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Comparison of ESD Immunity between GaAs-Based LNA and SiGe-Based LNA

Samarth Athreyas
Department of Telecommunication
R. V. College Of Engineering, Bangalore

Samarth S. Pai
Department Of Telecommunication
R. V. College Of Engineering, Bangalore

Abstract

The comparison of electrostatic discharge (ESD) immunity is studied between a GaAs-based low-noise amplifier (LNA) and SiGe-based LNA, both operating at 850 MHz, a typical application being a mobile communications system. It analyses the ESD effect, which occurs within communication components, such as LNA, and describes testing standard and methods. ESD test was done according to IEC61000-4-2 and MIL-Std 1686 standards in the contact mode. For further analysis on ESD test result of LNA,the effectiveness of ESD waveform into LNA was validated, using a commercial program. After the ESD test, the failed sampleswere carefully examined with optical microscope and environmental scanning electron microscope.

Index Terms—Electrostatic discharge (ESD), gallium arsenide LNA, low-noise amplifier (LNA), silicon germanium LNA.

1. Introduction

In recent years, there have been strong efforts for the development of high-frequency technologies for the cellular and wireless communication markets using either gallium arsenide (GaAs) or silicon-based devices [1], [2]. Among the semiconductor-based devices, particularly there is strong competition of silicon–germanium (SiGe) and GaAs devices for the wireless communication applications. GaAs is composed of gallium and arsenic and more efficient on high-frequency circuit because it has faster operation speed andlower heat generation than silicon semiconductor.Since these advantages are in the high-frequency region, GaAs-based devices have been used most widely. SiGe devices have a base layer mixed with germanium so thatthey can operate more efficiently among all silicon bipolar transistors [3]. The use of conventional Si production technology combined with high integration levels and high yield make SiGe technologies a cost-efficient alternative to compound technologies [4]. Electrostatic discharge (ESD) is a well-known reliability aspectin Si technologies and it is seriously addressed during the last years in many research papers [5]. And it is generally believed that GaAs circuits have a low susceptibility to ESD. In this paper, the comparison of ESD immunity is studied between a GaAs low-noise amplifier (LNA) and SiGe bipolar transistor LNA, both operating at 850 MHz, a typical application being a mobile communications system.

2. ESD Effects on LNA

ESD is the most common cause of malfunction for low powered components, such as large-scale integrated circuit. Among semiconductor product failures, more than 50% of them are caused by ESD and overvoltage [6]. In case of static discharge, electric charge transfer happens instantly and results in dielectric breakdown or metallization melt within semiconductor device from discharged voltage and induced current [7].LNA is a component that amplifies the signal while lowering the noise figure of high-frequency signal so that it is widely used for communication. Since the LNA is usually connected to the external of the RF receiver, LNA is more vulnerable for flow-in electrical stress such as ESD. ESD might occur during production or transportation when any static accumulated by a worker is discharged instantly into the product.Weak resistance to ESD causes a product malfunction and damage to the business. So high-frequency circuit concepts like LNA need specific requirements for possible ESD protection.

3. Test Method

An ESD event can be subdivided into human body model (HBM), machine model, and charged device model. HBM resistance has been most widely used standard for ESD evaluation. In the HBM, including human body, electrical equivalent circuit of discharge path has the form of double-exponential, and ESD waveform is determined by human body's charged capacitance and discharge resistance. As for HBM, the international test method standard can be categorized into component and system. Component testing standard has MIL-Std 1686, ANSI STMS5.1, and JESD22-A114 C, while system testing standard includes IEC61000-4-2 and ANSI C.63-16.There are two discharge methods for ESD simulator: air discharge mode and contact discharge mode. At the contact discharge method, the electrode of the test generator is held in contact with the test device, and the discharge is actuated by the discharge switch within the generator. While the air discharge method, the charged electrode of the test generator is brought close to the test device, and the discharge is actuated by a spark.Most ESD test is done in contact discharge. Air discharge shall be used where contact discharge cannot be applied. In this paper, ESD test was done according to IEC61000-4-2 and MIL-Std 1686 standards, which are representative standards of HBM, in the contact mode. ESD was applied with contact on the LNA input port, and positive and negative tests on five samples per test level were conducted. Even though the test voltage is required to be 2, 4, and 8 kV for standard test, for this study, LNA test voltage was applied from 0V up to the fail voltage so as to obtain more detailed ESD tolerance level. Testing equipment was Mini Zap (MZ-15) of Key-Tek. Table 1 shows test condition. For further analysis on ESD test result of LNA, the effectiveness of ESD waveform flowing into LNA was validated using commercial software FLO EMC6.1 (Flomerics Co., Ltd., Westborough, MA). Fig. 1 illustrates HBM's equivalent circuit and Fig. 2 illustrates and compares among input waveform of contact discharge 2 kV, defined in IEC61000-4-2; the actual waveform measured from LNA static discharge experiment; and the input waveform from static discharge test modeling. The waveforms from the actual experiment and the model are almost identical to the standard waveform. Measured wave has a similar overall shape to that of the ideal wave but yet, not identical. Every time when a measurement is taken, there exists a slight difference. It seems to be a human or measurement error.

