Application Note No. 099

A discrete based 315 MHz Oscillator Solution for Remote Keyless Entry System using BFR182 RF Bipolar Transistor

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Page	**Subjects (major changes since last revision)**
9 – 14	Added typical characteristic vs. both supply voltage and temperature

1 Introduction

This application note gives an introduction on how one can make a simple oscillator for low-cost applications like remote keyless entry (RKE). For demonstration purposes, the oscillator is designed for a frequency of 315 MHz, a commonly used frequency for remote keyless entry (RKE) and tire pressure monitoring systems (TPMS). The oscillator is designed as a Colpitts oscillator, which is stabilized with a SAW-resonator and allows for a simple design with only a few components besides the transistor and SAW-resonator. The modulation used for such a design is amplitude shift keying (ASK) or simple on-off keying (OOK). Since the frequency of oscillation is fixed, frequency shift keying (FSK) is not possible.

The transition frequency f_T of the transistor should be several Gigahertz in order to ensure oscillator start-up. However, using a transistor with too high of a f_T will also increase the harmonic levels, and therefore it is not recommended to use state-of-the-art transistors with transition frequencies far beyond 10 GHz. Furthermore, it holds for silicon bipolar transistors that the phase noise gets smaller as the transition frequency decreases. Thus, it appears that using Infineon's RF transistor BFR182 with a transition frequency of 8 GHz is a good compromise. It should be noted that phase noise depends not only on the flicker noise of the transistor itself but also on the flicker noise and loaded Q-factor of the SAW-resonator. In fact, phase noise decreases quadratically with the loaded Q-factor of the resonator.

Within every transistor family there exists several versions with different emitter areas that provide for different collector currents. Since the loop gain of the oscillator must be greater than 1 in order to sustain oscillation, a transistor that provides sufficient gain at the desired DC operating point and frequency of oscillation must be selected. Infineon's RF transistor BFR182 is a perfect fit, with enough loop gain, to sustain oscillation.

2 Principles

A principle schematic of a Colpitts oscillator in common-base configuration is shown in **Figure 1**. The frequency of oscillation is determined by the resonance frequency of the parallel resonant circuit consisting of L_1 and the serial connection of C_1 and C_2, thus giving the resonance frequency as follows:

$$f_0 = \frac{1}{2\pi\sqrt{L_1 C}}, \qquad (1)$$

where C is the combined capacitance of C_1 and C_2 and is expressed as follows:

$$C = \frac{C_1 C_2}{C_1 + C_2}. \qquad (2)$$

The serial connection of C_1 and C_2 acts as a voltage divider, so that not the entire output power of the transistor is fed back to the input. By this means the harmonics will be kept low. The lower the ratio C_1/C_2, the higher the voltage drop across C_1 and therefore the lower the power that is fed back to the input. Furthermore, the ratio L_1/C is a figure of merit for the selectivity of the parallel resonance circuit. The higher the ratio L_1/C, the lower the selectivity and therefore the higher the second harmonic. On the other hand, to get the maximum power out of the transistor, power matching must occur and therefore the output power of the oscillator changes with the inductance value of L_1 for a fixed ratio of L_1/C and C_1/C_2.

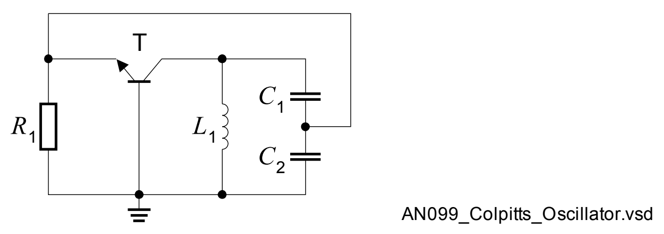


Figure 1 Small Signal Equivalent Circuit of Colpitts Oscillator

3 The Application Board

For this application board ease of use and test has been the main consideration and therefore a SMA-connector was used for measuring the output power directly into a 50 Ω load instead of using a loop antenna to make field-strength measurements. However, in the actual application the inductance L_1 will be realized partially or entirely with a loop antenna. Antenna design is a complex issue which goes beyond the scope of this application note. For details on antenna design, please refer to [1].

