Doctoral Forum on Vacuum Electronics (FVE 2017)

22–23 August 2017

Experiment on Ka-band amplifiers degraded and damaged by electromagnetic waves

Zhan-Liang Wang[1,2], Jinjin Luo[1], Xu Xiong[2], Yu-Bin Gong[1], Yan-Yu Wei[1], Zhao-Yun Duan[1], Huarong Gong[1]

[1]School of Electronics Science and Engineering, University Electronic Science and Technology of China (UESTC), No. 4, Section 2, North Jianshe Road, Chengdu, People's Republic of China
[2]State Key Laboratory of Complex Electromagnetic Environment Effects of Electronics and Information System, Luoyang 471003, People's Republic of China
E-mail: 46969449@qq.com

Published in *The Journal of Engineering*; Received on 7th February 2018; Revised on 19th April 2018; Accepted on 24th April 2018

Abstract: Research on amplifiers injected by high-power microwave is important and lays foundation for reinforce technology. This study reports an experiment on Ka-band amplifiers injected and damaged by electromagnetic waves. The continuous wave and the pulse wave are injected into the amplifiers which are based on HMMC5040 chips. The injected power level increases until the amplifiers are damaged. The results are recorded and analysed. The results show that: (i) the uncharged amplifiers need more injected power to be damaged compared with the charged amplifiers. (ii) To degrade or damage the amplifiers, the pulse wave need more power. (iii) The first node of the HMMC5040 chip is damaged in the experiment, so this is the key part for anti-radiation design.

1. Introduction

Currently, more and more millimetre (MM) wave circuits are used in all kinds of applications, such as electromagnetic counter, MM wave radar, communication equipment etc. [1–5]. MM wave amplifiers are the key parts of the circuits in all kinds of MM wave equipment, and the performance of the amplifiers directly dominate the ability of the equipment. However, the amplifiers based on solid state chips tend to degrade or fail under the attack of high-power electromagnetic (EM) waves, that will lead to the degradation or failure of the equipment. Therefore, research on the amplifiers injected by high-power microwave (HPM) is important and lays the foundation for the reinforce technology [6–15].

Many labs and institutes are carrying out research in this field. In the USA, army has established a database on the effect of the EM wave since the early 1980s [6]. Researchers in the University of Maryland studied the disturbance of metal-oxide-semiconductor field-effect transistor (MOSFETs) by injecting 1–20 GHz power microwave [7]. In German, the digital devices attacked by the ultra-wideband wave has been investigated in detail [8, 9]. In Sweden, Backstrom [10] studied the HPM effect of aircrafts, missiles, vehicles, and computers [11]. In South Korea, Inha University had studied the HPM effect of many devices [12, 13]. In China, the China Academy of Engineering Physics, Nanjing University, University Electronic Science and Technology of China, Sichuan University and the Northwest Institute of Nuclear Technology are researching on the HPM effect [1, 14–16].

Most of these research focus on low frequency, but the effect of high-power MM wave is absent. In this study, the Ka-band amplifiers damaged by high-power waves are reported. Section 2 presents the comparison of amplifiers. The experiments are shown in Section

