Application Note No. 167

ESD Protection for Broadband Low Noise Amplifier BGA728L7 for Portable and Mobile TV Applications

RF & Protection Devices

Never stop thinking

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Application Note No. 167

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1 Introduction

This application note shows how Infineon's broadband low noise amplifier BGA728L7 for portable and mobile TV applications can be protected from electrostatic discharges (ESD). Due to high electrostatic charging voltages of several kilovolt, ESD events can result in dielectric breakdown of insulating surfaces and do damage to electronics. The integrated on-chip protection of BGA728L7 results in an ESD hardness of at least 1 kV according to the human body model (HBM), which effectively protects the sensitive RF input transistor during manufacturing where stringent measures are taken to minimize the risk of damage from ESD. However, in the field electrostatic charging voltages much higher than 1 kV occur every day. Since the RF input pin of BGA728L7 is directly connected through a DC blocking capacitor to the antenna, there is a need for additional ESD protection to minimize the risk of damage from ESD events during daily use.

BGA728L7 covers the frequency range from 170 MHz to 1675 MHz for worldwide mobile broadcast TV services, which operate in the following frequency bands:

- VHF III band, 170 MHz to 230 MHz
- UHF band, 470 MHz to 860 MHz
- L band
  - 1452 MHz to 1492 MHz (Europe)
  - 1670 MHz to 1675 MHz (U.S.)

Due to the high operating frequency of up to 1.7 GHz only low-capacitive ESD protection diodes with capacitances of less than 1 pF are suitable for ESD protection for portable and mobile TV applications. Infineon offers ESD protection diodes with capacitances of 0.8 pF down to 0.2 pF in leadless packages of EIA case size 0503 (TSLP-4-7), 0402 (TSLP-2-17) as well as 0201 (TSSLP-2-1):

ESD0P8RFL / ESD0P4RFL

The Infineon ESD protection diodes ESD0P8RFL and ESD0P4RFL with line capacitances of 0.8 pF and 0.4 pF respectively, come in a TSLP-4-7 package (1.2 mm x 0.8 mm x 0.39 mm) as anti-parallel configuration.

ESD0P2RF-02LRH / -02LS

The Infineon TVS diode ESD0P2RF has a line capacitance of only 0.2 pF and comes in either a TSLP-2-17 package (1 mm x 0.6 mm x 0.39 mm) or a super small TSSLP-2-1 package (0.62 mm x 0.32 mm x 0.31 mm). ESD0P2RF is a bidirectional TVS diode with a maximum working voltage of ±5.3 V.

2 TVS Diode Concepts

Figure 1 shows two different configurations for low-capacitive ESD protection diodes to be used for RF antennas. In the anti-parallel configuration, as shown in **Figure 1 (a)**, either diode operates in forward biased condition, and thus the voltage on the signal line has to range approximately between -0.3 V and +0.3 V. This is equivalent to 0 dBm at an impedance of 50 Ω. For example, Infineon ESD0P4RFL with a line capacitance of 0.4 pF (this is the total parasitic capacitance) integrates two fast switching diodes in anti-parallel configuration into one package. Infineon ESD0P8RFL with a line capacitance of 0.8 pF is only recommended for VHF III and UHF bands, because due to the higher capacitance noise matching is already effected in the L band.

As shown in **Figure 1 (b)**, a further reduction of line capacitance is a bidirectional configuration. The bidirectional configuration incorporates a TVS Zener diode and therefore the voltage on the signal line can be between $-V_{RWM}$ and $+V_{RWM}$ (V_{RWM} is the maximum reverse working voltage). For example, the Infineon ESD0P2RF (line capacitance is 0.2 pF) is a bidirectional diode with a maximum reverse working voltage of 5.3 V and thus it does not start to clip the RF signal up to power levels of at least 25 dBm at an impedance of 50 Ω. The higher clamping voltage of the bidirectional configuration—the current from the ESD event has to flow through three diodes rather than only one diode like in the anti-parallel configuration—results in a slightly lower ESD hardness of roughly 15 % compared to the anti-parallel configuration.