Table 1. Test Condition

Test Standard	IEC61000-4-2	MIL-Std 1686
Discharge Network	330 Ω, 150 pF	1500 Ω, 100 pF
Test Mode	Contact Discharge	Contact Discharge
Test Voltage	From 0 V to Fail, 50 V step	From 0 V to Fail, 50 V step
Test Polarity	Positive and Negative	Positive and Negative
Test Interval	Over 1 sec.	Over 1 sec.
Number of Sample	5 ea/test level	5 ea/test level

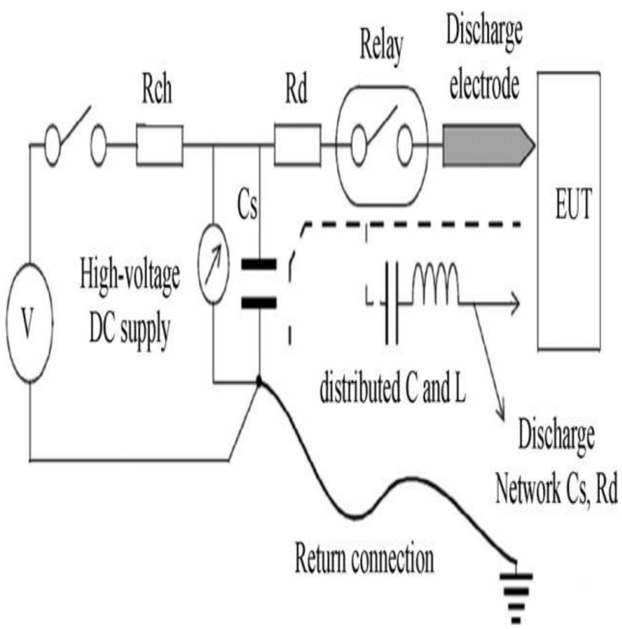


Fig.1. HBM's equivalent circuit

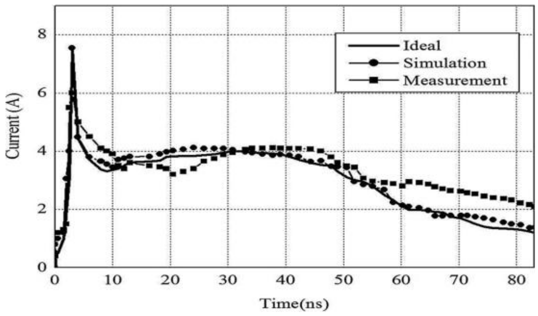
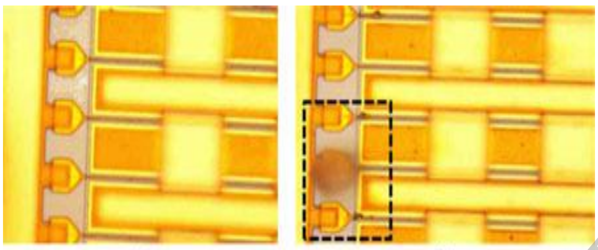
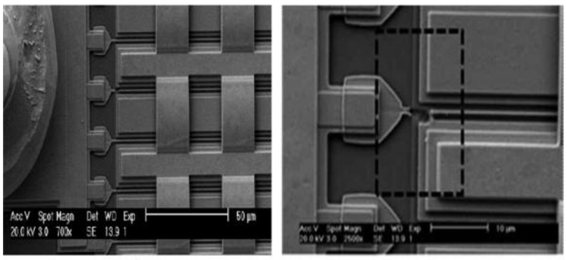


Fig.2. HBM input waveform of ESD (at 2 kV ESD impulse defined in IEC61000-4-2).



(a) (b)

Fig.3. ESD-induced metallization burn-out failure (at 3-kV HBM ESD impulse). (a)Normal and (b) metallization burn-out failure.



(a) (b)

Fig.4. ESD-induced line open failure (At 3-kV HBM ESD impulse) (a) Normal and (b) line open failure

4. Test Result

The measurement items to check the performance of the LNA are noise figure (N.F.), third-order intercept point (IIP3), return loss, and gain. As a result, in the case of IEC61000-4-2 standard test, failure of GaAs LNA was reported at 1.5 kV, and failure of SiGe LNA was reported at 2.2 kV. In the case of MIL-Std 1686standard test, failure of GaAs LNA was reported at 1.7 kV, and failure of SiGe LNA was reported at 2.3 kV.After the ESD test, the failed samples were carefully examined with optical microscope and environmental scanning electron microscope, for further analysis. From the analysis, either broken wire or burning trace could be observed in each sample's input port. In the LNA, active device such as transistor is easier to be damaged under external energy injection. If the instantaneous ESD enter within the transistor, it will generate the high heat flow called Joule Heat in the inner conductor. This heat destroys the internal circuit isolation and causes accidental disconnection. And it happens more frequently for GaAs wafer than Si wafer because GaAs is weak at statics. Fig. 3 illustrates ESD-induced metallization burn-out failure and Fig. 4 illustrates ESD induced line open failure at 3-kV HBM ESD impulse. Fig. 5 shows measurement result of LNA according to different applied voltage.

