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OPTIMAL ELECTRIC WAVE PROPAGATION PARAMETERS ON A TRANSMISSION LINE — SCHOTTKY DIODE SYSTEM

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Abstract—This paper explores the optimal conditions for wave propagation on a microstrip line loaded by a Schottky diode. Investigations are undertaken by studying the transmitted power versus frequency, power and place of injection of a continuous sine high frequency aggression signal. The aggression is injected in a near-field mode. Coupling conditions between the aggression signal in the 500 MHz–3 GHz frequency band and the system is thus determined.

1. INTRODUCTION

Today, electromagnetic susceptibility threshold for complex electronic components decreases continuously, due to two trends [1]. First, needs in speed transmission and wide frequency bandwidth result in a large increase in operating frequencies. Second, there is a drastic decrease in device size and in bias currents. With the increase in operating frequency, the length of the electromagnetic waves emitted by devices becomes smaller, reaching the size of the devices themselves. The electromagnetic wave will then couple itself to tracks and get processed towards devices. Hence, it becomes drastic that in circuit design risks due to electromagnetic susceptibility be reduced. For this, one needs the best information possible on the conditions for optimal coupling of an electromagnetic wave to circuit board tracks. These coupling problems are addressed in this paper in a concrete way, with a long microstrip line placed in front of a Schottky diode. To exhaustively study both wave coupling and propagation on the line, a high frequency

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signal is injected in a near-field injection mode. The impact of the aggression on the diode is investigated as a function of its frequency, power and place of injection.

2. DEVICE UNDER TESTS AND EFFECT ON ITS STATIC CHARACTERISTIC OF AN EMI

The device under test, a HSMS 2850 Schottky diode from Agilent Technologies, is placed on a microstrip line. For purpose of wave propagation analysis the line is $L = 10\,\text{cm}$ long to highlight stationary waves in the [500 MHz–3 GHz] frequency range. A block inductance L_t with a capacitance C_t prevents the high frequency aggression from propagating towards the *dc* generator. The electromagnetic interference (EMI) is injected through a probe. Probe-line distance h is $h \ll \lambda/10$ to work in the near field zone. Electric-field probes are made from semi-rigid coaxial cables and are characterized [2]. Places for injection are noted P_1 to P_{10} with P_1 located nearest to the diode and P_{10} at the furthest. A distance of 1 cm separates each possible location. Mean values for diode voltage V_d and current I_d are measured (Fig. 1) under EMI with frequency $f_a = 1\,\text{GHz}$.

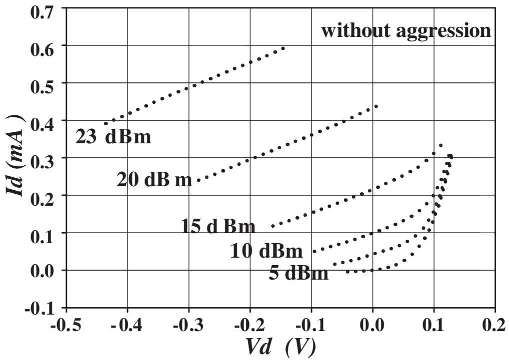


Figure 1. I_d-V_d curve of a Schottky diode subject to an EMI injected at 1 GHz for different power values.

A change in I_d and V_d values impacts the I_d-V_d curve. This is due to a rectification effect [3] because of nonlinear behaviors inherent to semiconductor devices.

In the following sections, experiments will be completed by simulations performed with the commercial software ADS of Agilent Technologies. S-parameter simulations are undertaken for a linear analysis while harmonic balance simulations [4–6] are performed for non linear analysis.

3. EXPERIMENTS AND SIMULATIONS OF TRANSMITTED POWER

3.1. Model of the System Under Test

The diode is modeled using ADS libraries [7]. The Sot-23 package includes parasite inductances and capacitances [8]. After adjustment, a good matching is obtained between static curves and S parameter measurements and simulations. The coupling between the electric probe and the microstrip line is modeled by a capacitance C_1 [9]. To determine C_1, one first calculates it approximately and then adjusts it for a good correlation between measured and simulated transmission coefficients on an open-ended line. The whole model is given on Fig. 2(a) and results on Fig. 2(b) with the electric probe set at 0.5 mm over the middle of the line.