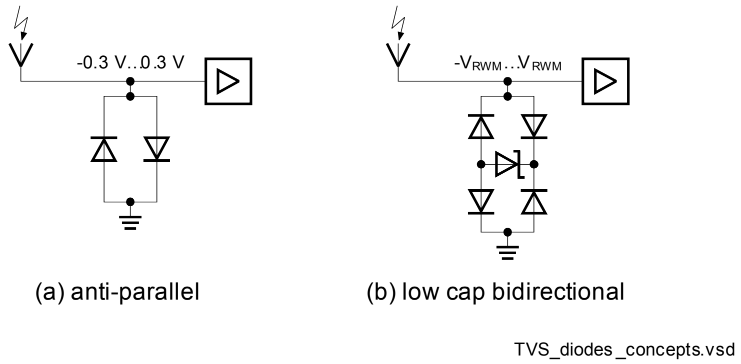

Figure 1 **Two different concepts for ESD protection of RF antennas: (a) two fast switching diodes in anti-parallel configuration, (b) a combination of four fast switching diodes and one TVS Zener diode to get a low capacitive, bidirectional TVS diode (simplified diagram)**

3 Application Information

The application circuit including ESD protection diode is shown in **Figure 2**. The circuit is shown with bidirectional ESD protection diode D1, however, an anti-parallel ESD protection diode can be used instead (denoted by D2 in **Figure 3**). Due to the fact that the packages TSLP-4-7 and the much smaller TSSLP-2-1 are not footprint compatible, there are two separate footprints on the PCB (see **Figure 3**), one for TSLP-4-7 (which can also be used for TSLP-2-17) and one for TSSLP-2-1. For the sake of clarity it is noted that only one diode is needed, either the bidirectional diode D1 or the anti-parallel diode D2.

The default values for C1 and L1 according to the bill of materials from the data sheet are 56 pF and 75 nH respectively. However, 33 pF and 68 nH can be used instead, which are values from the EIA E6 series and therefore easy and readily available. Furthermore, the E6 values result in a slightly higher gain in the VHF III band and, in the case of using the bidirectional ESD protection diode ESD0P2RF, a slightly enhanced ESD hardness, because of the higher impedance in the low-frequency range. The capacitance C5 is optional and only needed for the VHF III band. It has no influence on the ESD hardness.

Please also note the design of the ground connection for the ESD protection diode in order to minimize the inductance to ground. Ground inductance results in ringing and therefore higher peak voltage and should be kept as small as possible.

