Harmonics Effects on Microwave Low-Power Measurement

Murat Celep[1], Yaser Abdo[2], Karel Dražil[3], Jan Grajciar[3], Martin Hudlička[3], and Borut Pinter[4]

[1]TUBITAK UME, Kocaeli, Turkey, murat.celep@tubitak.gov.tr

[2]National Institute for Standards, Gizah, Egypt

[3]Czech Metrology Institute, Brno, Czech Republic

[4]Slovenian Institute of Quality and Metrology, Ljubljana, Slovenia

***Abstract* — The paper discusses the influence of higher harmonic components in the measured signal on the measurement uncertainty of RF level when diode power sensors are used. A method is proposed to evaluate the measurement uncertainty of different diode power sensors based on the signal harmonic content.**

***Index Terms* — Harmonic effect, microwave measurements, microwave power, power sensor, uncertainty**

I. Introduction

Microwave power is one of the basic parameters in microwave metrology. The traceability of microwave power is provided through a microcalorimeter setup typically around 0 dBm nominal power [1]. In practice, traceable power measurements are necessary also for power levels below 0 dBm, whereas thermistor sensors are used. To measure low power levels below -30 dBm, diode type power sensors are used which use the square-law region of their I-V characteristic. When the measured signal is not a pure continuous wave (CW), higher harmonics could cause a measurement error. When the square-law regime of the sensor is utilized, the measured power is close to the sum of the power of the fundamental component and the higher harmonic components, thus the measurement error is negligible. The transition region between the square-law and the linear regions is more difficult to be characterized, as the error is dependent on the order of the harmonic component and the sensor internal structure. Typical characteristics can be found in [2]. There exist a software for R&S power sensors [3] which contains the measurement uncertainty contribution of the 2nd and 3rd harmonics. In this work, different types of diode power sensors which are used for low power measurement are characterized for higher harmonics.

II. Diode Sensor Measurement Error Due to Harmonics

Modern diode power sensors make use of LBS (low-barrier Schottky) or PDB (planar doped barrier) diodes. The general I-V characteristic of a diode is given by

$$i = I_s\left(e^{\alpha V} - 1\right), \tag{1}$$

where $\alpha = q/nkT$ and I_s is the saturation current, q is the electron charge, k is the Boltzmann constant, T is the temperature and n is the ideality factor. For a typical detector, $I_s \approx 10$ μA, $n \approx 1.1$ [4]. A simplified schema of the detector with full-wave rectification is shown in Fig. 1.

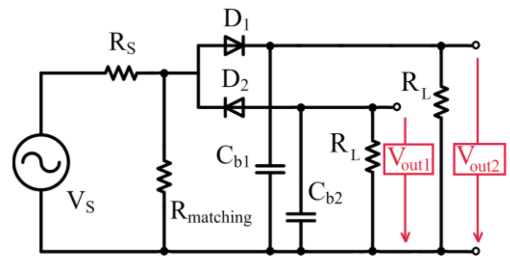

Fig. 1 Schematic view of a full-wave detector.

The capacitors are regarded as large enough to keep only the DC voltage. The current through each of diodes is given by

$$i(t) = I_s\left(e^{\alpha(v(t)-V_0)} - 1\right), \tag{2}$$

where $v(t) = V_m\left(\sin(\omega t) + r\sin m(\omega t - \varphi)\right)$, V_m is the amplitude of the signal at the fundamental frequency, V_0 is the DC voltage (V_{out1} or V_{out2} in Fig. 1, respectively), m is the order of the higher harmonic component, r is the amplitude ratio between the higher and fundamental harmonic components and φ is the phase shift of the m-th harmonic component. By numerical solving the steady-state circuit equations for the circuit in Fig. 1, theoretical values of maximum measurement error of diode sensors for various harmonic-to-carrier power ratios and various power levels have been calculated. Results are consistent with curves presented in [2].

It has been found that the measurement error can be approximated with acceptable accuracy by the formula

$$\delta = kr^{eo}\left[\left(\frac{P_m}{P}\right)^{ep_1 ep_2} + 1\right]^{\frac{-1}{ep_2}}, \tag{3}$$

where δ is the maximum measurement error in (%), P is the power level in (mW), r is the higher harmonic suppression, P_m, k, ep_2 are optimized constants for the best fit to the measured values, and eo, ep_1 are fixed constants chosen depending on the harmonic order and detector type.

III. Measurement Setup and Results

To characterize power sensors, a known signal with higher harmonics is necessary. Two signal generators were used to produce the basic and higher-order harmonics. Filters were used to eliminate higher harmonics from the generated main signal. Generated signals were combined using a power splitter or a directional coupler. The generated signal with known harmonics was applied to the power sensor to be characterized using the setup given in Fig. 2.