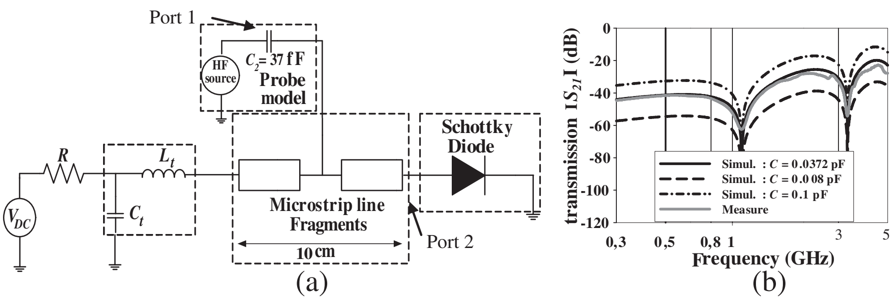


Figure 2. (a) Model of the near-field injection mode with the electric probe in its environment, (b) measured and simulated transmission coefficient between the electric probe and the microstrip line in an open-ended configuration.

Figure 2(b) shows a good agreement between simulation and measurement results with $C_1 = 37\,\mathrm{fF}$. One must adjust the value of C_1 between 19 fF and 37 fF depending on the frequency of the aggression signal. Fig. 3 shows the I_d-V_d curves for an EMI injected in position P_{10} at $f_a = 1\,\mathrm{GHz}$, probe-line distance kept to $h = 0.5\,\mathrm{mm}$.

3.2. Highlight on Resonance Phenomenon

The influence of the frequency of the EMI on the system is modeled. Probes are sufficiently unmatched to disregard their effect. Hence, the line can be considered as a cavity loaded on one end by the choke inductor L_t with a high impedance at operation frequency and on the other side by the diode. L_t is equivalent to an open circuit and the

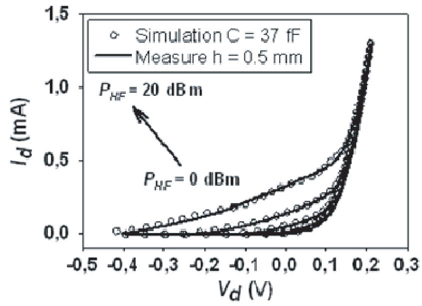


Figure 3. Measured and simulated I_d-V_d curves of a Schottky diode subject to a $f_a = 1$ GHz sine aggression signal.

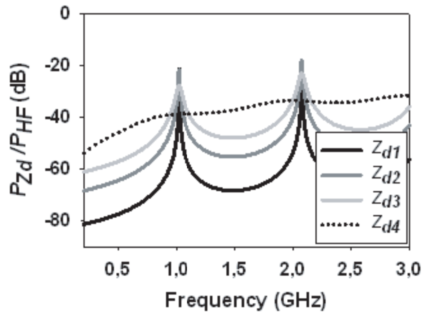


Figure 4. P_{Zd}/P_{HF} for different values of $|\bar{Z}_d|$ as a function of EMI frequency.

diode to a variable load $\bar{Z}_d$. According to line theory [10], resonance frequencies F_r for which the power transmitted to $\bar{Z}_d$ is maximum can be calculated by:

$$F_r = \frac{c}{2\pi L\sqrt{\varepsilon_{eff}}}\left[\tan^{-1}\left(j\frac{Z_c}{\bar{Z}_d}\right) + m\pi\right], \tag{1}$$

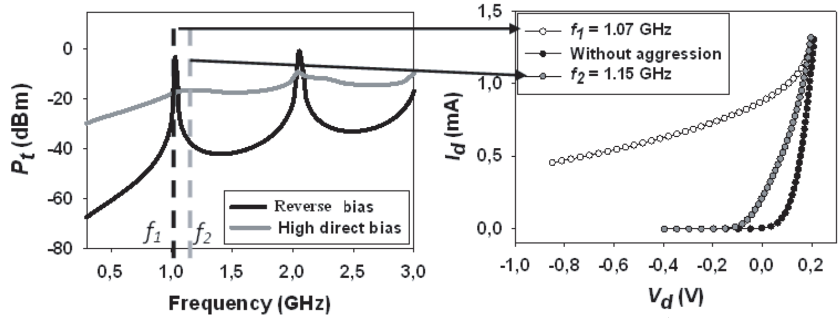
with ε_{eff} the effective permittivity, Z_c the characteristic impedance of the line, c the speed of light.

Values of F_r depend on the length L of the cavity, on Z_C and on the value of $\bar{Z}_d$. If $|\bar{Z}_d| \gg Z_c$, values for F_r can be calculated for which the power transmitted to $\bar{Z}_d$ is maximum. To check these resonances, we simulate the power ratio P_{Zd}/P_{HF} where P_{Zd} is the power transmitted to $\bar{Z}_d$, and P_{HF} the power provided by the high frequency source. The EMI is injected in P_{10} with power set to 10 dBm. Results are shown on Fig. 4.