5. Conclusion

The comparison of ESD immunity is studied between a GaAs based LNA and SiGe-based LNA, both operating at 850 MHz, a typical application being a mobile communications system. It describes the effect of ESD on low-powered circuit, such as LNA, and widely used ESD test standard and method, which it implemented to carry out an experiment on LNA's resistance to ESD. ESD test was done according to IEC61000-4-2 and MIL-Std 1686 standards in the contact mode. The effectiveness of ESD waveform flowing into LNA was validated usingcommercial software. In the case of IEC61000-4-2 standard test, ESD immunity of SiGe-based LNA is 0.7 kV higher than the GaAs-based LNA. And in the case of MIL-Std 1686 standard test, ESD immunityof SiGe-based LNA is 0.6 kV higher than the GaAs-based LNA. Test results shows that the GaAs-based LNA is more vulnerable to ESD than the SiGe-based LNA. Both SiGe-based LNA and GaAs-based LNA are weak to IEC61000-4-2 standard test than MIL-Std 1686 standard test. Analysis on failure of samplesrevealed LNA's input port had disconnection or burning problem.

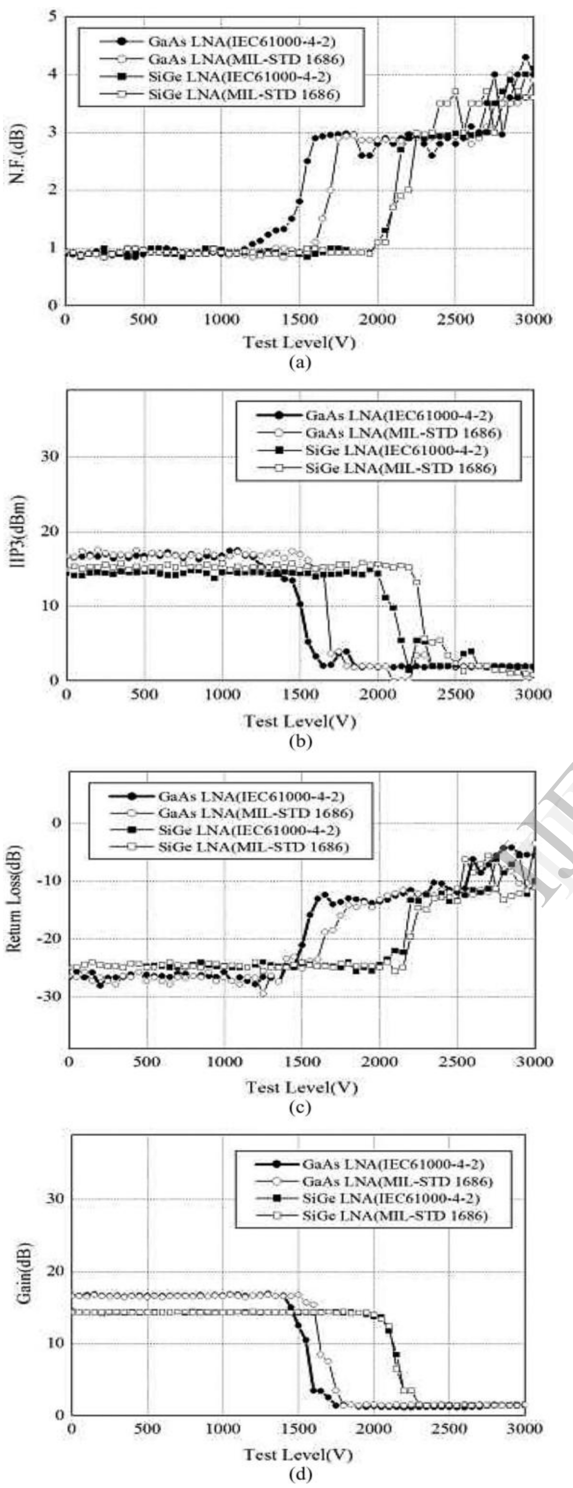


Fig.5. Measurement result of LNA according to different applied voltage (at 850 MHz).(a) Noise figure (N.F.), (b) third-order intercept point (IIP3), (c) return loss, and (d) gain.

6.References

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