Fig. 1 *Ka-band amplifiers*

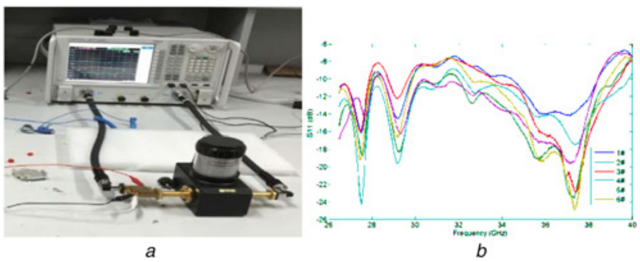

Fig. 2 *Measurement of S parameters and S_{11}*

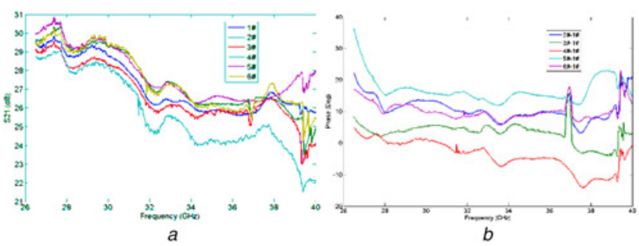

Fig. 3 *S_{21} and phase shift of the amplifier*

3. The broken amplifiers are analysed in section 4. Lastly, a brief conclusion is presented.

2 Amplifiers

Many chips have been used in Ka-band amplifiers, such as ALH369, ALH140C, ALH427, HMMC5040, TGA4508 and so on. HMMC5040 is a kind of chip with wide application, low cost and wide band. The work frequency, gain and saturated output of HMMC5040 are 20–40 GHz, ∼22 dB and ∼21 dBm, respectively. Six amplifiers have been manufactured, as shown in Fig. 1.

The S parameters of the amplifiers are measured with a vector network analyser, as shown in Figs. 2 and 3. In Fig. 2*a*, a 20 dB attenuator is connected with the output port of amplifiers in order to reduce the output power. Fig. 2*a* shows that most of the S_{11} curves are less than −10 dB. Fig. 3*a* shows that the average of S_{21} is about 27 dB, and all the S_{21} curves are high at the low-frequency section. The phase shifts of the amplifiers are different, although the same type of chip is used, as shown in Fig. 3*b*.

3 Experimental research

3.1 Degrade and damage of the charged amplifier with continuous wave (CW)

One of the amplifiers is tested using the flowchart shown in Fig. 4. The signal source has the maximum CW output of 38 dBm at the frequency of 35 GHz. A variable attenuator is used to adjust the injected power for the amplifier under test. A 20 dB directional coupler with a power meter is used to monitor the power of the EM wave. The output power of the amplifier is shown in Fig. 5, while the injected power gradually increases to 30 dBm. The amplifier has a 1 dB compression point when the input power is −2 dBm as shown in Fig. 5. When the input power is >0 dBm, the output power retains the maximum at 23 dBm, and the gain of the amplifier drops. When the input power exceeds the maximum output power, the gain is negative. When the input power exceeds 30.4 dBm, the amplifier is irreversibly degraded and the output power drops to 7 dBm. The maximum gain of the degraded amplifier is 12 dB (a half of the original gain), as shown in Fig. 6. When the input power increases to 37.7 dBm, the amplifier is irreversibly damaged. The effect of the amplifier is shown in Table 1.

