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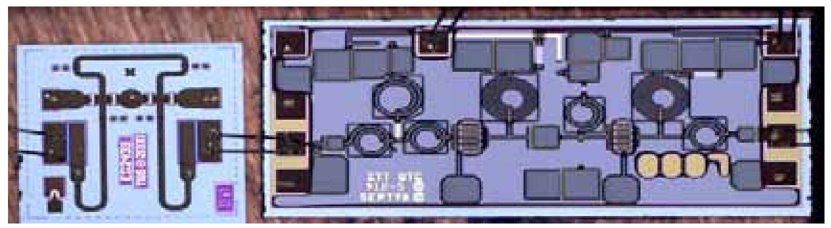
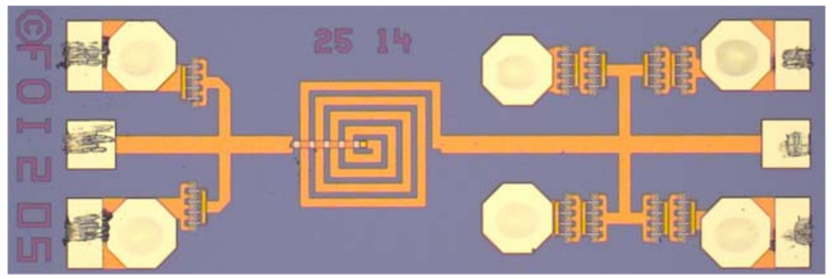
Implementation of HPM Front-door Protections and Component Investigations

TONY NILSSON, ROLF JONSSON





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Report title

Implementation of HPM Front-door Protections and Component Investigations

Abstract

This report summarises the work done in the HPM-protection project, within front-door protection. The results from HPM- and UWB-measurements on the limiter TGL2201EPU combined with the Low Noise Amplifier (LNA) MAALGM0003-DIE show that the combination works, the limiter protects the LNA against damage. For HPM-pulses (HPM single pulse, pulse width = 100 ns, f=6 GHz) the susceptibility level is 41 dBm in peak pulse power and for UWB-pulses the corresponding level is more than 60 dBm.

The results mentioned above can be compared with the results from the susceptibility testing of the LNA MAALGM0003-DIE from MA/Com, without limiter protection. Both UWB- and HPM-measurements were done, the susceptibility was of the LNA was 34 dBm for HPM-pulses and 52-54 dBm for UWB-pulses. The limiter increases the susceptibility level with at least approximately 7 dB.

The results from the MMIC Schottky-diode limiter designed at FOI have showed to have good agreement between measured and simulated values, but it is not good enough to be used in a real application. For DC up to 3 GHz the susceptibility was increased from 20 dBm to about 28 dBm at the cost of about 1.5 dB in small signal insertion loss.

Keywords

HPM, UWB, Front-door protection, Limiter, LNA

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Rapportens titel

Implementering av HPM framvägsskydd och komponentundersökningar

Sammanfattning

Denna rapport summerar det arbete som utförts inom HPM-skyddsprojektet, delområde framvägskopplingsskydd. De HPM och UWB-mätningar som gjorts på kombinationen limiter TGL2201EPU integrerade med lågbrusförstärkaren (LNA) MAALGM0003-DIE visar att kombinationen fungerar, limitern skyddar lågbrusförstärkaren från skada. För HPM-pulser (PRF: enkelpuls, puls längd = 100 ns, f = 6 GHz) är tålighetsnivån 41 dBm i topp puls effekt och för UWB-pulser är motsvarande nivå mer än 60 dBm.

De ovannämnda resultaten kan jämföras med resultat erhållna från tålighetsmätningar som gjorts på lågbrusförstärkaren MAALGM0003-DIE from MA/Com utan limiterskydd. Både HPM och UWB-mätningar har utförts. Resultaten från mätningarna visar att tåligheten för lågbrusförstärkaren är 34 dBm och 52-54 dBm för UWB-pulser. Detta betyder att limitern ökar tåligheten med omkring 7 dB.

Resultaten från MMIC Schottky-diode limiter som konstruerats på FOI visade att det var god överensstämmelse mellan simulerade och uppmätta värden, trots det är inte resultaten tillräckligt bra för att användas i riktiga tillämpningar. För frekvenser från DC och upp till 3 GHz hade tåligheten ökat från 20 dBm till omkring 28 dBm på bekostnad av omkring 1.5 dB i småsignals transmissionsförluster.

Nyckelord

HPM, UWB, Framvägskopplingsskydd, Limiter, LNA

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Table of Content

1 Background 7
2 Introduction 7
3 Summary of Results From Previous Limiter/LNA Tests 8
4 Integration of limiter and LNA 8
5 Test setups 9
5.1 HPM Test Setup 10
5.1.1 Measurement Uncertainty 11
5.2 UWB Test Setup 11
5.2.1 Measurement Uncertainty 12
6 LNA-measurements 13
6.1 Results From LNA UWB-measurements 13
6.2 Results From LNA HPM-measurements 14
7 MMIC Limiter Development 15
7.1 Small Signal Simulations and Measurements 15
7.2 Large Signal Simulations and HPM-Measurements 16
7.3 UWB Measurements 17
7.4 Conclusion 18
8 Measurement on The Combined Limiter and LNA 19
8.1 HPM Measurement on The Combined Limiter and LNA 19
8.2 UWB Measurement on the Integrated Limiter and LNA 21
9 Summary and Conclusions 23
10 References 24

1 Background

High Power Microwave (HPM) sources are continuously improving in performance. It is believed that HPM-sources soon will reach operational status on the battle field. Today Sweden tends to send more and more troops to foreign grounds within the peacekeeping missions of United Nations (UN) and the Nordic Battle Group (NBG). It is therefore more likely that our troops and their electronic equipments are exposed to high power electro magneticfields, such as radar, EW (Electronic Warfare) and HPM etc. Some military and most civil electronic equipment are not protected against HPM. It is of importance to increase the force protection methods to also include protections against HPM and other high power electromagnetic sources.

2 Introduction

This report is a continuing part of the work done on HPM front-door protection devices and it is also a mile stone report for the project HPM-protection methods for the network centric defence from the Swedish Armed Forces (FM). This work has also been sponsored by the project HPM protection technique from the Swedish Defence Material Administration (FMV).

The main focus of the report is concentrated on implementation of earlier investigated limiters. This is done by integrating one type of limiters with LNAs and investigate the properties of the combined circuit. The limiter TGL2201EPU from Triquint and the LNA MAALGM0003-DIE from MA/Com has been mounted in a fixture and bonded together. The circuit combination is then investigated to see if the limiter protects the LNA from HPM- and UWB-pulses (Ultra Wide Band). The maximum peak power levels before permanent damage occurs are investigated.

The report also includes results from the continuing research on the susceptibility of Low Noise Amplifiers (LNA). Various parameters have been investigated in order to get a better understanding of the susceptibility of the LNAs when subjected to HPM- and UWB-pulses. The results in this report is mainly for UWB-measurements done on low noise amplifiers in order to determine the damage levels.

In-house design of MMIC limiters has also been done at FOI, the results are presented in this report. Both low level measurements and high level HPM- and UWB-measurements have been done in order to characterize and investigate the susceptibility of the limiter.

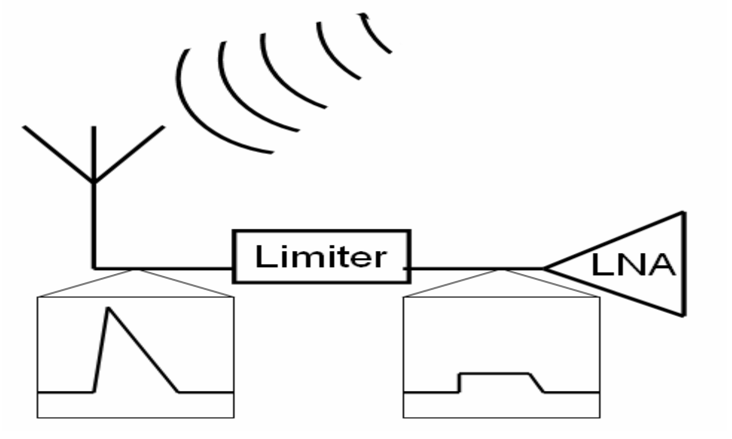


Figure 2.1 Schematic figure of limiter and LNA in front-door configuration.