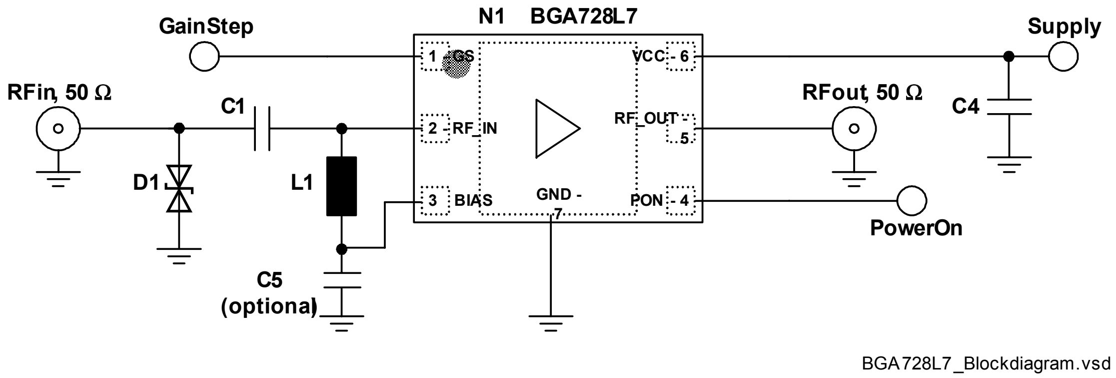

Figure 2 **Application circuit of BGA728L7**

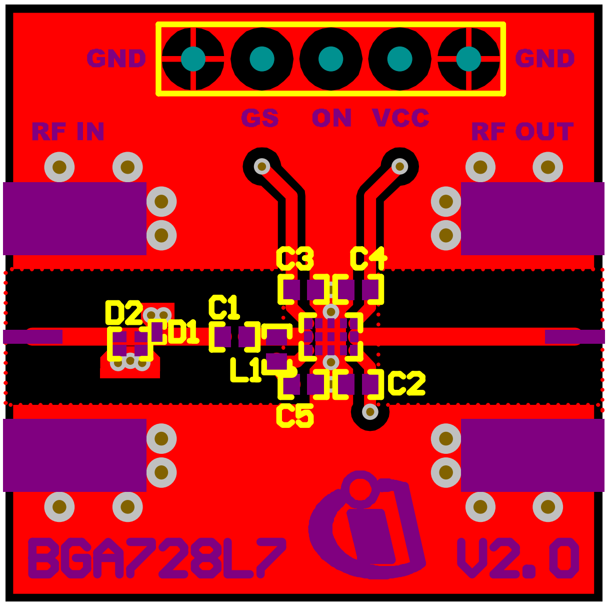

Figure 3 Application board including ESD protection

Table 1 Bill of Materials

Name	Value	Package	Manufacturer	Function
C1	56 pF (33 pF)	0402	Various	DC block
C4	1 nF	0402	Various	Supply voltage filtering
C5	1 nF	0402	Various	Optional for VHF III band
L1	75 nH (68 nH)	0402	Murata LQW15A	Bias feed
N1	BGA728L7	TSLP-7-1	Infineon	SiGe LNA
D1 (D2)	ESD0P2RF-02LS ESD0P2RF-02LRH ESD0P4RFL ESD0P8RFL	TSSLP-2-1 TSLP-2-17 TSLP-4-7 TSLP-4-7	Infineon	ESD protection
C2, C3	Not used			

4 Typical Measurement Results

Typical electrical characteristics are summarized in **Table 2**. Please note that PCB and SMA connector losses have not been subtracted from measurements results, that is measurements results of the evaluation board with either ESD0P2RFL-02LS or ESD0P4RFL are given here. For more detailed plots of noise figure or power gain vs. frequency please also see **Figure 5** to **Figure 8**.

In high-gain mode the ESD protection diode should not affect noise figure or power gain too much and in low-gain mode it should not have any affect on linearity or compression point of the LNA. Due to the low capacitance of only 0.2 pF and 0.4 pF respectively, neither diode significantly affects power gain up to 1.8 GHz and the effect on noise figure is less than 0.1dB in the L band. Please note that measurements results shown in **Figure 4** and the following also reflect variations in the electrical characteristics of BGA728L7, because different samples of BGA728L7 were used for these measurements.

LNAs have usually a much lower input 1 dB compression point (IP_{1dB}) and 3rd order input intercept point (IIP_3) than ESD protection diodes. Only in low-gain or off mode, that is when the LNA effectively operates as attenuator, IP_{1dB} or IIP_3 could be affected by the ESD protection diode. For example, the ESD protection diode ESD0P4RFL in anti-parallel configuration starts to clip a 900 MHz RF signal at 10 dBm (at 50 Ω) and the 3rd order intercept point of both ESD0P4RFL and ESD0P2RF is round about 38 dBm at 900 MHz (at 50 Ω). Since both IP_{1dB} and IIP_3 of BGA728L7 in low-gain mode are still much lower than that of the ESD protection diode, neither the anti-parallel ESD0P4RFL nor the bidirectional ESD0P2RF has any affect on IP_{1dB} or IIP_3. Please note that for IIP_3 measurements a frequency offset of 7 MHz was chosen, which is a typical TV channel spacing (USA, Japan: 6MHz; Australia: 7 MHz; Europe, China: 8 MHz).

ESD Testing

ESD tests were done as per IEC 61000-4-2 contact discharge, starting from 4 kV (or 1 kV in the case without ESD protection diode) and applying 50 discharges of each polarity per test voltage. After each run of 100 contact discharges in total, supply current of BGA728L7 was recorded and the procedure was repeated with an increased ESD test voltage until BGA728L7 has sustained significant damage. The measurements results are plotted in **Figure 4** and for the sake of clarity measurement points related to a single sample are joined by a line.

From **Figure 4** one can see that without any ESD protection diode BGA728L7 can typically withstand contact discharges of only 2 kV and it failed already at 3 kV. Using the bidirectional ESD0P2RF-02LS for ESD protection, ESD hardness increases to approximately 10 kV. This can be enhanced to 12 kV by using the BOM variant with C1 = 33 pF. This is because a 33 pF capacitor has a higher impedance in the lower frequency range than a 56 pF capacitor and thus more low-frequency energy from the ESD event is blocked and forced through the ESD protection diode. However, using either ESD0P4RFL or ESD0P8RFL in an anti-parallel configuration, ESD hardness can still be further enhanced to approximately 14 kV (13 kV…15 kV) for contact discharge. The test results do not show any significant difference between both diodes and also no significant difference between BOM variants. This is because due to the very low clamping voltage of an ESD protection diode in anti-parallel configuration there is only little low-frequency energy that bypasses the ESD protection diode and enters the circuit. Thus, there is only an insignificant difference between 33 pF and 56 pF. This is also the reason for the differences in ESD hardness between ESD0P2RF-02LS and ESD0P4RFL. Since the clamping voltage of a bidirectional diode compared to an anti-parallel configuration is always higher, there is also more low-frequency energy that bypasses the bidirectional diode.

