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Impact of GHz disturbances on DC parametric measurements

Hans P. Tuinhout* and Peter G.M. Baltus**

*Philips Research, High Tech Campus 5 (WAY41), 5656 AE Eindhoven, The Netherlands
**Philips Semiconductors ICRF, Eindhoven, The Netherlands

email: hans.tuinhout@philips.com

Abstract - RF signals from mobile phones or WLAN transmitters can affect DC parametric measurements. A transistor test structure inside a wafer prober can behave as a GHz receiver when the needles or the manipulators that probe these transistors pick up sufficiently strong GHz signals. This paper shows examples of such occurrences and presents a technique for assessing the vulnerability of parametric measurement systems for GHz signals.

I. INTRODUCTION

The availability of wafer probers with actively guarded metal enclosed wafer chambers meant a giant leap forward for low-level DC measurements. Since such systems became available, one could easily collect pico-Amp to femto-Amp measurements without having to keep one’s breath and sit perfectly still beside the probe station. The good shielding properties of advanced wafer probe systems [1,2] also opened up the way for ultra-high-precision parametric mismatch measurements. However, despite applying the most advanced measurement algorithms [3], unexpected and seemingly uncontrollable measurement disturbances were occasionally encountered, resulting in reduced precision and repeatability of our statistical mismatch measurements. This observation triggered an investigation that led to the recognition of the possible dangers of RF signals for high-precision DC parametric measurements.

This paper is structured as follows: After introducing the time sweep as a tool for investigating disturbances on DC parametric measurements in section II, some of the initial problem encounters are presented in section III. A new measurement method for assessing the susceptibility of DC parametric measurement systems for GHz signals is then described in section IV. Section V presents some results of such assessments. The discussion section VI puts these results into perspective and finally, the main conclusions of this study are summarised in section VII.

II. TEST STRUCTURE AND MEASUREMENT METHOD

The main measurement method as used in this paper is formed by time sweeps; simple, fixed-bias (1 PLC meter integration) DC measurements that are repeated over relatively long time periods of 30 seconds up to several minutes. Time sweep measurements are useful for capturing and evaluating a variety of (slow) measurement disturbances, ranging from temperature drifts [4] and transistor noise and random telegraph signals [5], through environmental disturbances such as power net spikes, ground loops and vibrating cables [1], up to EMC effects related to switching power supplies, electrostatic discharges [4] and, as shown in this paper, RF signals.

Most of the results discussed in this paper were obtained using Bipolar Junction Transistor (BJT) current measurements with BJT matched pair test structures, biased in the active forward region (ideal part of the Gummel plot). The test structure, measurement circuit and default biasing conditions are shown in figure 1. Using the matched pair test structures proved instrumental for triggering this study. We observed that transistor 2 of the pair, whose Base (B2) is contacted with the manipulator placed on the 'East-position', reacted differently during time sweeps when simultaneously compared to the transistor 1, probed with the 'West' manipulator.

![Figure 1. Measurement circuit and default bias conditions for time sweeps. Inset: Matched pair test structure.](Image)

III. DC MEASUREMENT PROBLEM ENCOUNTERS

One of the first encounters of unexpected observations during the time sweep measurements was that walking (slowly) around the prober of our measurement system (figure 2c), affected nA to µA BJT DC current measurements (figure 2a.). Current dips of levels up to one percent were (repeatedly) observed during these tests. These dips were much larger than expected for this system. Checking loose cables (vibrations) and ground loops did not solve this problem.
Practically identical current changes were observed when an Agilent 4156 parameter analyzer was used instead of the Keithley 4200-SCS measurement system. A rather unconventional aluminum foil wrapping of the prober (figure 2d.) resulted however in a significant improvement (figure 2b.). This observation suggests that the disturbance was caused by an EMC signal coupling into the DC probes. The probed (common Emitter & common Collector) matched pair test structure (figure 1 inset) apparently forms a sensitive receiver for RF signals in the used common-base bias and measurement configuration (figure 1). Note that the average current level shift between figures 2a and b implies that the observations that were originally interpreted as the error, namely the drop in the currents during the interval between 10 and 15 seconds, in fact represents the correct measurements. During the walk around the prober, a particular position near the right front side of the prober apparently provided enough attenuation to shield the EMC disturbance.

To verify whether RF signals can indeed cause disturbances that are large enough to affect our DC measurements, a time sweep was recorded while a GSM phone call was made (figure 3). The call was started using a conventional wired telephone inside the measurement lab. The connection was established and the GSM phone started ringing at t ≈ 30 s. At that moment the receiving phone was approximately 12 meters away from the probe station in an office outside the measurement lab. At time ≈ 75 s, the person answering the phone walked into the lab. The impact of the telephone’s RF signals on the current measurements increased up to levels of as high as 10 % with the GSM phone near the probe station. Moreover, this example demonstrates that even somebody walking in a corridor near a measurement room while making a phone call (around time ≈ 60 s) can significantly disturb DC parametric measurements.