3 Summary of Results From Previous Limiter/LNA Tests

During the years a number of different limiter and transient protections have been tested and evaluated [1]. This was done to further characterize the limiters, which are mainly characterized in CW (Continues Wave) performance. A broad diversity of different technologies has been investigated. From this investigation it is seen that not all limiter/transient protections are suitable as front-door protection against HPM- and UWB-pulses. However from the results is seen that diode based limiters in general provided a good protection against HPM- and UWB-pulses [1]. The diode based limiters have a drawback in power handling capability. They can only handle moderate power levels (tens of watts). This is partly due to the small sizes of diode limiters, but the small size also makes it possible to integrate them in phased array antennas and other systems where size is critical. However the diode limiters need to be complemented with a first stage limiter that can handle high power levels.

The results from previous LNA-testing presented in [1, 2], show that the LNAs are vulnerable to both HPM- and UWB-pulses. Measurements have been done with variation in lots of parameters such as HPM/UWB-pulses, pulse width, PRF (Pulse Repetiton Frequency), biasing on/off, in-band/out-of-band etc. The results show that an LNA suffers permanent damage at peak power levels around 35 dBm (HPM), with a variation of 4 dB depending on parameters, in some cases even more variation.

4 Integration of limiter and LNA

The LNA is one of the first components in the front-end receiver that will be hit by high power pulses in case of an attack.In order to protect the LNA, usually the first sensitive component, from HPM and UWB-pulses, a limiter has been put before the LNA. In the investigated configuration the limiter TGL2201EPU from Triquint has been integrated with the LNA MAALGM0003-DIE from MA/Com. Both the circuits have been mounted into a fixture, seen in figure 4.1. The limiter and LNA are mounted and bonded together in series, with the limiter at the input followed by the LNA which is to be protected. The LNA has also two DC-biasing connections, Vg (gate voltage) and Vd (drain voltage). A DC ground connection is also available on the fixture. The fixture has SMA connectors and is easily connected to different measurement setups. A close-up of the limiter and LNA is seen in figure 4.2.

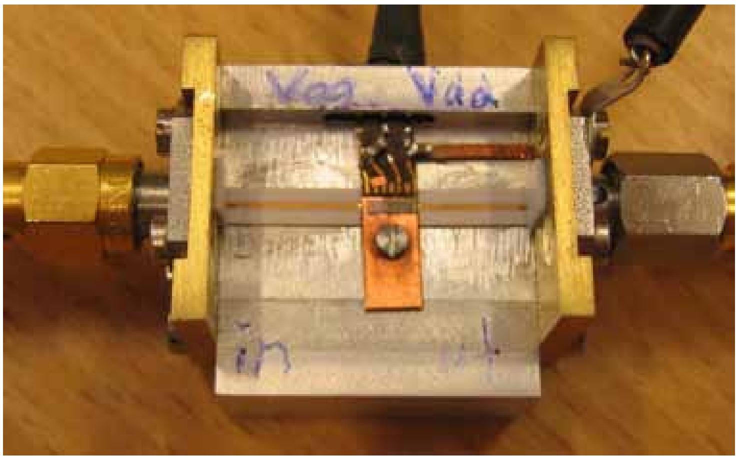


Figure 4.1 Photograph of the limiter and LNA mounted in a fixture.

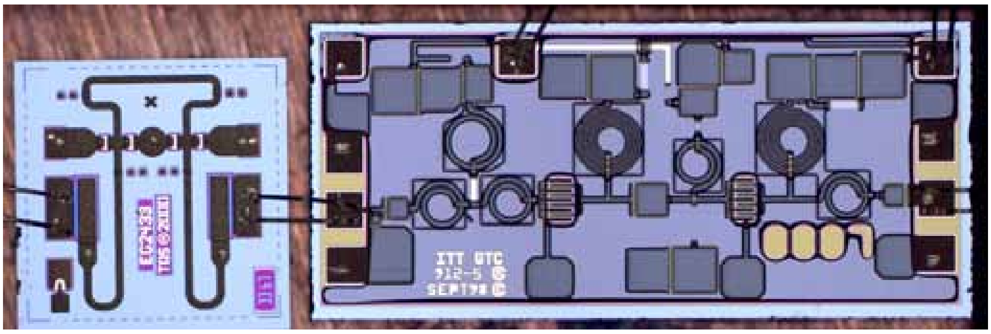


Figure 4.2 Close-up photograph of the limiter (left) and LNA (right). Two bonding wires connect the limiter and LNA.

The integrated limiter and LNA have been measured both separately and in combination. A network analyzer (HP8510C) was used to measure S-parameters and a noise figure meter (HP8970A) was used to measure the NF. This was done before high level HPM and UWB testing in order to get reference values, it was also done in between the high level testing to detect degradation and damage of the circuits.

5 Test setups

Two different measurement setups for high level testing were used. One for HPM and one for UWB-measurements. These two set-ups will be further described in this section. The measurement setup for S-parameter and noise figure measurements is seen in figure 5.1

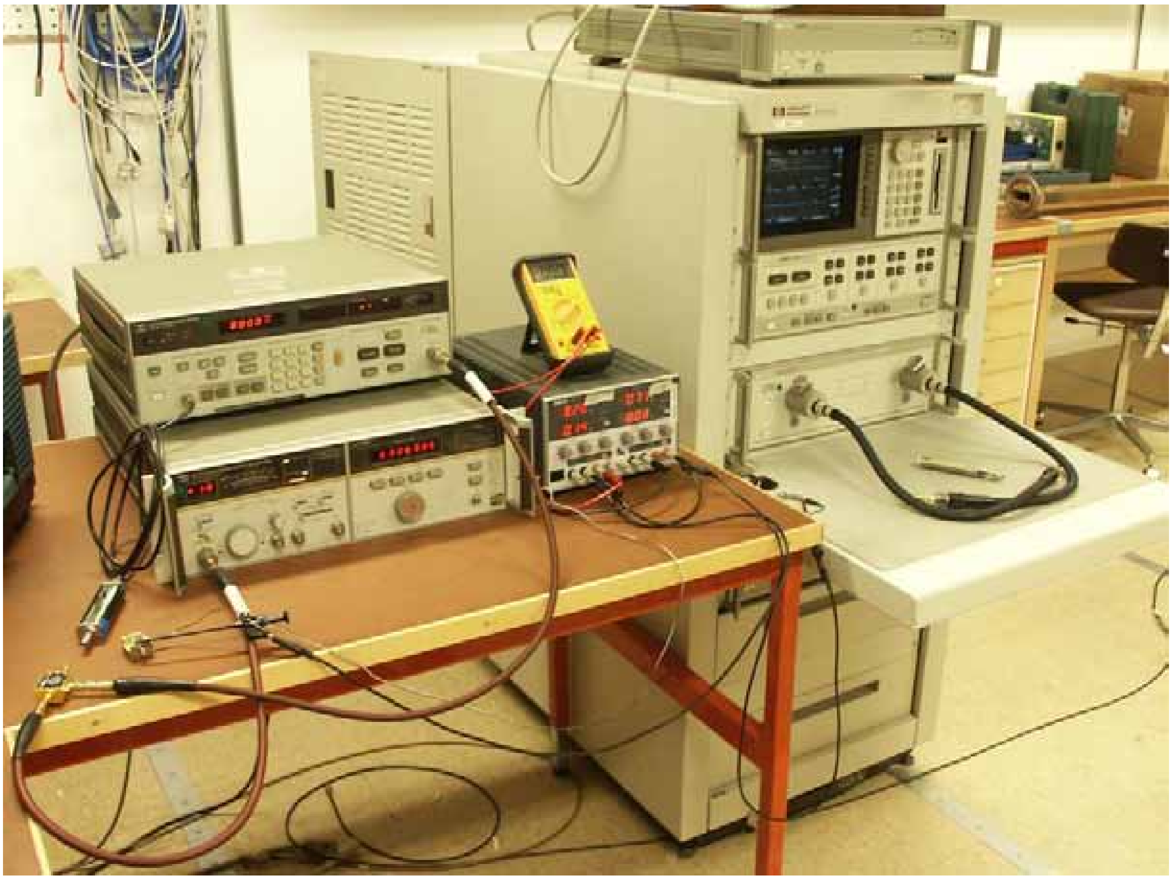


Figure 5.1 Photograph of the measurement setup for noise figure (left) and S-parameters (right).