Figure 2 shows the schematic of the application board and in comparison with Figure 1 additional components are necessary for proper function. First of all, some resistors for biasing the transistor are required. The voltage divider consisting of R_2 and R_3 is designed for a control voltage V_{ON} of 3 V, but different voltage levels require different voltage dividers. Since the Q-factor of a LC-resonator is limited and the resonance frequency can change by several percent due to tolerances, a SAW-resonator (SAWR) for frequency stabilization is required. The matching network consisting of L_1 and C_3 transforms the 50Ω load to an inductive impedance value and C_4 is simply a DC block. However, the matching network is also part of the LC-resonator, and therefore a clear separation between matching network and LC-resonator is not possible. As already mentioned in the previous chapter, output power changes with the inductance value of L_1. It has been shown that the maximum output power is achieved with an inductance value of 40 nH to 50 nH for L_1. The RF chokes L_2 and L_3 as well as the RF bypass capacitors C_5 and C_6 are optional and will not be required in the final, battery-powered application. The complete bill of materials for the application board can be found in Table 1 on the next page.

The frequency of oscillation of the unstabilized oscillator, that is with the SAW-resonator replaced by a 560 pF capacitor having a series resonant frequency of approximately 300 MHz, shall be roughly the desired frequency of oscillation. Otherwise, one run the risk of causing a pseudo-oscillation at the unstabilized frequency of oscillation. This is because of the SAW-resonator's high Q-factor, which will result in a long settling time that gives the oscillator enough time to start oscillation at the unstabilized frequency. Furthermore, the oscillator will not oscillate exactly at the resonant frequency of the unloaded SAW-resonator, but the frequency of oscillation will be shifted towards the unstabilized one. This is another reason why the unstabilized frequency of oscillation should be close to the desired one. For this application board the frequency of oscillation of the unstabilized oscillator is approximately 320 MHz, which results in a frequency shift of approximately 30 kHz compared to the resonant frequency of the unloaded SAW-resonator.

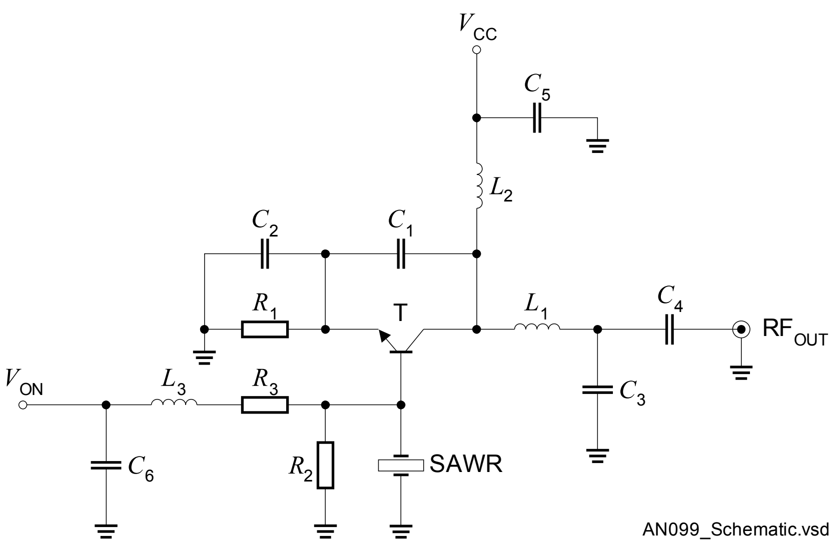


Figure 2 Schematic of Application Board

Figure 3 Photo of Application Board

Table 1 Bill of Materials

Designator	Value	Package	Vendor	Function
C_1	5 pF	0402		LC resonator
C_2	33 pF	0402		LC resonator
C_3	15 pF	0402		Matching
C_4	560 pF	0402		DC block
C_5, C_6	100 nF	0402		RF bypass (optional)
L_1	47 nH	0402		LC resonator
L_2, L_3	1000 nH	0805		RF choke (optional)
R_1	100 Ω	0402		Biasing
R_2	1.8 kΩ	0402		Biasing
R_3	2.7 kΩ	0402		Biasing
SAWR	R961	DCC6E	EPCOS	SAW resonator, 315 MHz
T	BFR182	SOT23	Infineon	NPN Silicon RF transistor