Figure 2. Initial encounter of the problem. a: time sweep while slowly walking in front of the probe station (c). b: same time sweep after the prober was 'covered' with aluminium foil (d).

Figure 3. Time sweep of BJT during GSM phone call. Note that even at much higher current levels (V_B=0.83 V), disturbances of up to 10 % are observed.

Figure 4. The 2.5 GHz antenna on the platen of the probe station.

IV. NEW MEASUREMENT TECHNIQUE

To allow identification of the part of the measurement system that is most vulnerable to RF disturbances, and to assess the effectiveness of countermeasures, an experimental set-up was configured with a custom-built 2.5 GHz directional antenna (figure 4) connected to a Marconi 2032 signal generator. The directional antenna provides the possibility to aim at different parts of the measurement set-up. The used RF frequency was determined by the antenna, which was designed for 2.5 GHz. As the experiments were performed in a regular measurement lab, results are most likely somewhat disturbed by RF signal reflections on walls, cabinets and the prober itself. This implies that method presented here would certainly not qualify as a well-calibrated and highly-accurate experiment but nevertheless this approach proved much more reliable and repeatable than making little ‘rain dances’ around the prober or experimenting with mobile phones.
The signal generator output power level can be adjusted over a wide range up to +11 dBm. The crux of the new technique is the application of a slow AM modulation of the GHz signal level. By applying a 0.1 Hz, 99.9 % triangular modulation, the impact of the GHz signal can be observed on the monitor of the parametric measurement system during the time sweep (figure 5).

![Figure 5. Example of the time sweep of the BJT matched pair currents with a 0.1 Hz triangular modulated 2.5 GHz signal from the antenna that is placed on the platen (as in figure 4): I_B2 is the Base current of the transistor that is probed with the (East) manipulator closest to the antenna.](image)

The result as depicted in figure 5 closely resembles a textbook example of a diode radio receiver sensitivity. The peaks are perfectly triangular while the valleys are rounded, leveling off to the undisturbed (slightly noisy) transistor currents. The modulation of the (DC) transistor current by the GHz signal is defined as the relative increase of the current at the peaks with respect to the unperturbed current level in the valleys. The example of figure 5 demonstrates that the position of the antenna (as in figure 4) indeed has a significant impact on the resulting GHz disturbance. In this case, B2 (with probe manipulator closest to the antenna) is much stronger affected than B1. Since the test structure is a common Collector & common Emitter matched pair (figure 2), the modulation of the Collector current is the average of the two Base current modulations (both transistors are ON during the time sweep).

The peak signal power as delivered by the generator can be adjusted such that the current modulations correspond to the earlier observed disturbance levels as depicted in figures 2 and 3. Figure 6 for instance demonstrates the fairly linear relation between the Base current (I_B2) modulation and the signal level. In this particular example, the modulation is changes from roughly 0.4 to 1.4 and 2.7 % when increasing the power level from −3 to +3 and +6 dBm respectively. In general, the modulation depends strongly on the antenna position as well as prober shielding properties.

![Figure 6. Example of modulated 2.5 GHz disturbances of I_B2 (V_{EB} = 0.73 V) for three different signal generator peak power levels.](image)

V. MEASUREMENT SYSTEM ASSESSMENT

The main purpose for developing the new measurement technique was to assess the effectiveness of an improvement of the prober’s top hat shielding. Figure 7 presents the outcome of this test. A – 10 dBm signal with the antenna on the prober platen (as in figure 4) resulted in a substantial (> 90 %) modulation of the measured current when using the system’s original top hat. After replacing the top hat with the newer version with conductive slit rubbers, the same signal level did not result in appreciable current modulations. Only after turning-up the generator signal a factor 100 (to + 10 dBm), the effect on the currents became visible. The (expanded) scale of the I_B2 Base current indicates that the 2.5 GHz signal disturbance modulation now is about 2.4 %, hence suggesting a shielding improvement of more than 3500x.

![Figure 7. Effect of better shielding of new top hat on 2.5 GHz disturbances of I_B2 (V_{EB} = 0.73 V). Note expanded y2 axis.](image)
In another set of experiments we investigated in more detail how the needles are picking up the 2.5 GHz RF signals. Initially we suspected that the GHz signal could penetrate the (rubber) slits in the (old) top hat. However, no evidence of this could be found, as the size, number and coverage of the slits did not have a significant effect on the observed current modulation. Then we postulated that the arm connecting the needle and the manipulator must have been acting as the antenna. Apparently the arm is not grounded sufficiently effective to short the GHz signal. By comparing modulated $I_{h2}$ time sweeps with various types of additional copper shields, this hypothesis was tested. Two simple copper shields were constructed (figure 8), the first one consisting of a single copper sheet that can be placed between the antenna and the manipulator (middle), while a second copper plate was bent into a box to fit over the entire manipulator (bottom).