5.1 HPM Test Setup

The HPM-signal is generated from a Synthesized Sweeper (HP 83630A), which is triggered by a pulse generator (HP8112A). The microwave pulse is then propagated through internal switches before it reaches one of the four power amplifiers. The HPM-measurement set-up consists of four different amplifiers, two solid-state amplifiers and two TWT (Traveling Wave Tube) amplifiers. Each amplifier has a certain operating frequency-band, which in total comprise the band 0.5 to 18 GHz. The amplifiers have a maximum output power of 20 to 30 Watt depending on the frequency and which amplifier that is used. In this measurement a 4-8 GHz TWT amplifier was used. After the amplifier, the microwave pulse is injected into the directional coupler. The main pulse is injected in the DUT (Device Under Test) and a reference signal (attenuated 20 dB) is also given from directional coupler. The reference signal is measured by an Oscilloscope to see if the input pulse is correct. The setup is managed by a PC, which runs a HP-Vee program. The program is used to control switches, power levels, pulse width, PRF and to collect measured data etc. A photograph of the measurement setup is seen in Figure 5.2 and a block diagram in Figure 5.3.

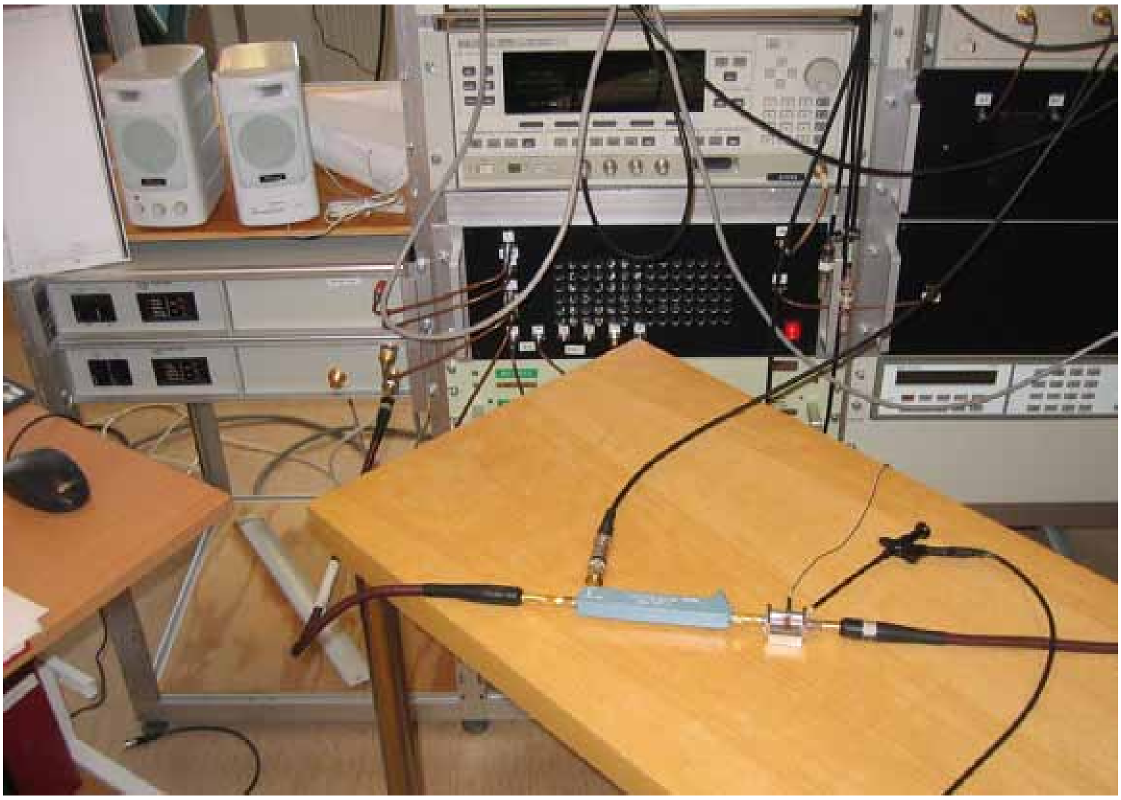


Figure 5.2 Photograph of the measurement setup for HPM-pulses.

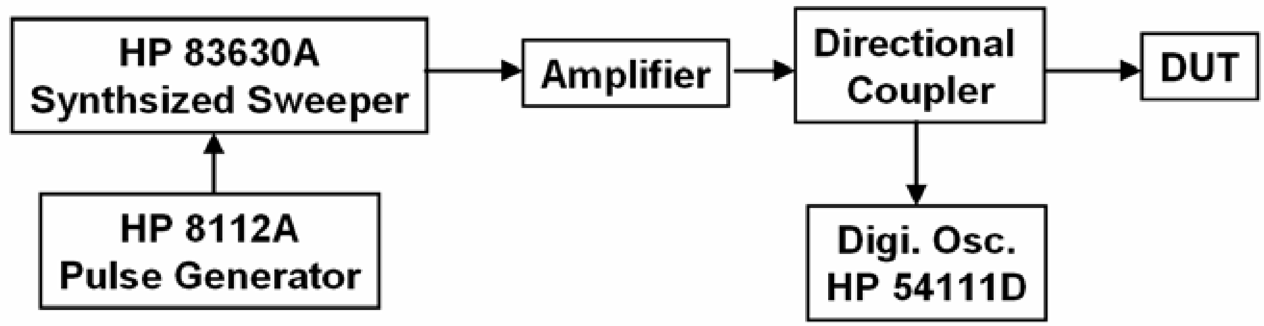


Figure 5.3 Block diagram of the measurement setup for HPM-pulses.

5.1.1 Measurement Uncertainty

The measurement uncertainty for the HPM-measurement set-up has been estimated. Several parameters have been taken into account, for example losses in cables, connectors and switches etc. The estimated uncertainty for the HPM power levels is 0.5 dB. The oscilloscope has about 1 % in measurement uncertainty. The detectors used for the measurements have finite rise time, 3.5 ns, which may change the shape of the pulse.

5.2 UWB Test Setup

The UWB-measurement setup consists of a PGS402 pulse source from Power Spectra. A HP 8112A pulse source is used to trigger the PGS402. This source generates UWB- pulses, with very short rise-time and pulse width. Special attenuators are placed before and after the DUT. These high voltage attenuators (from Barth Electronics) are used to regulate the power delivered to the DUT. Attenuators where also used between the DUT and the oscilloscope to limit the voltage at the oscilloscope input to 5 V (maximum input level to the oscilloscope) when needed. The pulse source generates a 400 Volt uni-polar pulse with a rise-time of about 150 ps and a pulse width of about 1 ns into a 50Ω load. The pulse is measured with a fast Tektronix TDS 6604 Digital oscilloscope (6 GHz analog bandwidth, 20 GSample/s). A photograph of the measurement set-up can be seen in Figure 5.4 and a block diagram in Figure 5.5.

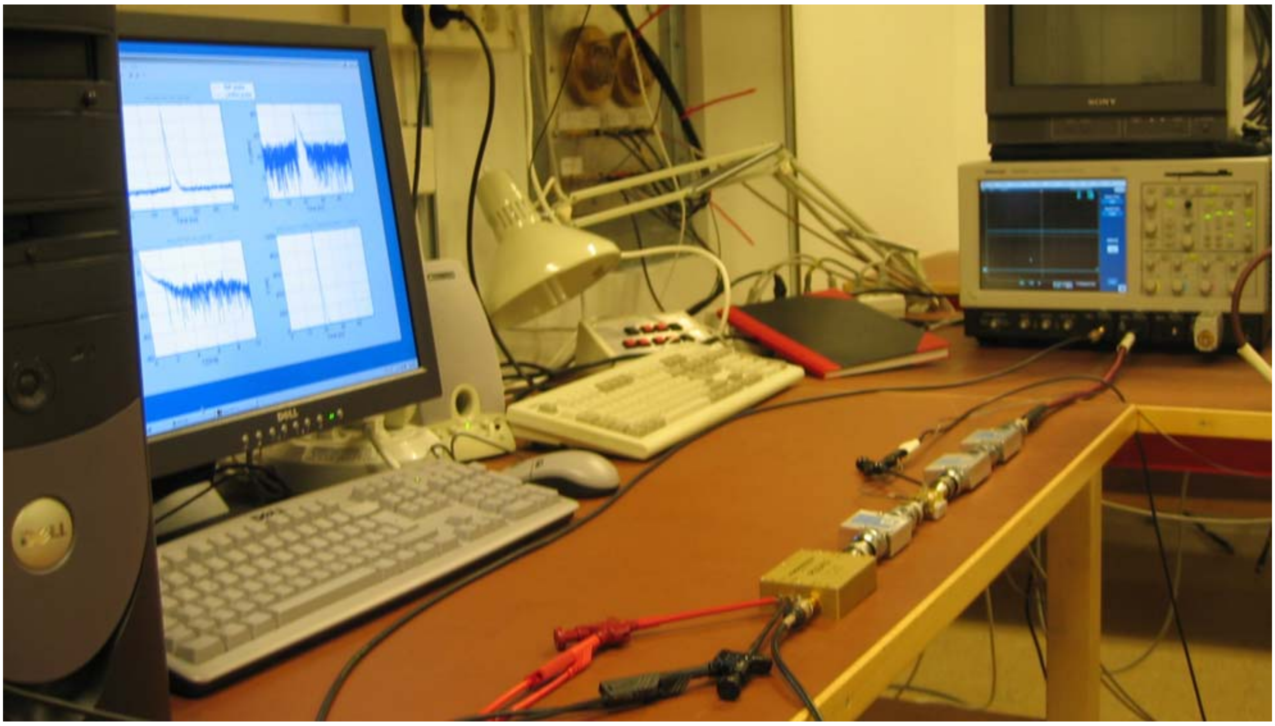


Figure 5.4 Photograph of the measurement setup for UWB-pulses.