Highest test level defined by IEC 61000-4-2 is level 4 with 8kV test voltage for contact discharge. Thus ESD hardness of BGA728L7 protected by either the bidirectional or an anti-parallel ESD protection diode exceeds by far level 4. Please note that since the evaluation board has no cover at all, air discharge testing is not suggested by IEC 61000-4-2. In any case, it would not make much sense to perform air discharge tests on the evaluation board, because there is no antenna at all to which air discharges can be applied to.

Table 2 Electrical Characteristics
T_A = 25 °C; V_{CC} = 2.8 V, V_{PON} = 2.8 V, Z_S = Z_L = 50 Ω,
C_1 = 33 pF, L_1 = 68 pF, C_5 = 1 nF, D_1 = ESD0P2RF-02LS or ESD0P4RFL, unless otherwise noted

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Supply voltage	V_{CC}	1.5		3.6	V	
Supply current high gain mode	I_{CCHG}		5.5		mA	V_{GS} = 0 V
Supply current low gain mode	I_{CCLG}		0.55		mA	V_{GS} = 2.8 V
High-Gain Mode: V_{GS} = 0 V						
Power gain	$\|S_{21}\|^2$		15.0		dB	f = 170 MHz
			15.5		dB	f = 470 MHz
			15.5		dB	f = 860 MHz
			14.8		dB	f = 1452 MHz
			14.1		dB	f = 1675 MHz
Input return loss	RL_{IN}		>10		dB	f = 170 MHz
			>8		dB	f = 470 MHz
			>8		dB	f = 860 MHz
			>12		dB	f = 1452 MHz
			>14		dB	f = 1675 MHz
Output return loss	RL_{OUT}		8		dB	f = 170 MHz
			16		dB	f = 470 MHz
			15		dB	f = 860 MHz
			11		dB	f = 1452 MHz
			10		dB	f = 1675 MHz
Noise figure[1)]	NF		1.4		dB	f = 170 MHz
			1.4		dB	f = 470 MHz
			1.4		dB	f = 860 MHz
			1.4		dB	f = 1452 MHz
			1.5		dB	f = 1675 MHz
3rd order input intercept point	IIP_3		-7		dBm	f_1 = 470 MHz, f_2 = 477 MHz
Input 1 dB compression point	IP_{1dB}		-9		dBm	f = 170 MHz
			-9		dBm	f = 470 MHz
			-8		dBm	f = 1675 MHz
Low-Gain Mode: V_{GS} = 2.8 V						
3rd order input intercept point	IIP_3		22		dBm	f_1 = 470 MHz, f_2 = 477 MHz
Input 1dB compression point	IP_{1dB}		3		dBm	f = 170 MHz
			3.5		dBm	f = 470 MHz
			5		dBm	f = 1675 MHz

Table 2 Electrical Characteristics

T_A = 25 °C; V_{CC} = 2.8 V, V_{PON} = 2.8 V, Z_S = Z_L = 50 Ω,
C_1 = 33 pF, L_1 = 68 pF, C_5 = 1 nF, D_1 = ESD0P2RF-02LS or ESD0P4RFL, unless otherwise noted

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Electrostatic Discharge						
ESD hardness[2)]	V_{ESD}		12		kV	ESD0P2RF-02LS
			14		kV	ESD0P4RFL
			14		kV	ESD0P8RFL

1) Including PCB and SMA connector losses, with ESD0P2RF-02LS as ESD protection
2) As per IEC 61000-4-2 contact discharge