The resulting $I_{h2}$ time sweeps are shown in figure 9. To obtain an appreciable modulation signal, the antenna was placed close to the B2 manipulator with the maximum signal at $+20$ dBm, which resulted in a current modulation of approximately 15%. When the single copper plate was placed between the antenna and the manipulator arm, the current modulation decreased more than a factor of ten, to about 1.3%. This corroborates the hypothesis that the signal is picked up by the positioner arm. With a copper box over the entire manipulator, the signal modulation drops roughly another factor of two to about 0.7%.

![Figure 9. Effect of extra copper shielding to block 2.5 GHz signals.](image)

Figure 8. Photographs of B2 manipulator without (top) and with extra shielding: copper plate (middle); copper plate box (bottom).

### VI. DISCUSSION

It does not require too much imagination to appreciate that the kind of disturbances as depicted in figure 2 can have significant impact on high-precision parametric mismatch measurements, often looking for parameter differences substantially below 1%, requiring short-term measurement repeatabilities of 100 ppm or better [3].

Neither will it raise many eyebrows when an advice is given not to hold lengthy GSM (cell phone) conversations inside measurement labs where parametric testing is ongoing (figure 3 and [6]). The problem with occasional passing-by people with cell phones in corridors that are meters away from the measurement systems is one that is hard to tackle. Prohibiting cell phones in the entire building is not a very likely option, these days.

From the results presented so far, it will be evident that BJTs in the active forward region form excellent RF detectors due to their exponential characteristics. It should be realized however, that all non-linear devices, including MOS-FETs in subthreshold, saturation or linear region can suffer from these GHz disturbances.
Figure 10. Drain current time sweeps of W/L=4/1 MOSFET. Upper curve: Linear region \( (V_{GS}= 0.7 \text{ V}, V_{DS} = 0.05 \text{ V}) \); Lower curve: Sub-threshold region \( (V_{GS}= 0.0 \text{ V}, V_{DS} = 0.05 \text{ V}) \).

Figure 10 shows that a MOSFET in the (exponential) sub-threshold region can indeed be affected to comparable orders of magnitude (2.5 % modulation) as encountered in the previous examples for BJTs, albeit that the 1 \( \mu \text{m} \) long MOSFET used for this test is operated well above its \( f_r \) under these bias conditions. As expected, the MOSFET becomes much less sensitive for the GHz signals when it is biased in a more linear region \( (V_{GS}= 0.7 \text{ V}) \). With unchanged antenna position and signal level, the modulation drops to a barely perceptible 0.04 %. Nevertheless, it is striking that the 10 seconds periodicity is still quite discernible. The sharp observer will even notice that the triangular peaks have reversed in the linear region. This is a sign of current saturation due to mobility reduction with higher gate bias!

Not all wafer probe systems are equally well constructed in terms of EMC shielding. Therefore, it is more than likely that the presented effects affect many more DC parametric measurements than the applications discussed in this paper. Obviously, placing copper shields and boxes as depicted in figure 8 is not a very practical solution since this prohibits access to the position adjustment screws. Nevertheless, the reported observations are useful in the sense that they give an indication about what can be gained by placing the entire probe, or at least the manipulators and cables in a metal cabinet, as offered by prober vendors [7].

VII. CONCLUSIONS

The pervasive encroachment of wireless communication equipment on our daily life is now (also) disturbing DC parametric measurements. This paper discusses some of the first encounters with unexpected detrimental effects of practically unavoidable mobile phone and WLAN GHz signals in and around measurement labs.

A new characterisation technique was introduced for assessing the vulnerability of DC parametric measurement systems for GHz disturbance signals. This method is based on DC transistor current time sweeps while the probe is subjected to a 0.1 Hz AM modulated 2.5 GHz signal from a directional antenna. The new technique is used to quantify the effectiveness of EMC (RFI) countermeasures such as improved shielding constructions. We found that the enhanced top hat shielding option as provided by the probe manufacturer reduced the sensitivity for GHz disturbance signals by more than three orders of magnitude. Extra copper plates and copper shielding boxes were found to reduce the susceptibility even further, confirming that the RF signal is picked up by the arms of the probe manipulators.

GHz disturbance effects are observable on all non-linear devices. Understandably, high speed BJTs in the active forward operation region are most susceptible for these effects. DC MOSFET measurements can also be affected, most clearly in the subthreshold region, but also in the 'linear' and saturation regimes (minor) effects could be observed.

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References

[6] (www.cmicro.com/pubs/PureLine_Brochure.pdf); The PureLine Brochure of Cascade-Microtech shows an example of the impact of cell phone RF interference during a common MOSFET peak \( g_m \) threshold voltage extraction.
[7] (www.suss.com); Süss MicroTec for instance offers a solution of this kind with their ProbeShield systems.