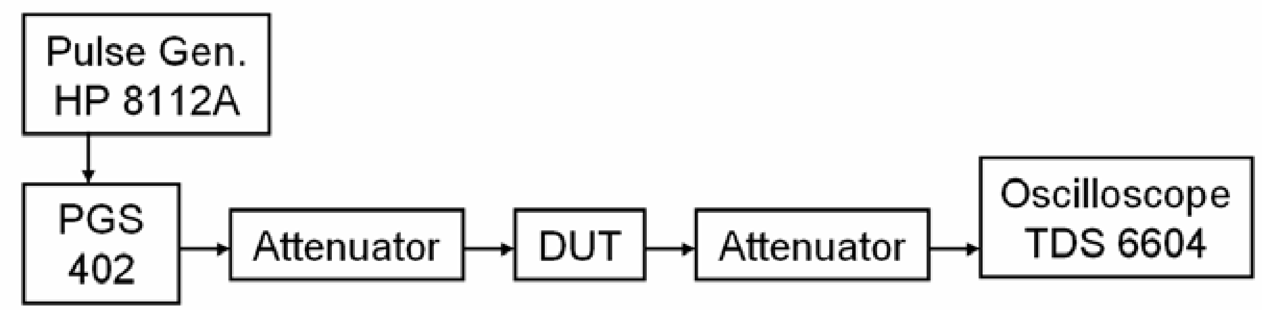


Figure 5.5 Block diagram of the measurement setup for UWB-pulses.

5.2.1 Measurement Uncertainty

The dominating uncertainty in the UWB measurements is believed to be due to the use of attenuators to regulate the power to the limiter and the power to the oscilloscope. The uncertainty of the specified attenuation of the attenuator and the real attenuation is estimated to 0.1 dB. The uncertainty due to loss in coaxial transitions is estimated to 0.1 dB at the relatively low frequencies used in these measurements. A maximum of four attenuators was used between the pulse source and the DUT and not more than two attenuators were used between the DUT and the oscilloscope.

This gives a possible uncertainty of 0.1 dB in $(4+5)\cdot 2 = 18$ instances which yields an uncertainty of $\sqrt{18}\cdot 0.1 = 0.43$ dB for the signal at the limiter input, (4 attenuators and 5 transitions). The factor of 2 at the end is due to the fact that one reference measurement of the pulse is used to calculate the input pulse of all subsequent measurements, this measurement is then scaled with the used value of attenuation to calculate the real input power, both the reference measurement and the scaling is subject to errors in the attenuators and loss in coaxial transitions.

The uncertainty for the output pulse becomes $\sqrt{2+3}\cdot 0.1 = 0.23$ dB (2 attenuators and 3 transitions).

The uncertainty of the oscilloscope is estimated to be negligible in comparison to the uncertainties in attenuators and transitions discussed above, although at very low signal level this might not be true.

6 LNA-measurements

The testing of LNAs has proceeded. The measurements on LNAs have been done with both HPM- and UWB-pulses. The measurements were done on the LNA MAALGM0003-DIE from MA/Com. The new results are from UWB-tests, where the LNA has been subjected to single pulses with very short rise time (150 ps) and pulse width (1 ns) and from single pulse HPM-tests with a rise time of 5 ns, pulse width of 100 ns and frequency of 6 GHz. In both measurements the LNAs have been properly biased.

6.1 Results From LNA UWB-measurements

Three samples of the same type of LNA were subjected to single UWB-pulses. The peak power and the pulse energy required for permanent damage was investigated. The damage level showed to be in the interval of 52-54 dBm for two samples and 50-52 dBm for one sample. This corresponds to an pulse energy of about 170 nJ and 130 nJ respectively. In the figures below the results are presented. Figure 6.1 show the peak power levels for permanent damage and figure 6.2 show the corresponding pulse energy levels required for permanent damage.

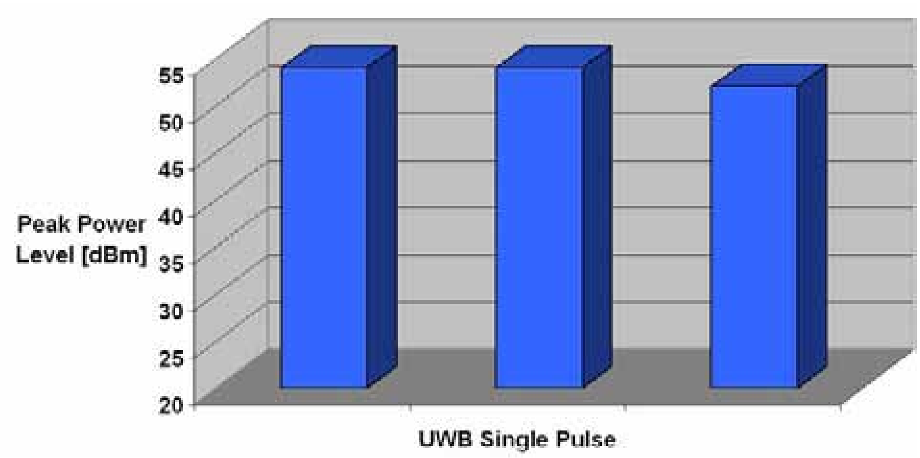


Figure 6.1 UWB peak power levels required for permanent damage.

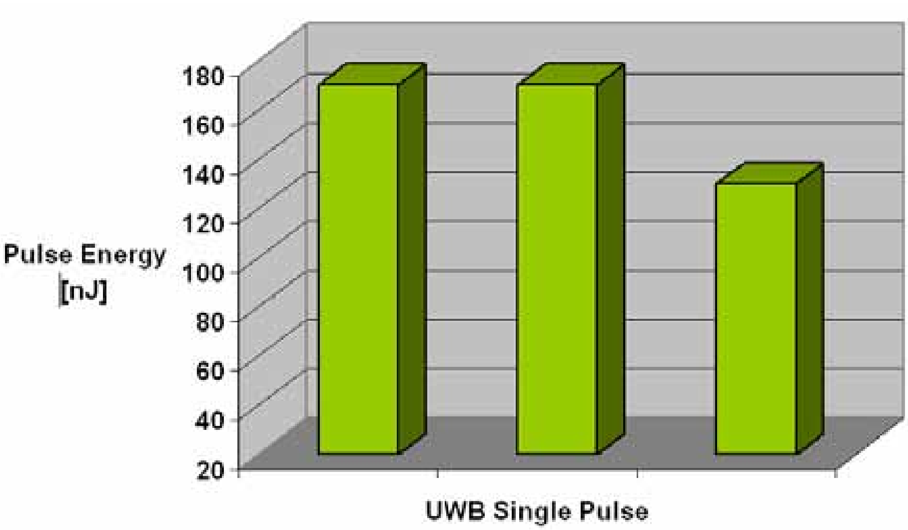


Figure 6.2 UWB pulse energy levels required for permanent damage.

6.2 Results From LNA HPM-measurements

Three samples of the LNA were subjected to single HPM-pulses. The peak power and pulse energy required for permanent damage was investigated. The HPM-signal has the following properties, PRF: single pulse, frequency = 6 GHz, pulse width: 100 ns. The damage level showed to be 34 dBm for two samples and 35 dBm for one sample. This corresponds to a pulse energy of 250 nJ and 320 nJ respectively. In the figures below are the results presented. Figure 6.3 shows the peak power levels for permanent damage and Figure 6.4 shows the corresponding pulse energy levels required for permanent damage.