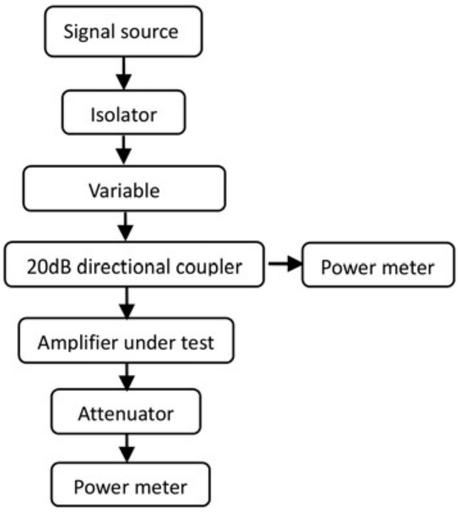

Fig. 4 *Sketch of the test*

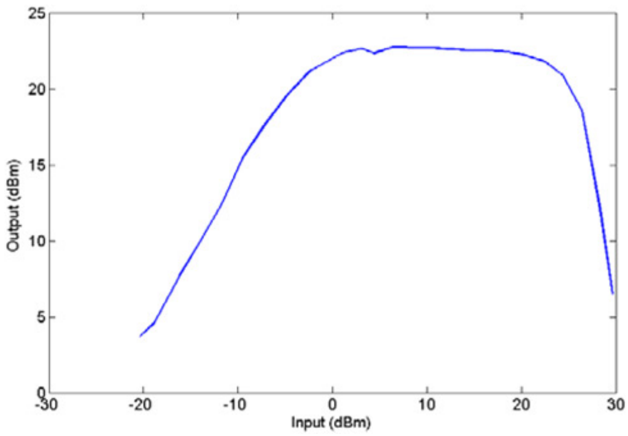

Fig. 5 *Output with injecting CW*

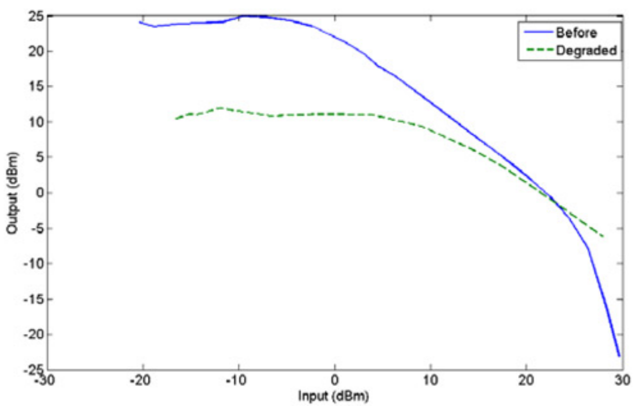

Fig. 6 *Gain of the amplifiers with before and after degraded*

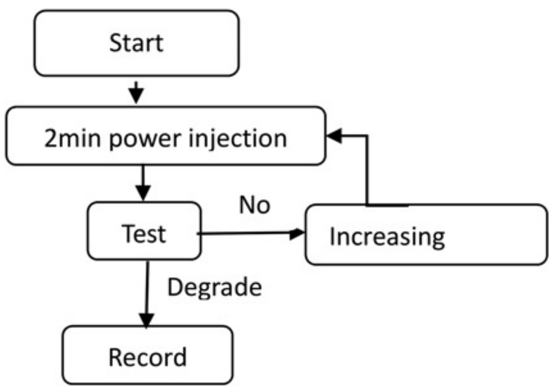

Fig. 7 *Sketch for testing uncharged amplifier*

Table 1 Effect of the charged amplifier injected with CW

No.	1	2	3	4	5	6	7	8	9
input, dBm	21.1	23.8	26.4	28.6	30.4	32.2	34.8	37	37.7
result	normal	normal	normal	normal	degraded	degraded	degraded	degraded	damaged

Table 2 Effect of the uncharged amplifier injected with CW

No.	1	2	3	4	5	6	7	8
input, dBm	27	30	31.4	33.1	34.1	36.5	37.4	38
result	normal	normal	degraded	degraded	degraded	degraded	degraded	degraded

3.2 Degrade of the uncharged amplifier with CW

An uncharged amplifier is tested with the CW. The test flowchart is shown in Fig. 7. The CW injects the amplifier for 2 min, and then the amplifier is charged and tested. If the amplifier is not degraded or damaged, the injected CW power will be increased in the next test step. Here, the 2 min test is the same as the test shown in Fig. 4. The results are shown in Table 2. However, the maximum power of the source cannot damage the amplifier.

3.3 Degrade and damage of the charged amplifier with pulse wave (PW)

Fig. 8 shows the PW test flowchart. There are two injected powers. One is the CW and the other is the PW. The CW is set to 34 GHz, 0 dBm in order to keep the amplifier satiating. The PW signal is originating from a Ka-band magnetron operating at a frequency of 35 GHz. The width of the PW power is 2 µs. Two antennas are used to transmit the pulse power and isolate the high voltage of the magnetron. A variable attenuator is used to adjust the input PW power. A magic T combines the CW and the PW. A 20 dB directional coupler is used to monitor the injecting wave. Here, a wave detector instead of the power meter measures the power, because the power meter is not able to measure the PW power. The results are shown in Table 3 and the amplifier is degraded at 33 dBm and damaged at 43 dBm. The typical waveform is shown in Fig. 9. The gains of the amplifiers before and after degraded are shown in Fig. 10.

