

Thermal Effect on Wideband Harmonic Generation for Future Wireless Sensing

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Abstract— The stability of an SMS7630 diode's harmonic output spectrum under the fluctuation of operating temperature and frequency is analytically and experimentally investigated in this work. Measurements were conducted between -40°C and 80°C while the diode was powered by a 7 dBm input power at 1 ± 0.05 GHz. Stability and performance drifting effects were assessed by analyzing the output spectrum, which includes the fundamental frequency as well as its first and second harmonics. Results show that the diode behaves consistently (± 1 dBm in average) under a variety of operating temperature, underscoring its dependency on real-world usage in temperature-variable environments.

I. INTRODUCTION

Due to their strong performance under a variety of situations and great non-linearity, semiconductor diodes—particularly the SMS7630 series—are frequently used in radiofrequency applications [1]. In devices like frequency multipliers and mixers for microwave applications such as next-generation wireless sensing, a steady harmonic output is necessary, the performances of these diodes are crucial. However, the behavior of such diodes can be greatly influenced by external conditions such as temperature and operating frequency.

The stability of the SMS7630 diode's output spectrum under various frequency and thermal circumstances is the main goal of this investigation. Its robustness and applicability for temperature-critical situations are to be quantified.

Measurements related to the fundamental, first, and second harmonics were made, and performance drifts were examined to gain insight into reliability consideration and design strategy.

II. THEORETICAL ANALYSIS

With a high non-linearity in Schottky diode current-voltage characteristics, a frequency-modulated continuous-wave (FMCW) input signal sweeping from 0.95 to 1.05 GHz will output sweeps from 0.95 to 1.05 GHz, 1.90 to 2.10 GHz, 2.85 to 3.15 GHz, and higher harmonics. For a sinusoidal biased (V_{bias}) mono-frequency excitation of the diode with amplitude V_m , and considering a series resistor R_S , the open voltage can be expressed as: $v_{open}(t, T) = V_{diode}(t) - R_S i_D(t) = V_{bias} + V_m \cos(\omega t) - R_S i_D(t, T)$. The diode's temperature-dependent current equation $i_D(t, T)$ is formulated [2]:

$$i_D(t, T) = I_S(T) \left(e^{\frac{v_{open}(t)q}{nk_B T}} - 1 \right) \quad (1)$$

where n is the ideality factor, k_B is the Boltzmann's constant, q is the electrical charge and $I_S(T)$ is the temperature-dependent saturation current and is expressed by [3]:

$$I_S(T) = I_S \left(\frac{T_0}{T} \right)^{\frac{Xti}{n}} e^{\left(1 - \frac{T}{T_0} \right) \frac{E_G q}{nk_B T}} \quad (2)$$

where I_S is the saturation current at room temperature T_0 , Xti is the saturation current temperature exponent and E_G is the energy gap. After some manipulation and using W_0 , the 0-th branch of the Lambert-W function, the analytical formulation of the diode's current can be written as:

$$i_D(t, T) = \frac{nk_B T}{q R_S} W_0 \left[\frac{I_S(T) q R_S}{nk_B T} \left(e^{\frac{V_{diode}(t)q}{nk_B T}} - 1 \right) \right] \quad (3)$$

To further compare the harmonic amplitude levels, a Fourier transform on (3) is performed and the results are summarized in TABLE I with 7 dBm input power at 1 GHz and 0.10 V bias voltage.

TABLE I. THEORETICAL OUTPUT HARMONIC POWER IN DBM

Harmonic	-40°C	-20°C	0°C	20°C	40°C	60°C	80°C
1 GHz	-3.3	-3.6	-3.9	-4.1	-4.4	-4.7	-5.0
2 GHz	-10.5	-10.6	-10.6	-10.7	-10.9	-11.1	-11.2
3 GHz	-35.2	-33.2	-31.6	-30.4	-29.4	-28.5	-27.8

III. EXPERIMENTAL VERIFICATION

A continuous wave (CW) signal with a fundamental frequency of 1 GHz and an input power level of 7 dBm was used to power the SMS7630 diode. To operate and evaluate the diode, a harmonic generator is fabricated using the SMS7630 diode and a set of input and output matching networks developed on Rogers 5880 substrate with 31 mil thickness. At 20°C intervals, measurements were conducted across a regulated temperature range of -40°C to 80°C . The fundamental frequency and its first and second harmonics, which cover 1 GHz, 2 GHz, and 3 GHz, respectively, were examined in the output spectrum. Fig. 1(a) shows the harmonic generator's temperature-dependent output power at the fundamental, first, and second harmonic frequencies across the whole sweeping band (0.95 to 1.05 GHz, 1.90 to 2.10 GHz, 2.85