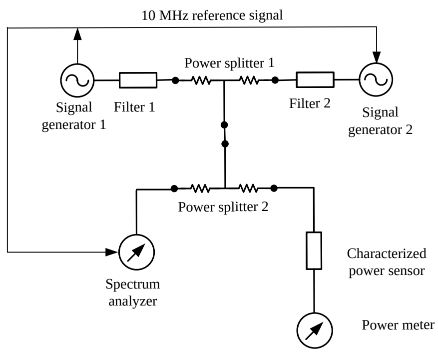

Fig. 2 Setup for characterization of power sensors.

The level of the main signal and the higher harmonic were varied and the frequency of the higher harmonic generator was slightly detuned in order to achieve a slow varying power meter reading due to changing mutual phase of the harmonic components. The worst-case error was then obtained from the min/max and also individual carrier and harmonics power readings analysis.

Various available sensors have been measured and characterized. The evaluated power measurement errors due to harmonics for the HP 8481D power sensor are given in Fig. 3 at the frequency 13 GHz. Note that the power deviation below -55 dBm is caused by the noise and not by harmonic effects. Further, the measurement was performed for the Anritsu MA2442D sensor in the frequency range up to 1.5 GHz and the largest observed error caused by higher harmonics was typically below 2 %. The above mentioned sensors are designed to operate in the square-law region and are quite insensitive to the effect of higher harmonics. On the other hand, the power sensors like e.g. R&S NRV-Z1, NRV-Z4, or HP ECP-E26A allow the user to operate not only in the square-law region and are much more suitable for harmonics effect investigation.

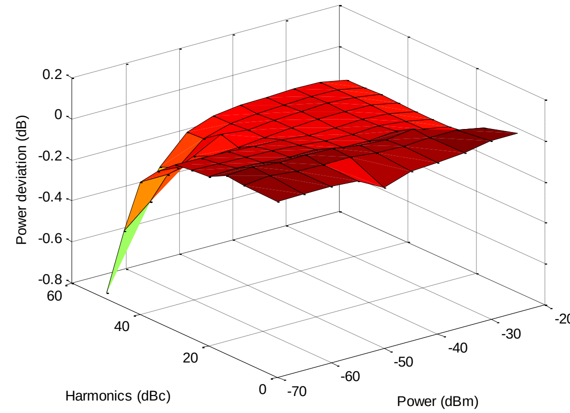

Fig. 3 Evaluated measurement errors due to harmonics versus applied power and harmonics-to-carrier power ratio at 13 GHz.

The measurement error at the frequency 2.5 GHz for the HP ECP-E26A sensor is plotted in Fig. 4 and Fig. 5, respectively. The circles represent errors obtained by the measurement. The set of curves was obtained using the equation (3) while the constants P_m, k, ep_2 have been found for the best fit to the three measured points lying at the above (blue) curves.

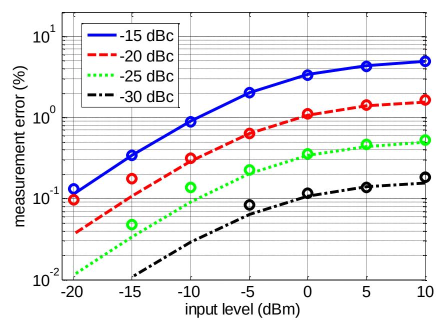

Fig. 4 Maximum measurement error caused by 2nd harmonic (HP ECP-E26A sensor). Lines = fit to theory (3), circles = measured.

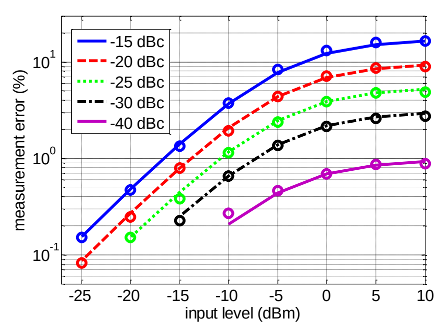

Fig. 5 Maximum measurement error caused by 3rd harmonic (HP ECP-E26A sensor). Lines = fit to theory (3), circles = measured.

V. Conclusion

A method was shown for evaluating of the influence of higher harmonic components on the measurement uncertainty when measuring power using diode power sensors. The higher harmonics can cause a significant measurement error, especially for older types of sensors.

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REFERENCES

[1] Y. Abdo, M. Celep, "New Effective Coaxial Twin-Load Micro-calorimeter System," *Proc. of CPEM 2016*, Ottawa, ON, 2016.

[2] Rohde & Schwarz, "Voltage and power measurements," PD 757.0835.23.

[3] Rohde & Schwarz, "Program for Measurement Uncertainty Analysis with R & S Power Meters", AN 1GP43_0E, 2001.

[4] Agilent, "Fundamentals of RF and microwave power measurements", NA 64-1A, 5989-6255EN, 1998.