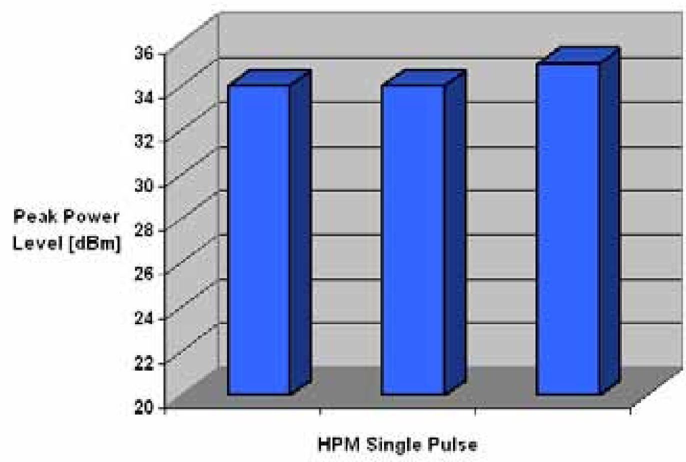


Figure 6.3 HPM peak power levels required for permanent damage.

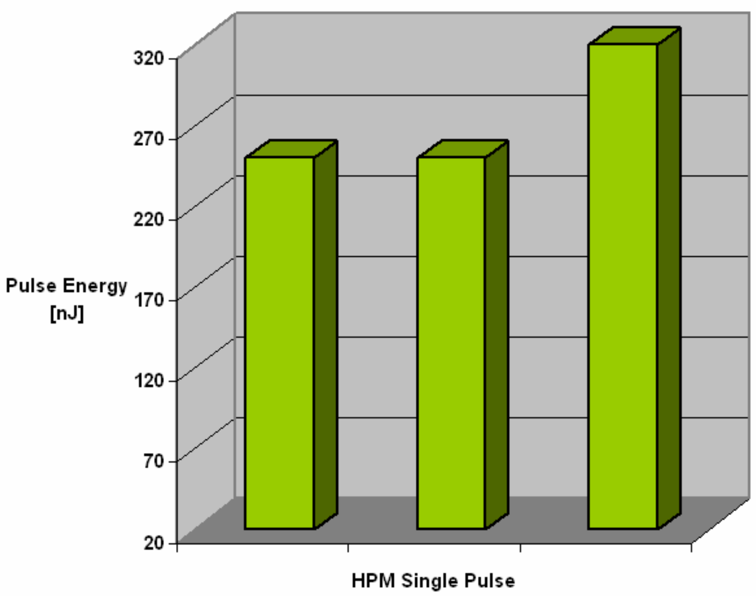


Figure 6.4 HPM pulse energy levels required for permanent damage.

7 MMIC Limiter Development

A compact and cost-efficient solution for highly integrated receivers (such as in electronically steered antennas) would be to integrate the limiter and the low noise amplifier, which the limiter is to protect, on the same chip. At least one such component is commercially available (the M/A-COM MA01502D), which has been tested in [2] and [3] and there are indications that others are also investigating this possibility. Therefore we have studied the feasibility of limiters made in the same process which is already in use for making various receiver circuitry within other projects at FOI (the OMMIC ED02AH GaAs MMIC -process). Two process runs were completed with various components test circuits and limiters. Presented below is one of the limiters that was fabricated in the second process run. The limiter was designed as a low-pass filter in order to minimize the small signal loss. The off-state capacitance of the Schottky diodes is used as the shunt capacitance of the filter and a spiral inductor as the series inductance, see figure 7.1. Important design parameters of the limiter are small signal loss, limiting threshold, maximum isolation and the current distribution among the diodes. To maximize the burnout power the current distribution among the limiter diodes should be as even as possible at the maximum power. The design of the second iteration of the FOI limiter has been described in detail in [1]. The limiting devices in the limiter shown in figure 7.1 are Schottky diodes. Basically the diodes turns gradually on when the input power is increased, the RF output power is limited partly by the power dissipated in the diodes and partly by the reflection at the input which is caused by the lower impedance of the turned on diodes. In a good limiter the second part is dominating, this requires low on-resistance in the diodes.

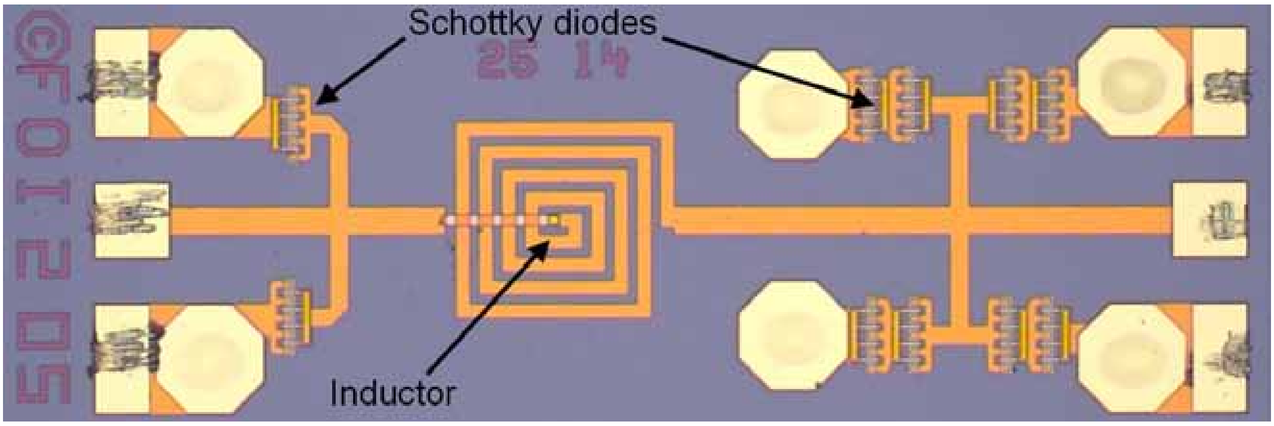
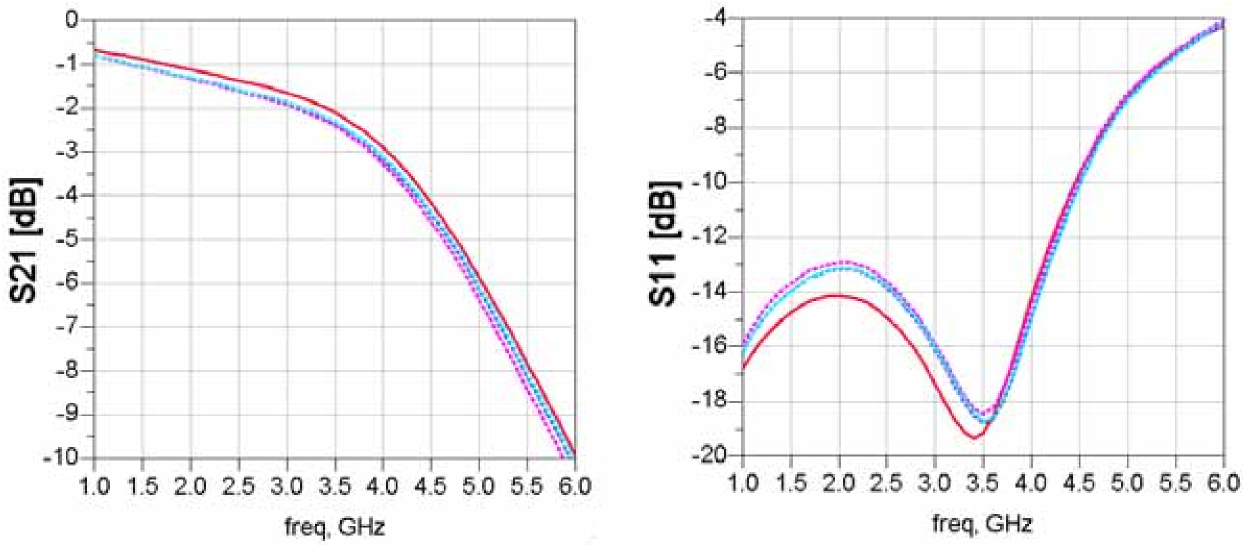


Figure 7.1 Photograph of the GaAs MMIC limiter chip.

7.1 Small Signal Simulations and Measurements

The small signal performance of the processed limiters was measured using a network analyzer. The simulated and measured S-parameters, shown in figure 7.2, are similar as expected.



(a) (b)

Figure 7.2 Simulated (solid) and measured (dashed) S21 (a) and S11 (b) S-parameters of the limiter. The measurements show results from 3 different limiter chips.

7.2 Large Signal Simulations and HPM-Measurements

HPM high level testing was carried out using the test system described in [2]. This measurement system differs from the system described in section 5.1 of this report in the way that it measures the input, reflected and transmitted pulse at the test object during each pulse but has lower maximum power than the system described in section 5.1. Figure 7.3 shows large signal simulation results for the limiter and figure 7.4 the corresponding HPM-measurements, with a pulse width of 1 µs, frequency of 2 GHz and a PRF of 10 kHz. Because of operator induced limitations it was not possible to use pulsed excitation in the limiter simulations as was the case in the measurements.