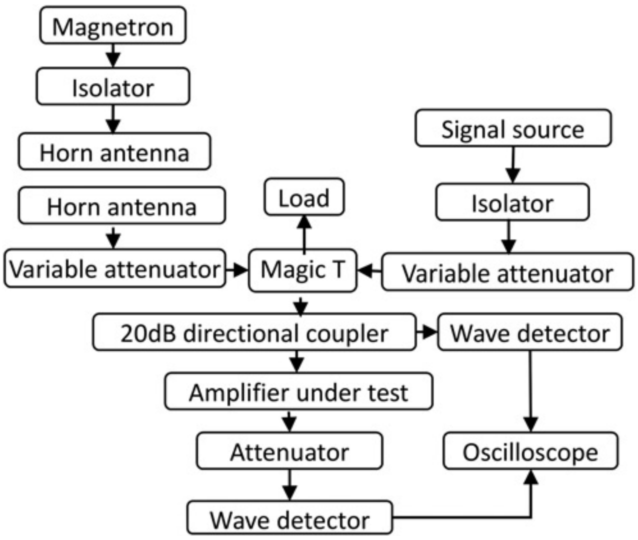

Fig. 8 *Sketch of the test with the PW*

Table 3 Effect of the charged amplifier injected with PW

No.	1	2	3	4	5
input, dBm	18.4	23.2	28	30.4	32.5
result	normal	normal	normal	normal	degraded
no.	6	7	8	9	—
input, dBm	34.5	37.5	40.9	43	—
result	degraded	degraded	degraded	damaged	—

3.4 Degrade and damage of the uncharged amplifier with PW

The test flowchart for the uncharged amplifier is the same as the charged one, as shown in Fig. 8. Here, the amplifier is uncharged when the PW injected three times with the same power level. The amplifier is recharged and tested after the attack. If the amplifier is not degraded or damaged, the injected PW power will be increased until the amplifier is damaged. The results are shown in Table 4.

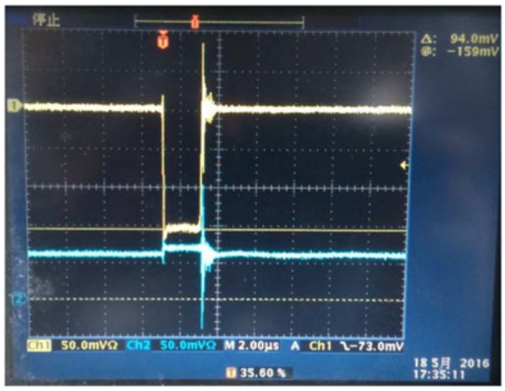

Fig. 9 *Typical waveform in the oscilloscope*

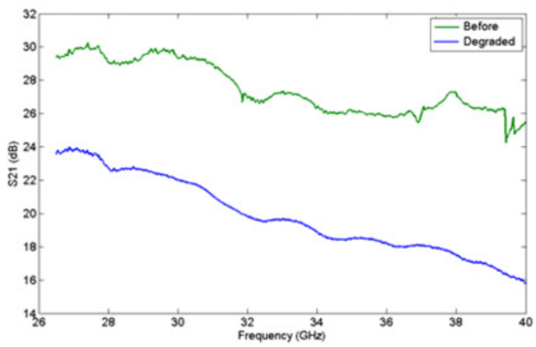

Fig. 10 *Gain of the amplifier*

Table 4 Effect of the uncharged amplifier injected with PW

No.	1	2	3	4
input, dBm	26.4	28	29.7	31.6
result	normal	normal	normal	normal
no.	5	6	7	8
input, dBm	33	34.7	35.2	36.5
result	normal	normal	normal	degraded
no.	9	10	11	12
input, dBm	38.2	40.5	41.8	43
result	degraded	degraded	degraded	damaged

4 Broken amplifiers

The amplifiers are observed with a microscope after the experiments. The HMMC5040 chip consists of four amplifier nodes, and the first node is denoted in Fig. 11. The reason for the degraded amplifiers is that the first node is injured, and the reason for the damaged amplifiers is that the first node is broken. The injured first node is shown in Fig. 12 and the broken one is shown in Fig. 13.