When $|\bar{Z}_d| \ll Z_C$, two F_r values are measured. When $|\bar{Z}_d|$ become closer to Z_C, the power ratio at F_r decreases. When $|\bar{Z}_d| = Z_C$, no resonance frequency can be calculated, resonance peaks disappear. These resonance frequencies impact directly the quantity of transmitted power to the disturbed circuits.

3.3. Effects of Power Resonances on the Detection Phenomena

We simulate P_t the power transmitted to the diode in Fig. 5(a). In reverse bias, F_r values, for which P_t is maximum, are measured at 1.07 GHz and 2.14 GHz. These values have been previously calculated.



(a) (b)

Figure 5. (a) Transmitted power P_t for reverse and forward bias as a function of EMI frequency. (b) Effect of the EMI on the I_d-V_d curve.

No F_r peaks appear in forward bias. The I_d-V_d curve is measured experimentally (Fig. 5(b)) for an EMI injected in the middle of the line at P_5 with $f_1 = 1.07\,\text{GHz}$ (resonance frequency) and $f_2 = 1.15\,\text{GHz}$ (non resonance frequency).

Figure 5(b) shows that the power of the EMI detected by the diode depends on the EMI frequency. For reverse bias at $f_1 = 1.07\,\text{GHz}$, $P_t \approx -5\,\text{dBm}$. The diode detects the aggression signal and a voltage change $\Delta V_{d2} \approx 200\,\text{mV}$ is measured. For $f_1 = 1.15\,\text{GHz}$, $P_t \approx -40\,\text{dBm}$. This value is too small to be detected; hence no change of V_d is measured. In forward bias, whatever the frequency of the aggression signal, $P_t \approx -20\,\text{dBm}$. The diode detects very small power values and nearly no disturbances are measured. The EMI has a maximum effect on the diode for resonance frequencies F_r which appear when the diode is under reverse bias. It is then interesting to study the influence of the injection point at these resonance frequencies.

3.4. Influence of the Position of the Injection Point

P_t is simulated for an EMI injected in a conducting mode. EMI is injected in P_{10}, P_7, P_4, P_1 with power set to 10 dBm (Fig. 6). For each location, resonance phenomena occur for the same F_r values. However, depending on the place of injection, anti-resonance frequencies may also appear. When the probe is placed over a zone with minimum voltage, the probe-line coupling can be neglected. Therefore even if the aggression signal is injected with a frequency equal to F_r, no power is transmitted to the diode, there is no disturbance.

A field mapping (Fig. 7(a)) of the line is carried out for an EMI with $f_a = F_r = 1.07\,\text{GHz}$ and power 10 dBm. The diode is biased at 0 V.

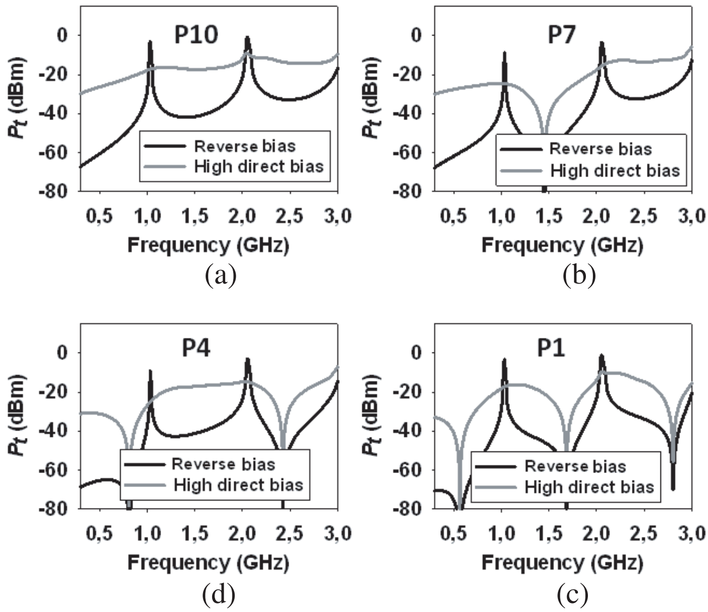


Figure 6. Study of P_t as a function of EMI location: in P_{10}, P_7, P_4 and P_1 and for two bias of the diode.