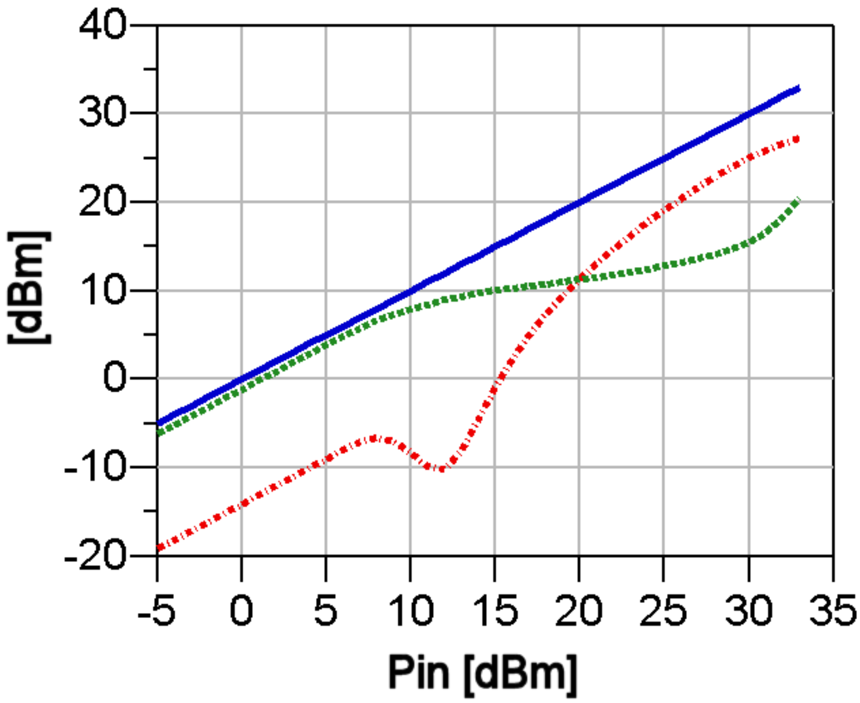


Figure 7.3 Large signal simulation (HPM) results for the FOI MMIC limiter, showing input power (solid), transmitted power (dashed) and reflected power (dash-dot) as a function of input power. The CW carrier frequency in these simulations was 2 GHz.

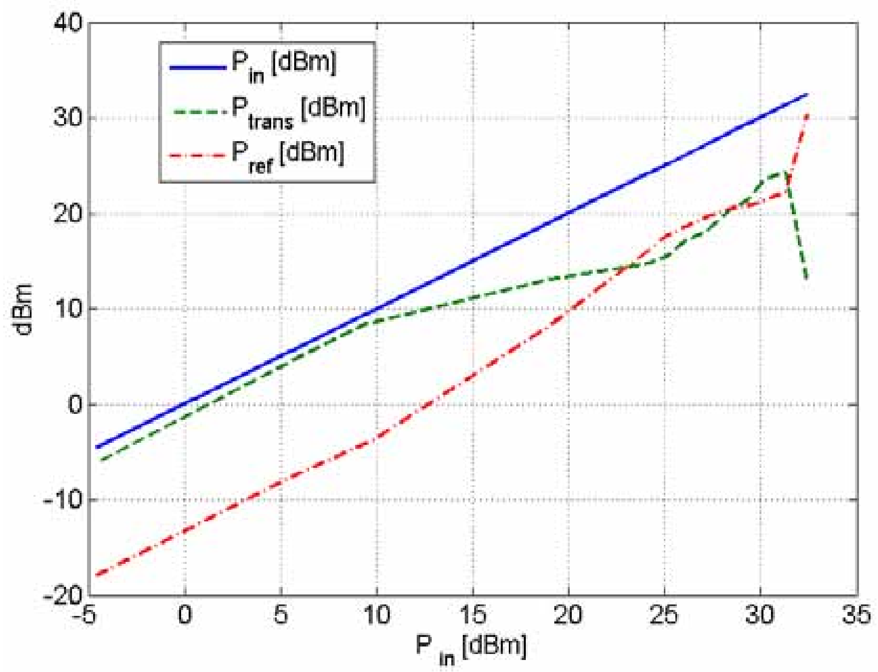


Figure 7.4 Pulsed HPM-measurement results for the FOI MMIC limiter, showing input power (solid), transmitted power (dashed) and reflected power (dash-dot) as a function of input power. The carrier frequency in these measurements was 2 GHz and the pulse length 1 μs.

In general the simulated results are better than the measured with higher isolation and higher saturation power. These differences are not believed to be due to the difference in excitation but rather to limitations in the diode model at high excitation. The peculiar dip in S11 in the simulation is due to the limiter input impedance moving closer to the system impedance when the diodes just start to turn on. The reason why this dip is not observed in the measurement is a combination of lower sensitivity and coarse power stepping in the measurements. However the onset of limitation and the general behavior of the limiter are reasonably adequately simulated.

7.3 UWB Measurements

UWB measurements using the same measurement system as described in section 5.2 was also carried out on the MMIC limiter. Figure 7.5 shows the incoming and transmitted pulse for a pulse close to the onset of limiting (a) and for a larger pulse when diode-current is saturated (b). As can be seen the limiting is fairly efficient even at high voltages but the transmitted voltage is far above the diode turn on voltage due to current saturation.

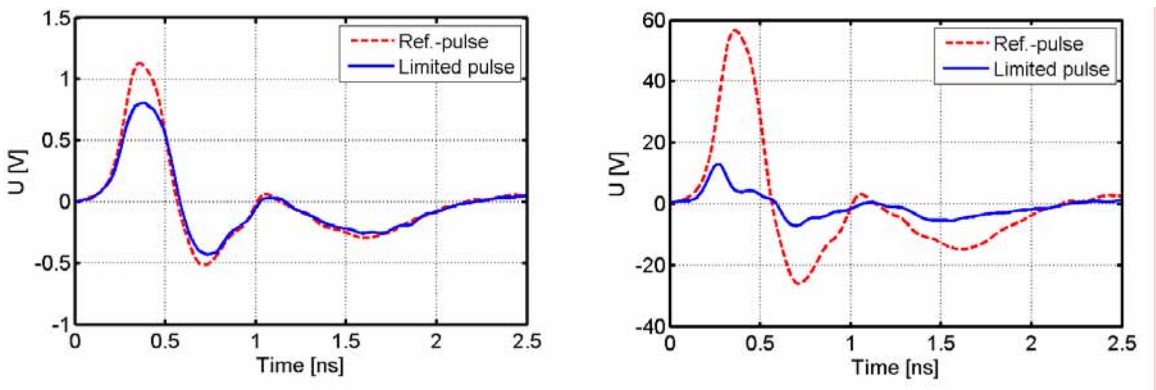


Figure 7.5 Time domain response of MMIC diode limiter. Small signal pulse (left) and large signal pulse (right).

7.4 Conclusion

The measured performance of the limiter is similar to the simulated but is not quite good enough to be used in a real application, although it could be used from DC to 3 GHz to raise the allowed input signal strength of a sensitive circuit from 20 to ~28 dBm at the cost of ~1.5 dB small signal loss. The main problem is the parasitic resistance of the diodes that increase the off-state small signal loss of the circuit, limiting both bandwidth and the use of larger diodes that would allow better isolation in the on-state. Most discrete limiters use PIN diodes, which have more suitable properties for microwave limiters, or a combination of PIN and Schottky diodes, but PIN diodes is very rarely available in MMIC processes. One alternative would be to use a smaller diode, for detection of incoming high power signals, to trigger an active limiter using diodes (switches) or transistors and external bias. But usually passive limiter circuits are preferred as they are more reliable and offer protection also when the system is not powered on. With the use of a process with more suitable Shcottky diodes though we conclude that the MMIC integrated limiter might be an important alternative in some applications.

8 Measurement on The Combined Limiter and LNA

In general the tested diode-limiter has provided good protection against HPM- and UWB-pulses. But due to the small size and semiconductor properties of the diode-limiter, the power handling capability is only moderate. According to the specifications the maximum CW power level is greater than 5 Watt (37 dBm). Two samples of the combinded limiter (from Triquint, USA) and LNA (from MA/Com, USA) were tested, one for HPM and one for UWB-pulses.

8.1 HPM Measurement on The Combined Limiter and LNA

The HPM-measurements were done using the setup described in section 5.1. Before the high level HPM measurements began, a visual inspection of the circuits was done, followed by noise figure and S-parameter measurements, seen in figure 8.1 and 8.2 respectively. For the measurements the following parameters were choosen; Pulse width: 100 ns, PRF: single pulse, frequency: 6 GHz, Biasing of the LNA Vd=3.2 (Id=50 mA), Vg=-0.7 V.