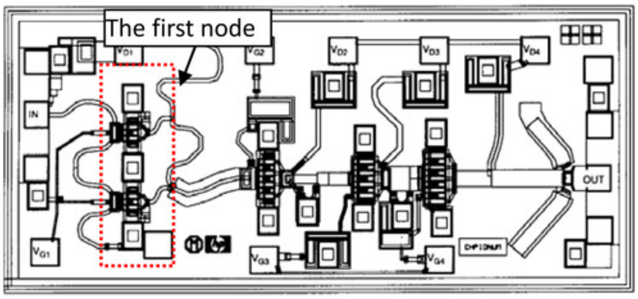

Fig. 11 *Sketch of HMMC5040*

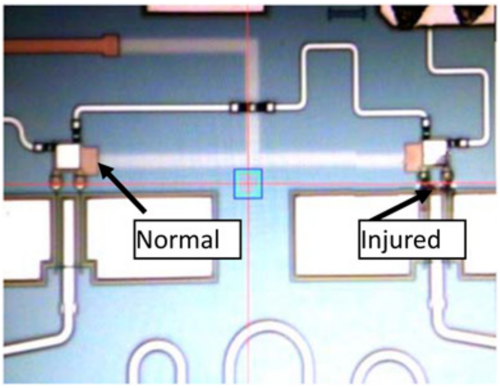

Fig. 12 *Injured first node of the degraded chip*

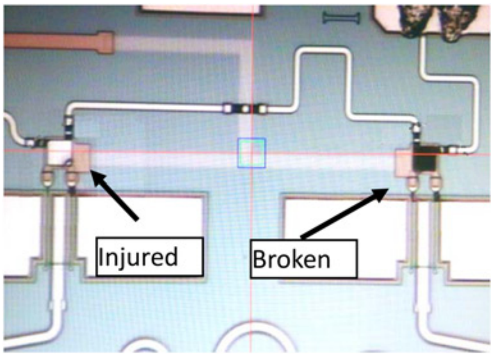

Fig. 13 *Broken first node of the damaged chip*

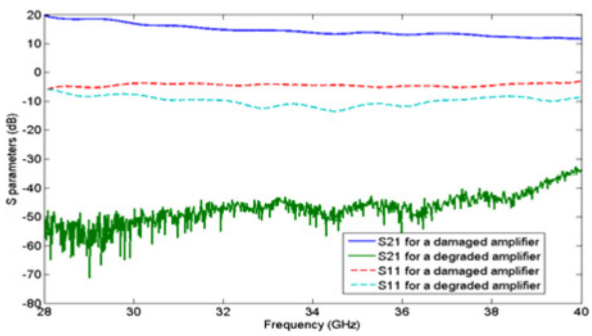

Fig. 14 *Classic S parameters for the degraded and the damaged amplifiers*

The S parameters of the degraded and the damaged amplifiers are measured again as shown in Fig. 14. Here, the performance of the degraded amplifier is poor. The damaged amplifier is an attenuator now and the S_{11} shows increased reflection.

5 Conclusions

HMMC5040 is a kind of popular broadband chip for Ka-band amplifiers. Here, the amplifiers based on HMMC5040 are injected with CW and PW in order to test. The results can draw the following conclusions: (i) the charged chip is degraded at 30.4 dBm and damaged at 37.7 dBm with the CW. (ii) The uncharged chip is degraded at 31.4 dBm with the CW. (iii) The charged chip is degraded at 33 dBm and damaged at 43 dBm with the PW. (iv) The uncharged chip is degraded at 36.5 dBm and damaged at 43 dBm with the PW. (v) The first node is injured for the degraded amplifiers and broken for the damaged amplifiers in the experiments. Therefore, it should be improved for the anti-radiation design. (vi) The damaged amplifier is an attenuator with poor performance of S_{11}.

