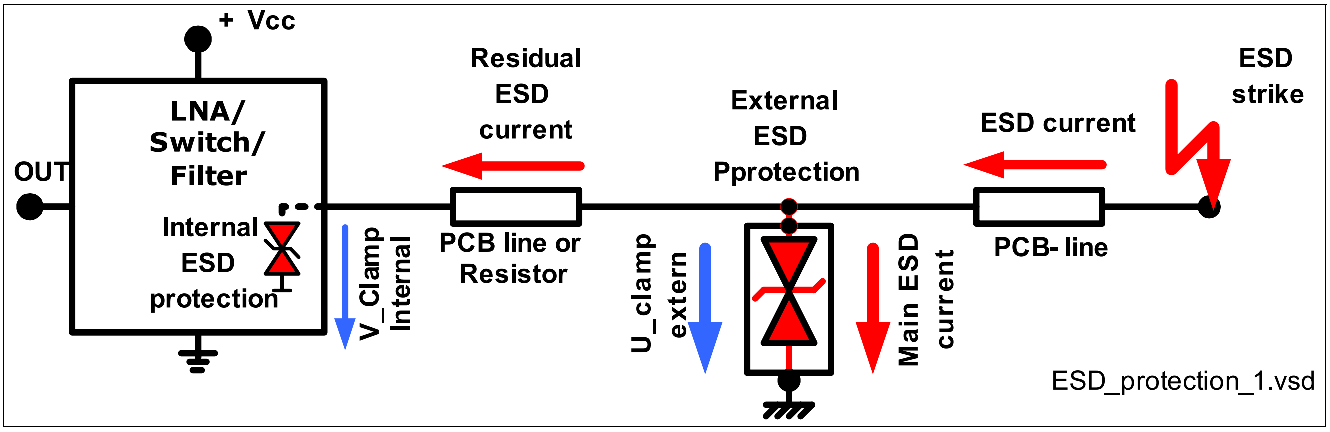

Figure 12 Smart 2-step ESD protection approach based on external and internal ESD protection structure

For further ESD improvement it is highly recommend to add a serial capacitor (C1). The capacitor cuts off most of the high energy created by the ESD strike. For an improved ESD robustness, C1 should be as small as possible, but has to match to the intended application frequency as well. For a broadband ESD protection (80MHz…3GHz) C1 should be about 150pF…50pF. Optional matching can be implemented with a serial inductor L1 for a dedicated frequency. In combination with L1, C1 can be reduced significantly which improves the ESD performance further more. The serial inductor should be a low Q type serving a (small) serial resistor which is helpful for the ESD performance. An serial resistor of e.g. 2.2 Ohm costs 0.2dB IL, but limits the residual ESD current significant to reduce the ESD stress for the IC input.

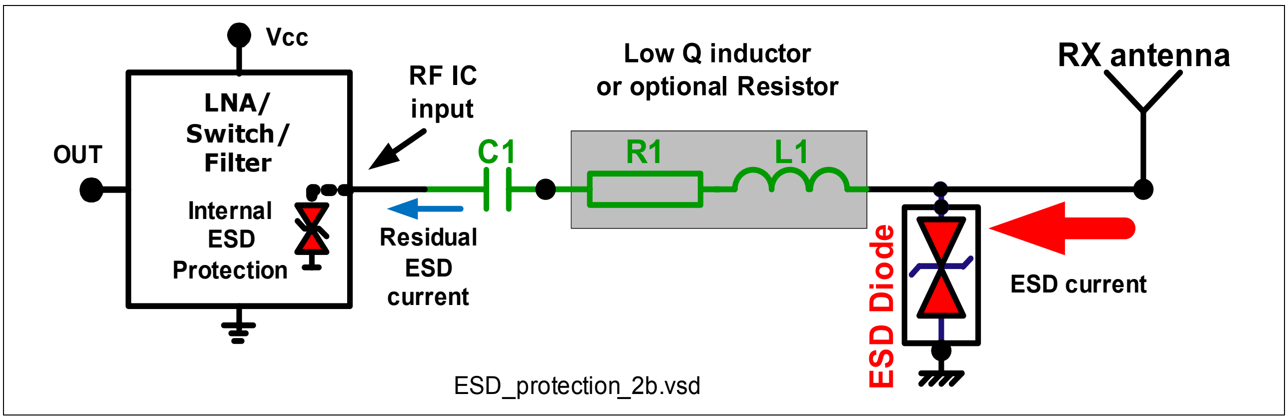

Figure 13 Standard ESD protection topology with optional ESD resistor, blocking capacitor and a serial inductor

Alternatively another TVS diode (ESD5V3L1U-02LRH/LS, unidirectional) can be used for ESD performance improvement in order to reduce the residual stress for the IC (FM-LNA) in case of high IEC61000-4-2 ESD strikes.

The ESD5V3L1U-02LRH/LS provides a dynamic resistance of 0.31 Ohm only (1 Ohm for ESD0P2RF) and a diode capacitance of 1pF typically. For the FM radio frontend the low diode capacitance of 1pF is not affecting the circuit matching performance, the very low dynamical resistance (0.31 Ohm) makes the serial resistor (2.2 Ohm in Figure 2/3) obsolete.

However designers have to obey that in packed design with possible high RF interference level e.g. from the TX path of GSM the unidirectional ESD5V3L1U could clip the signal in the negative direction. In a more "non hostile" environment the ESD5V3L1U-02LRH/LS works very fine and provides lower R_dynamic/lower clamping voltage, resulting in in a lower residual ESD stress for the FM radio LNA.

For hostile interfering environment, the bidirectional ESD0P2RF is the preferred ESD solution for FM radio, for other FM radio environments, the ESD5V3L1U-02LRH/LS is the better alternative.

References

[1] **BFR340F Datasheet**, Infineon Technologies AG.

[2] Application Note **AN175**, RF CMOS SPDT Switches, Infineon Technologies AG

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