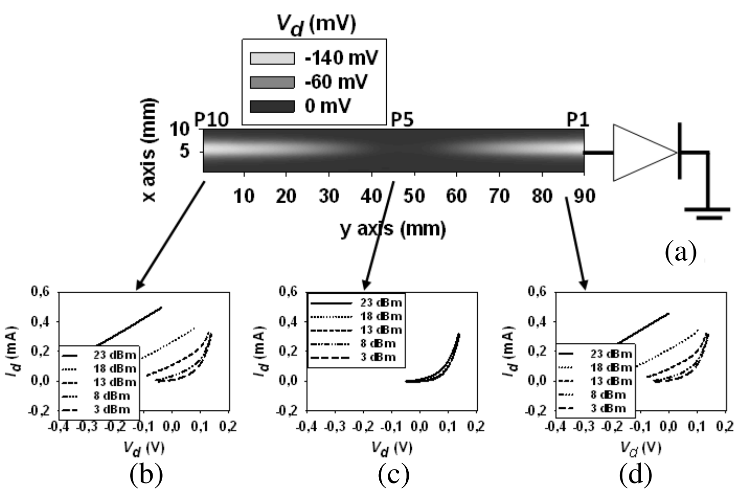


Figure 7. Electric susceptibility field mapping of the line. EMI frequency is fixed to 1.07 GHz, i.e., the resonance frequency I_d-V_d curves for an aggression signal injected: (b) in P_{10}, (c) in P_5 and (d) in P_1.

The line is loaded on its left by the choke inductance, a maximum voltage occurs in P_{10} and a maximum coupling is measured. On the other end, the line is loaded by the diode non-biased, hence with a high dynamic impedance. A maximum voltage then appears in P_1, a maximum coupling is measured. Maxima and minima voltages are separated by a distance equal to a quarter effective wave length $\lambda_{\mathit{eff}}/4$. If a maximum voltage appears in P_{10} then a minimum voltage appears in P_5, in the middle of the line, and a minimum coupling is measured. In Fig. 7(b), Figs. 7(c) and 7(d), when the probe-line coupling is maximum, the power transmitted to the diode is maximum, a large change in the I_d-V_d curve is measured.

4. CONCLUSION

A commercial Schottky diode placed at the output of a microstrip line is studied when subject to an EMI. This aggression has a frequency value out of band of operation of the diode. The diode exhibits a change in its I_d-V_d curve due to rectification effects. A complete model of the diode in package, bias system, microstrip line and near-field injection for aggression signal, is established. The non linear behavior of the diode is considered. The diode detects power if the EMI has a frequency equal to resonance frequencies dependent on the load of the line; hence it is a function of diode bias. Resonance frequencies impact the quantity of transmitted power, leading to more or less disturbance on the behavior of the diode.

Location of aggression injection plays a major role in the probe-line coupling. If the probe is placed over a zone with minimum voltage, the probe-line coupling can be neglected. Even if the EMI is injected at a resonance frequency value of the system considered, no power is transmitted. Hence there will be no diode disturbance.

This work should help give parameters for estimating susceptibility to high frequency signals of a system.

REFERENCES

1. Ramdani, M., E. Sicard, A. Boyer, S. Ben Dhia, J. J. Whalen, T. H. Hubing, M. Coenen, and O. Wada, "The electromagnetic compatibility of integrated circuits-past, present, and future," *IEEE Trans. on Electromagnetic Comp.*, Vol. 51, No. 1, 46–52, 2009.
2. Jarrix, S., T. Dubois, R. Adam, P. Nouvel, B. Azais, and D. Gasquet, "Probe characterization for electromagnetic near-field

studies," *IEEE Trans. on Instrumentations and Meas.*, Vol. 59, No. 2, 292–300, 2010.

3. Larson, C. E. and J. M. Roe, "A modified Ebers-Moll transistor model for RF-interference analysis," *IEEE Trans. on Electromagnetic Comp.*, Vol. EMC-21, No. 4, 283–291, 1979.
4. Hattori, Y., T. Kato, H. Hayashi, H. Tadano, and H. Nagase, "Harmonic balance simulation of RF injection effects in analogs circuits," *IEEE Trans. on Electromagnetic Comp.*, Vol. 40, No. 20, 120–126, 1998.
5. Maas, S. A., *Non Linear Microwave and RF Circuits*, 2nd edition, Artech House, 2003.
6. Rizzoli, V. and A. Neri, "State of the art and present trends in nonlinear microwave CAD techniques," *IEEE Trans. on Microwave Theory and Tech.*, Vol. 36, No. 2, 343–365, 1988.
7. Antognetti, P. and G. Massobrio, *Semiconductor Device Modeling with SPICE*, 2nd Edition, McGraw-Hill, 1993.
8. Angelo, E., *Electronic Circuits*, McGraw-Hill, 1958.
9. Kanda, M., "Standard probes for electromagnetic field measurements," *IEEE Trans. on Antennas and Propagat.*, Vol. 41, No. 10, 1349–1364, 1993.
10. Chand, C., *RF and Microwave Wireless Systems*, 2nd edition, Wiley, 2000, ISBN: 978-0-471-35199-3.