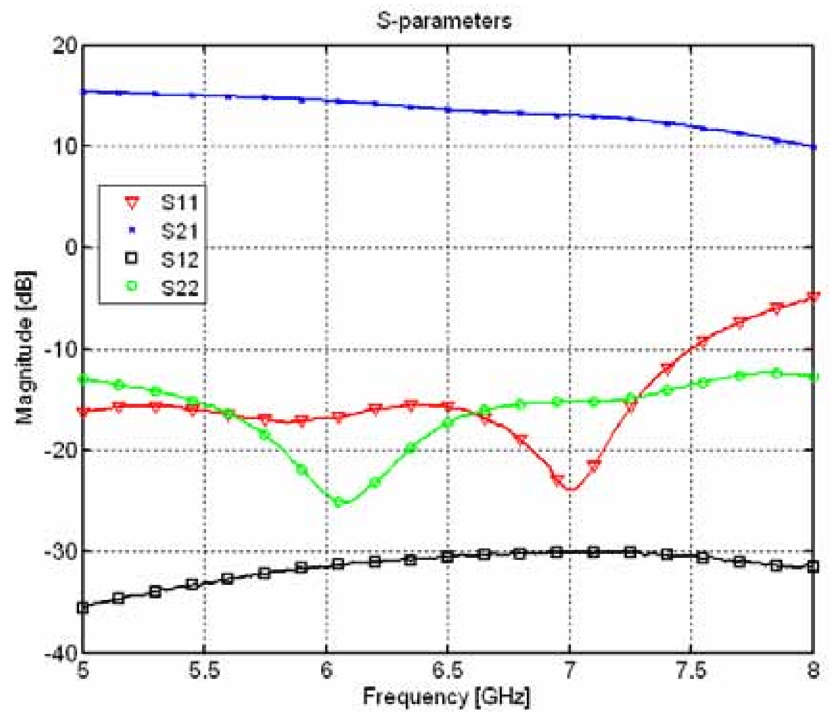


Figure 8.1 Measured S-parameters before high level HPM measurements.

The measurements started at 25 dBm input peak power that was step-wise increased with increments of 1 dB to 43 dBm (Maximum output from the power amplifier (PA)). The drain current (Id) of the LNA was used as an indicator of damage or degradation of the LNA. During the measurements the drain current was monitored. Based on the knowledge from previous LNA [1,2] measurements, the drain current (Id) is know to change during the pulse and also increase just before damage occurs (dagradation). No indication of degration was seen after the maximum power of the PA was reached. The limiter and LNA were taken out for control measurements. The results showed that the gain of the circuit had dropped 20-25 dB (G = -10 to -15 dB), and the noise figure had increased to 17-23 dB for the 5 to 8 GHz band, seen in figure 8.2. All indications showed that the LNA was functioning well and was not damaged. The conclusion from this was that the limiter had been damaged and not the LNA.

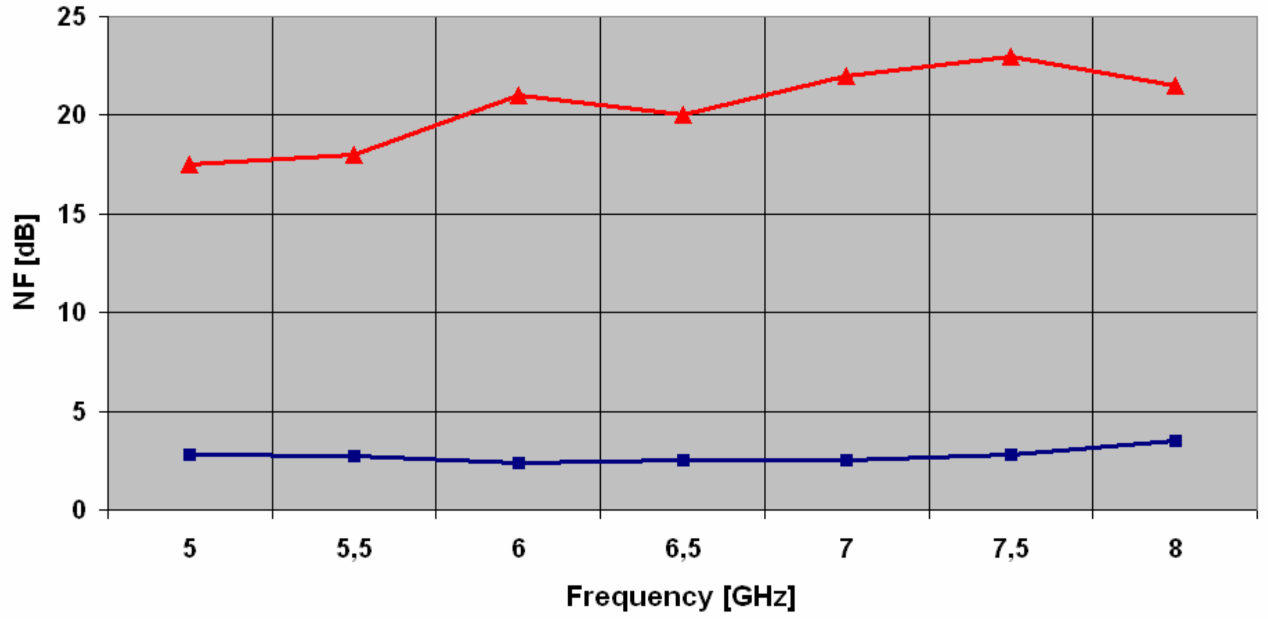


Figure 8.2 Measured noise figure before (square) and after (delta) high level HPM measurements.

A separate measurement of the TGL2201EPU limiter was now done in order to determine the susceptibility in terms of peak power level. S-parameter and noise figure measurements were done before and between the high level HPM-tests. The measurements showed that the limiter was permanently damaged at 41 dBm peak power input, for a HPM-pulse, with a pulse width of 100 ns, frequency of 6 GHz and PRF: single pulse.

From the results of the measurements it was seen that the limiter provides good protection against HPM-pulses up to 41 dBm peak input power. In practice the LNA can withstand 7 dB higher peak input power without permanent damage, compared to the unprotected LNA which was permanently damaged at 34 dBm peak input power, with the same pulse parameters, according to the test described earlier in this report.

The corresponding pulse energy which the limiter and LNA can withstand is 1,25 µJ. This level is 1 µJ higher than if the LNA would be unprotected (250 nJ), with the same pulse parameters.

8.2 UWB Measurement on the Integrated Limiter and LNA

The UWB-measurements were done using the setup described in section 5.2. Before the high level UWB-measurements could begin, a visual inspection of the circuits, noise figure and S-parameter measurements were done. After every increase of input power S-parameter and noise figure measurements were also done, in order to detect any change or degradation. For the UWB-measurements, the following parameter values were choosen; Pulse width: fixed, about 1 ns, PRF: single pulse, frequency: Ultra Wide Band, Biasing for LNA Vd=3.2 (Id=50 mA), Vg=-0.6 V.

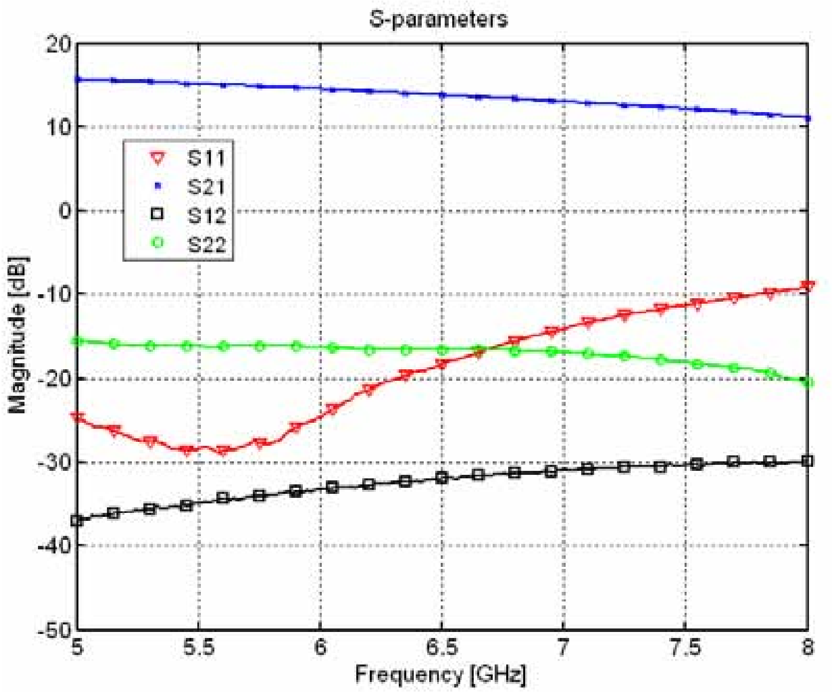


Figure 8.3 Measured S-parameters before high level UWB measurements.