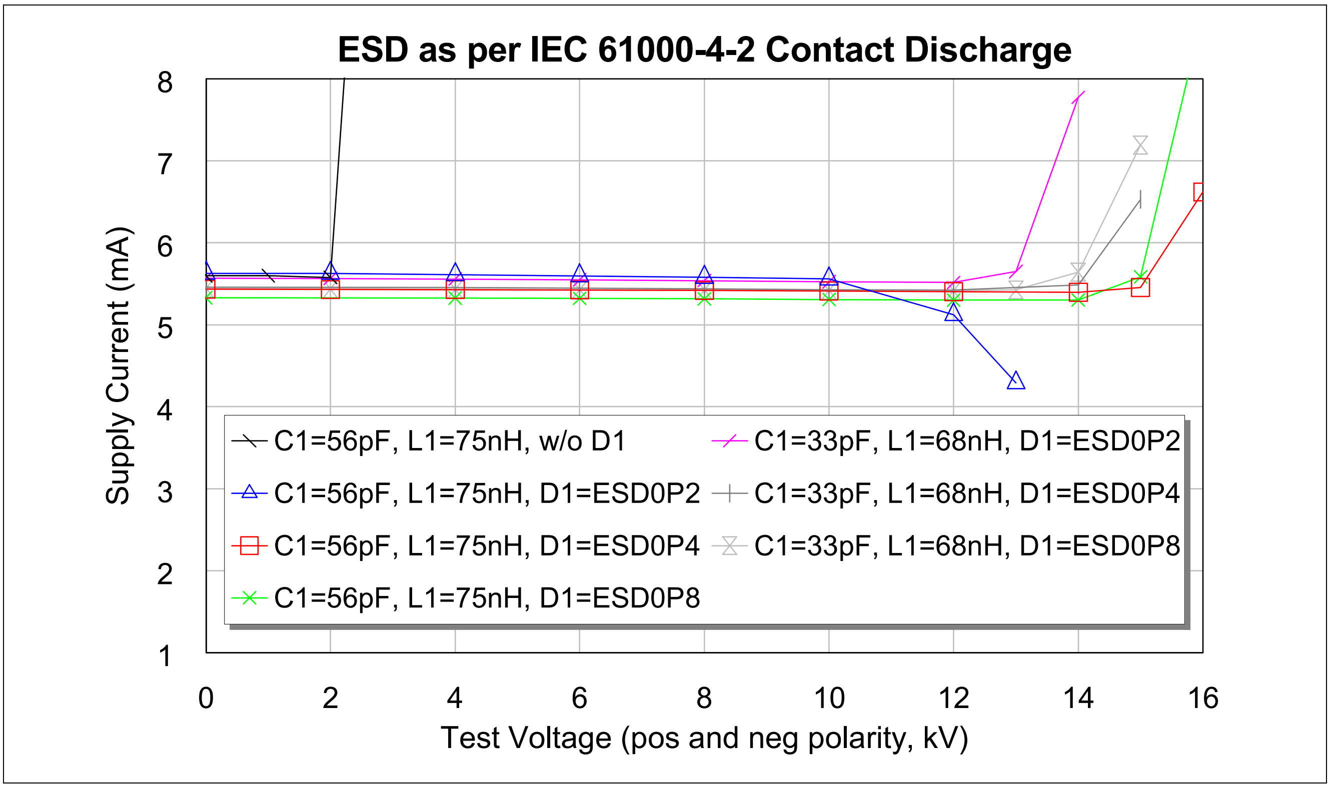

Figure 4 ESD hardness of BGA728L7 on evaluation board as per IEC 61000-4-2 contact discharge (50 pulses per test voltage and polarity)