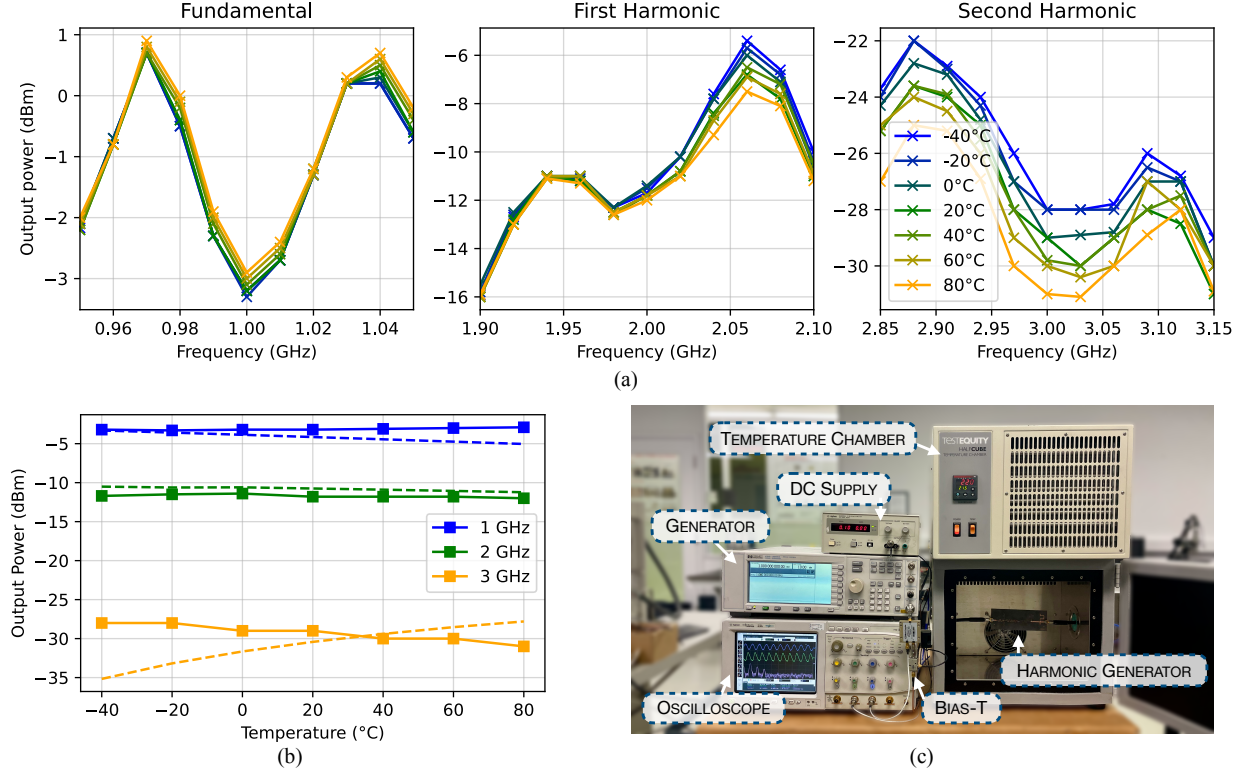


Figure 1. (a) Measured output power of the fundamental, first and second harmonic with an input power of 7 dBm and $V_{bias} = 0.1$ V from 0.95 to 1.05 GHz. The temperature covers -40°C to 80°C (b) Measured output power at 1, 2 and 3 GHz from -40°C to 80°C with 7 dBm input power. Theoretical power levels are marked by the dashed line (c) Measurement setup where the harmonic generator is biased with a bias-T, powered by frequency generator and the output is monitored by an oscilloscope.

to 3.15 GHz). Fig. 1(b) presents the comparison between the measurements (plain line) and the theory (dashed line) at 1, 2 and 3 GHz output with 7 dBm input power. Fig. 1(c) shows the actual measurement setup. The fabricated harmonic generator is placed inside the temperature room and the frequency generator provides the sweeping frequency. The output is captured with the oscilloscope.

The following important findings are highlighted as follows: 1) Fundamental frequency stability: There was less than a 1 dB fluctuation in the fundamental output power across the temperature range. This suggests that the diode's principal operating mode has good thermal stability; 2) Harmonic behavior: At very high temperatures, the output power of the first harmonic (2 GHz) decreased slightly, indicating a modest temperature sensitivity. With a theoretical power increase at higher temperatures (60°C to 80°C), the second harmonic (3 GHz) showed more noticeable fluctuations. Indeed, contrarily to the other outputs that showed very satisfactory correlation with their respective model, it appears that the model of the second harmonic loses its accuracy at extreme temperatures, although it yields adequate estimation between 0°C and 60°C . Additionally, across the sweeping band, the fundamental output varies by ± 2 dBm, when the first harmonic varies by ± 5 dBm and the second harmonic varies by ± 2 dBm, being independent of temperature variation. The temperature variation is responsible for ± 1 dBm, in average, in a 120°C range.

IV. CONCLUSION

The output spectrum of the SMS7630-diode based harmonic generator for future wireless sensing applications exhibits remarkable stability over several harmonics and a wide temperature range of 120°C . It shows a pattern where harmonic power decreases as frequency rises, especially at higher harmonics. These patterns support the diode's steady output spectrum and offer vital information for applications that need consistent harmonic performances. The investigation highlights the diode's dependable performance in systems needing less spectrum drift and validates its viability for RF applications in thermally fluctuating conditions. Future research might involve other environmental elements such as humidity and the impacts of long-term aging.

REFERENCES

- [1] M. E. Hines, "The Virtues of Nonlinearity - Detection, Frequency Conversion, Parametric Amplification and Harmonic Generation," *IEEE Transactions on Microwave Theory and Techniques*, vol. 32, no. 9, pp. 1097-1104, 1984, doi: 10.1109/TMTT.1984.1132821.
- [2] W. Shockley, "The theory of p-n junctions in semiconductors and p-n junction transistors," *The Bell System Technical Journal*, vol. 28, no. 3, pp. 435-489, 1949, doi: 10.1002/j.1538-7305.1949.tb03645.x.
- [3] X. Gu, S. Hemour, R. Khazaka, and K. Wu, "Improving Temperature Stability of Dickson Charge Pump Rectifiers for Battery-Free Wireless Sensing Applications," in *2023 IEEE/MTT-S International Microwave Symposium - IMS 2023*, 11-16 June 2023, pp. 1160-1163, doi: 10.1109/IMS37964.2023.10188165.