6 Acknowledgments

This work was supported by the National Natural Science Foundation of China (grant nos. 61531010, 61371052 and 61471091) and by the Joint Project of the Ministry of Education (grant no. 6141A02022402) and the National Key Laboratory Foundation of China (grant no. 9140A23010415DZ02001)

7 References

[1] HaiYang W.: 'Theoretical and experimental research on HPM effection', Doctorate, University of Electronic Science and Technology of China, Chengdu, 2010

[2] Dobykin V.D, Kharchenko V.V.: 'Electromagnetic pulse functional damage of semiconductor devices modeled using temperature gradients as boundary conditions', *J. Commun. Technol. Electron. (Russia)*, 2016, **51**, (2), p. 231

[3] Hannachi C., Hammou D., Djerafi T., ET AL.: 'Complete characterization of novel MHMICs for V band communication systems', *J. Electr. Comput. Eng.*, 2013, **686708**, pp. 1–9

[4] Joongheon K., Jae-Jin L., Woojoo L., ET AL.: 'Strategic control of 60 GHz millimeter wave high speed wireless links for distributed virtual reality platforms', *Mobile Inf. Syst.*, 2017, **5040347**, pp. 1–8

[5] Yang X., Fan Y., Zhang B., ET AL.: 'A novel terahertz rat-race hybrid coupler based on PPDW', *J. Infrared, Millim. Terahertz Waves (JIMTW)*, 2011, **32**, (11), pp. 1291–1298

[6] Van K.E., Knighten J.: 'Implications of high power microwave weapon threat in electronic system design'. IEEE Symp. on electromagnetic Compatibility, NJ, USA, 1991, pp. 370–371

[7] Kim K., Iliadis A.A., Granatstein V.L.: 'Effects of microwave interference on the operational parameters of n channel enhancement mode MOSFET devices in CMOS integrated circuits', *Solid-State Electron.*, 2004, **48**, (10–11), pp. 1795–1799

[8] Nitsch D., Camp M., Sabath F., ET AL.: 'Susceptibility of some electronic equipment to HPEM threats', *IEEE Trans. Electromagn. Compat.*, 2004, **46**, (3), pp. 380–389

[9] Camp M., Garbe H., Nitsch D.: 'Influence of the technology on the destruction effects of semiconductors by impact of EMP and UWB pulse'. Int. Symp. Electromagn. Compat., Minneapolis, United States, 2002, pp. 87–92

[10] Backstrom M.G., Lovstrand K.G.: 'Susceptibility of electronic systems to high-power microwave: summary of test experience', *IEEE Trans. Electromagn. Compat.*, 2004, **46**, (3), pp. 396–403

[11] Bayram Y., Chang P.C., Volakis J.L., ET AL.: 'High power EMI on digital circuits within automotive structures'. IEEE, Int. Symp.

Electromagn. Compat., Portland, OR, United States, 2006, pp. 507–512
[12] Hwang SM., Hong JI., Huh CS.: 'Characterization of the susceptibility of integrated circuits with induction caused by high power waves', *Prog. Electromagn. Res.*, 2008, **81**, pp. 61–72
[13] Yoo M., Kim W., Park Y.M., *et al.*: 'The investigation of measurement method for HPM radiation to the analogy switch chip'. IEEE Int. Electromagn. Compat. (EMC), FL, USA, 2010, pp. 364–369
[14] Liu C.J., Yan L.P., Fan R.D., *et al.*: 'Radiation effects of microwave pulse in lband on personal computer', *High Power Laser Part. Beams*, 2007, **19**, (9), pp. 1580–1584
[15] Li P., Liu G.Z., Huang W.H., *et al.*: 'The mechanism of HPM pulse-duration damage effect on semiconductor component', *High Power Laser Part. Beams*, 2001, **13**, (3), pp. 353–355
[16] Chai C.C., Yang Y.T., Bing Z., *et al.*: 'Mechanism of energy injection damage of silicon bipolar low noise amplifiers', *J. Semicond.*, 2008, **29**, (12), pp. 2403–2406