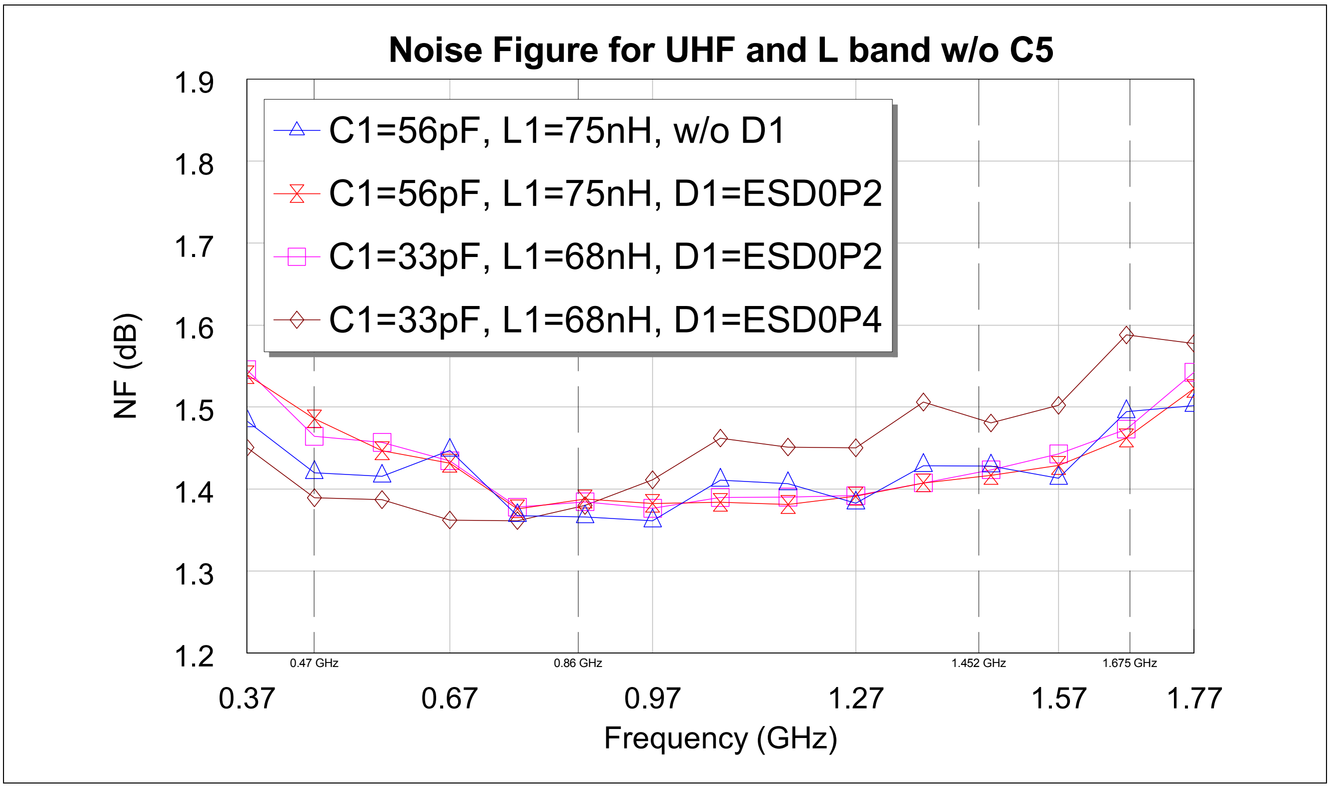

Figure 5 **Noise figure in high gain mode without C5**

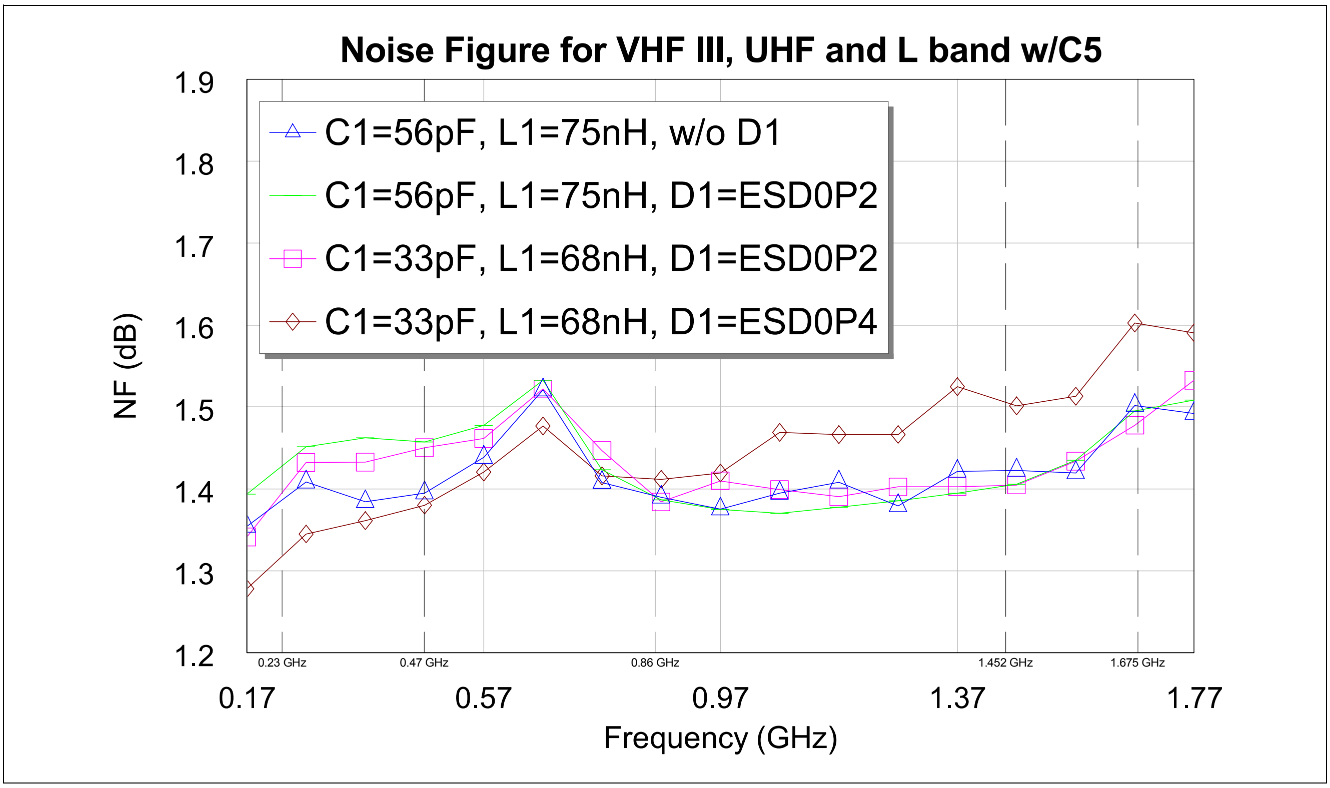

Figure 6 **Noise figure in high gain mode with C5**

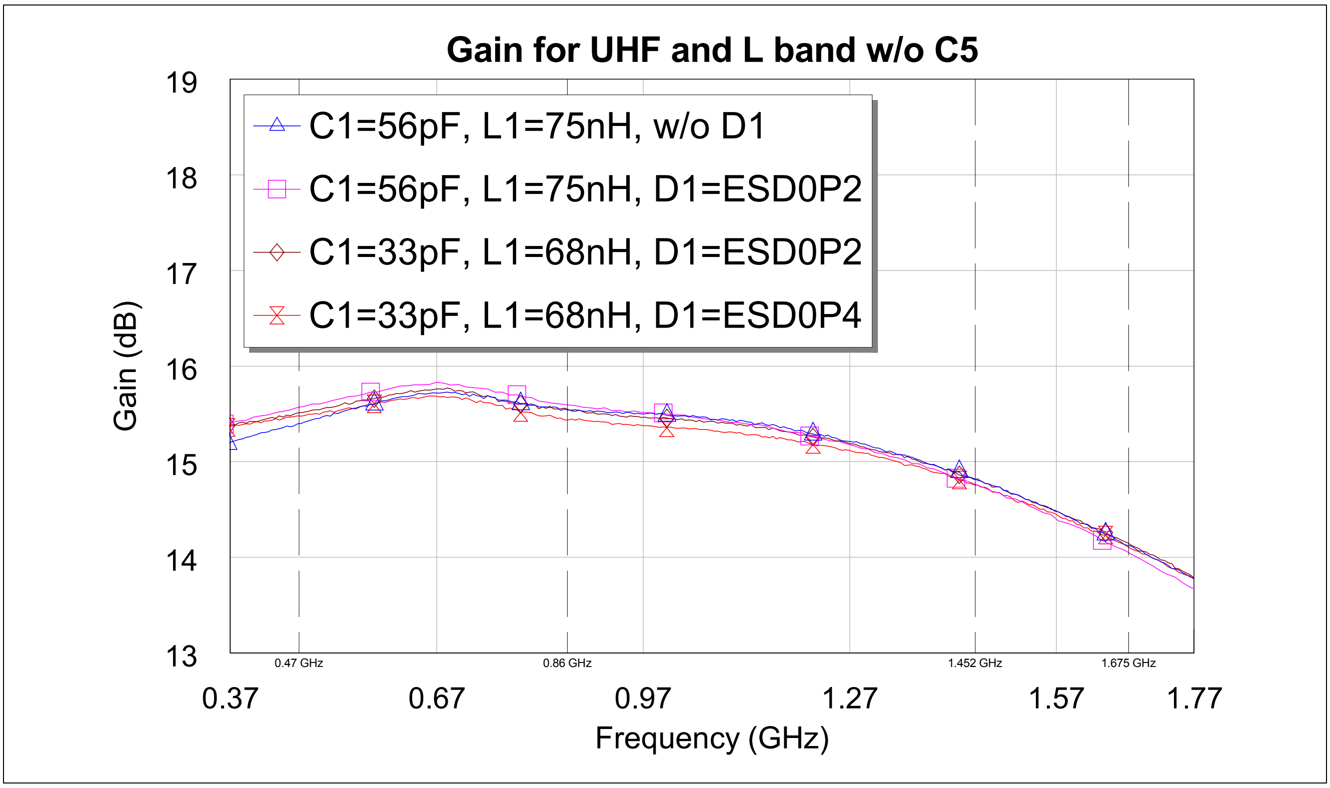

Figure 7 Power gain in high gain mode without C5

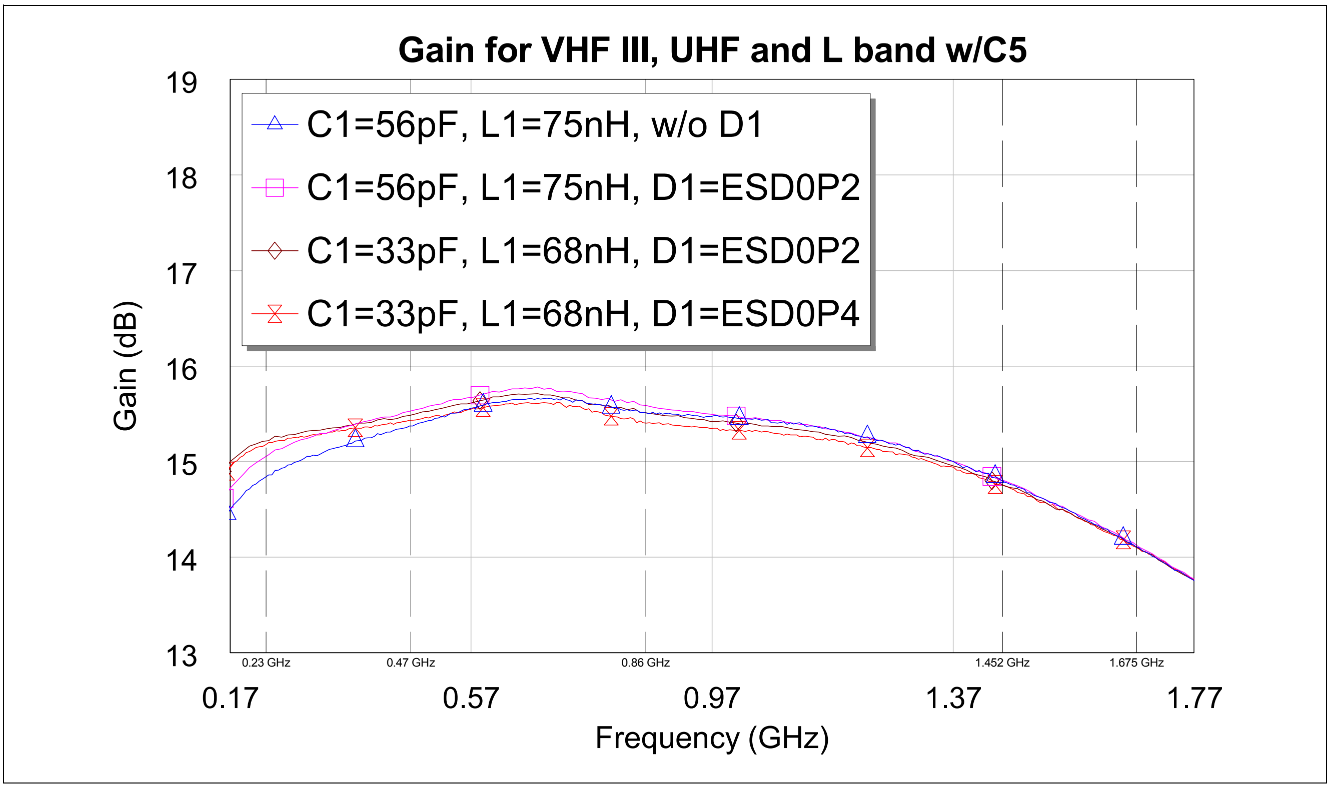

Figure 8 Power gain in high gain mode with C5

5 Conclusion

It was shown that Infineon's low-capacitive ESD protection diodes with capacitances of as low as 0.2 pF are very much suitable for ESD protection of Infineon's wideband LNA