The UWB-measurements started at 30 dBm peak input power and was step-wise increased with increments of 2-4 dB (depending on the configuration of attenuators) to the maximum peak input power of 60 dBm. The drain current of the LNA was monitored during the measurements in order to see indications of degradation or damage. S-parameter and noise figure measurements were also done between the high level UWB-measurements in order to dertemine if damage or degradation had occurred. No unusual values of the LNA drain current was seen during the measurements. After the maximum peak input power (60 dBm) was reached, the S-parameters and the noise figure were measured for limiter and LNA combination. The S-parameter measurements showed that the S11 had improved with about 10-20 dB for frequencies below 6 GHz, the S11 was also somewhat improved over the rest of the measured frequency band, otherwise the rest of the S-parameters remained unchanged. The noise figure was practically unchanged compared to the reference values measured before high level UWB-testing. However the change in S11 indicates that some kind of permanent damage has been sustained.

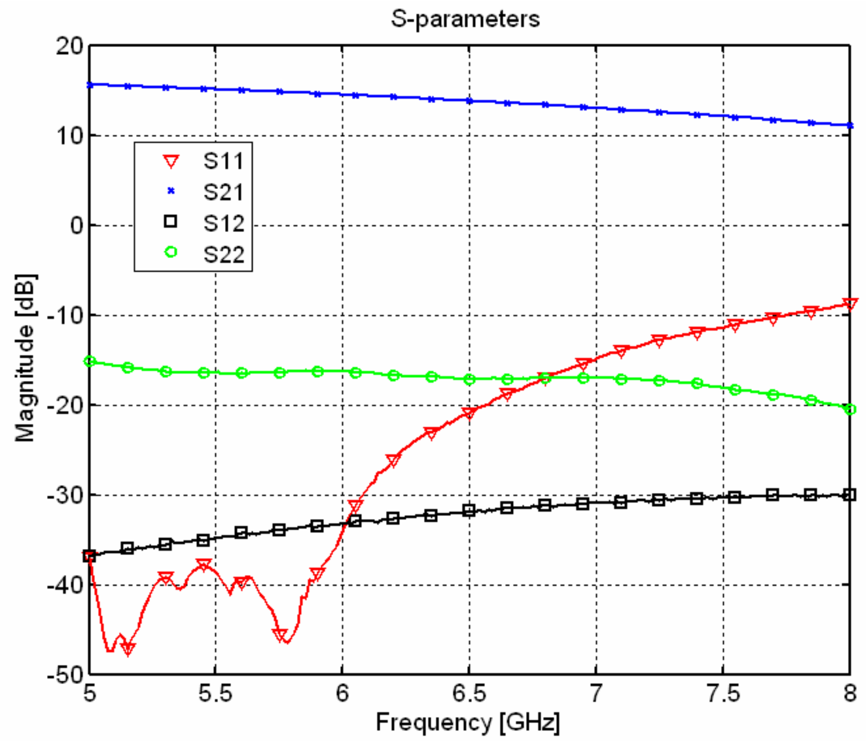


Figure 8.4 Measured S-parameters after high level UWB measurements.

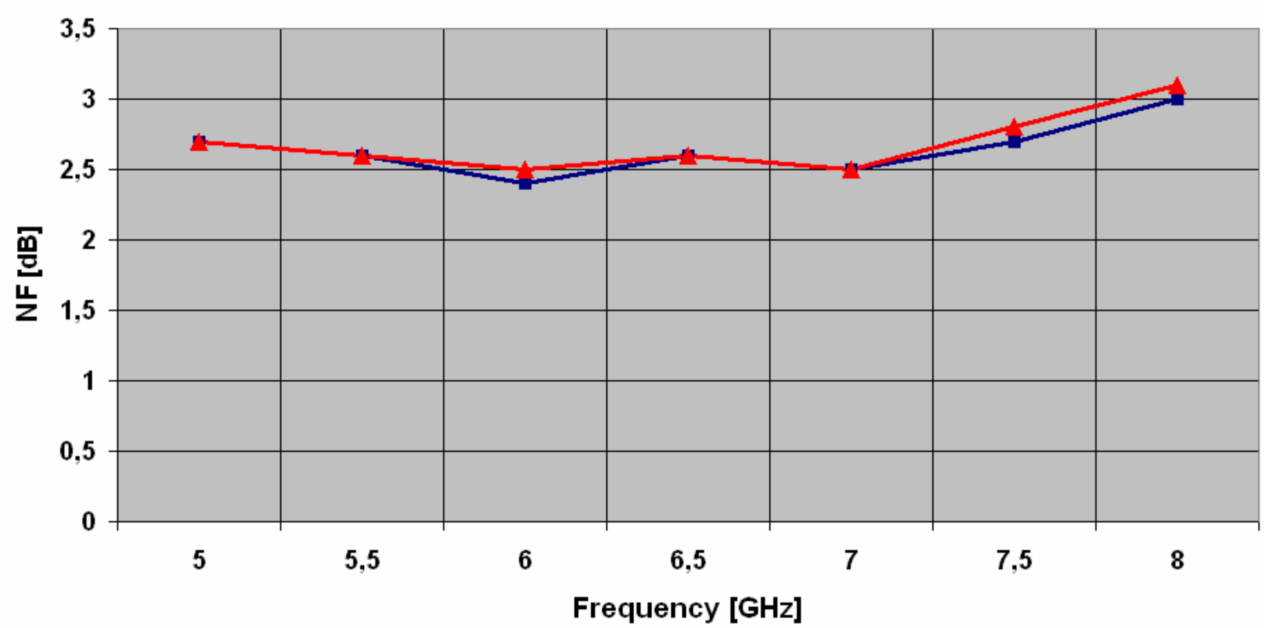


Figure 8.5 Measured noise figure before (square) and after (delta) high level UWB measurements.

The limiter provides good protection against UWB-pulses up to 60 dBm peak input power, which in practice means that the LNA can survive more than 6-8 dB higher peak input power without permanent damage compared to LNA-measurements without limiter (permanent damage at 52-54 dBm, section 6.1).

The corresponding pulse energy which the limiter and LNA can withstand is 710 nJ. This level is 540 nJ higher than if the LNA would be unprotected (170 nJ), with the same pulse parameters.

9 Summary and Conclusions

The HPM- and UWB-measurements show that the Triquint TGL2201EPU limiter works well as a limiter and prevents damage to the LNA MAALGM0003-DIE, with up to 41 dBm in peak pulse power for HPM-pulses and 60 dBm peak pulse power for UWB-pulses. Without the limiter the LNA would suffer permanent damage at 34 dBm peak power for HPM-pulses and for UWB-pulses at 52-54 dBm peak power, with the same pulse-parameters. The corresponding peak energy levels showed to be 1,25 µJ (HPM) and 710 nJ (UWB) respectively, without causing permanent damage or degradation. The TGL2201EPU works very well as front-door protection and increases the susceptitbility level with about 7 dB. The small size enables a high level of integration, but is also contributing to the main drawback, which is the power handling capability.

The limiter TGL2201EPU itself was also investigated separately. The HPM susceptibility of the LNA showed to be 41 dBm in peak pulse power. This is equivalent to 1.25 µJ in pulse energy.

The susceptibility of the LNA MAALGM0003-DIE from MA/Com has been investigated. Both HPM (single pulse, pulse width = 100 ns, f=6 GHz) and UWB-pulses were used in the measurements. The results show that permanent damage occurs at about 34 dBm peak power, which correspondes to 250 nJ in pulse energy, for HPM-pulses. The corresponding results for the UWB-measurements were about 52 dBm in peak input power, to cause permanent damage. The corresponding pulse energy level is about 150 nJ for permanent damage.

The MMIC schottky-diode limiter designed at FOI has showed to have good agreement between measured and simulated values, but it is not good enough to be used in a real application. For DC up to 3 GHz the susceptibility was increased 20 dBm to approximately 28 dBm at the cost of about 1.5 dB small signal insertion loss. The main problem is the parasitic resistance of the diodes that increase the off-state small signal loss of the circuit, limiting both bandwidth and the use of larger diodes. With the use of a process with more suitable Schottky diodes though we conclude that the MMIC integrated limiter might be an important alternative in some applications.

10 References

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