BGA728L7 for portable and mobile TV applications, without having a significant effect on power gain, noise figure or linearity. With each of the ESD protection diodes discussed in this application note ESD hardness of BGA728L7 considerably exceeds the highest level defined by IEC 61000-4-2, which is level 4 with 8 kV test voltage for contact discharge. Thus, the risk of damage from ESD is greatly minimized and therefore the objective of safe and reliable operation can also be met in environments where no precaution against ESD has been established.

Table 3 Infineon ESD protection diodes to be used for ESD protection of BGA728L7

Part number	Capacitance	Package	EIA size	Package dimensions	Typical ESD hardness of BGA728L7[1)]
ESD0P8RFL[2)]	0.8 pF	TSLP-4-7	0503	1.2 mm x 0.8 mm x 0.39 mm	14 kV
ESD0P4RFL	0.4 pF	TSLP-4-7	0503	1.2 mm x 0.8 mm x 0.39 mm	14 kV
ESD0P2RF-02LRH[3)]	0.2 pF	TSLP-2-17	0402	1.0 mm x 0.6 mm x 0.39 mm	12 kV
ESD0P2RF-02LS[3)]	0.2 pF	TSSLP-2-1	0201	0.62 mm x 0.32 mm x 0.31 mm	12 kV

1) As per IEC 61000-4-2 contact discharge
2) Not recommended for L band
3) Modified BOM with C1 = 33 pF recommended