4 Measurement Results

The (constant) collector voltage is provided through the V_{CC} pin, while the (amplitude-modulated) control voltage is provided through the V_{ON} pin. This makes it easy to measure collector current and control current independently. All measurements for this application note were done with an unmodulated control voltage, that is in continuous wave mode. Please note that for start-up time measurements of the oscillator, capacitor C_6 has to be removed first, if the function generator used to supply the control voltage has a source impedance of 50 Ω, rather than Milliohms. Otherwise, one measures the low-pass filter consisting of capacitor C_6 and the generator's source impedance.

Table 2 summarizes important electrical parameters of the discrete oscillator. The given values are an average of six measurements on nominally identical boards. The oscillator is optimized for maximum output power at a low collector current of only 6 mA. Along with the control current of 0.7 mA, the total DC current consumption of only 6.7 mA results in a high DC-RF conversion efficiency of 35%.

Table 2 Electrical Characteristics at T_A = 25°C

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
DC Characteristics (verified by 6 samples)						
Supply Voltage	V_{CC}		3		V	
Control Voltage	V_{ON}		3		V	Unmodulated
Collector Current	I_C		6		mA	
Control Current	I_{ON}		0.7		mA	
Collector Cutoff Current	$I_{C,OFF}$		2		nA	V_{CC} = 3.2 V, V_{ON} = 0
AC Characteristics (verified by 6 samples)						
Oscillation Frequency	f_{OSC}		315		MHz	
Output Power	P_{OUT}		8.3		dBm	315 MHz
Second Harmonic	$P_{OUT,2}$		-34		dBc	630 MHz
Third Harmonic	$P_{OUT,3}$		-56		dBc	945 MHz
SSB Phase Noise	$L(\Delta f)$		-110		dBc/Hz	Δf = 1 kHz
Start-up Time[1)]	$t_{ON,3dB}$		15		µs	3 dB down (50% output power)
	$t_{ON,1dB}$		22		µs	1 dB down (80% output power)
	$t_{ON,½dB}$		28		µs	½ dB down (90% output power)

1) For start-up time measurements, the capacitor C_6 was removed.

Figure 4 shows the harmonic suppression of three out of six boards, one with the lowest collector current (5.76 mA), one with a typical collector current (6.01 mA) and one with the highest collector current (6.36 mA). The second harmonic suppression of 34 dBc and even the third and subsequent harmonic suppressions of more than 50 dBc are much greater than the mandatory 20 dBc. A plot of the oscillator's single sideband (SSB) phase noise is shown in **Figure 5**. For comparison reasons, the noise floor of the source signal analyzer (SSA) is also shown. For phase noise measurements with the SSA a 10 times correlation was used, which improves the SSA's SSB phase noise sensitivity by 5 dB. As shown in **Figure 5**, this simple SAW-resonator based oscillator achieves exceptional low phase noise levels, much lower than PLL-based oscillators would ever achieve. On **Page 9** to **Page 14** average-value curves of important electrical parameters are shown versus supply voltage as well as versus temperature. The supply voltage for these measurements was varied between 2.5 V and 3.2 V, the typical battery voltage of a nominal 3 V battery during its lifetime, and the temperature was varied between -40 °C and 85 °C. The shift in frequency of oscillation shown on **Page 9** and **Page 12** relates to the typical frequency of oscillation at a temperature of 25 °C and a supply voltage of 3 V. Please note that the shift in frequency of oscillation is only a few kilohertz and this shift depends strongly on the performance of the SAW-resonator used in the application.

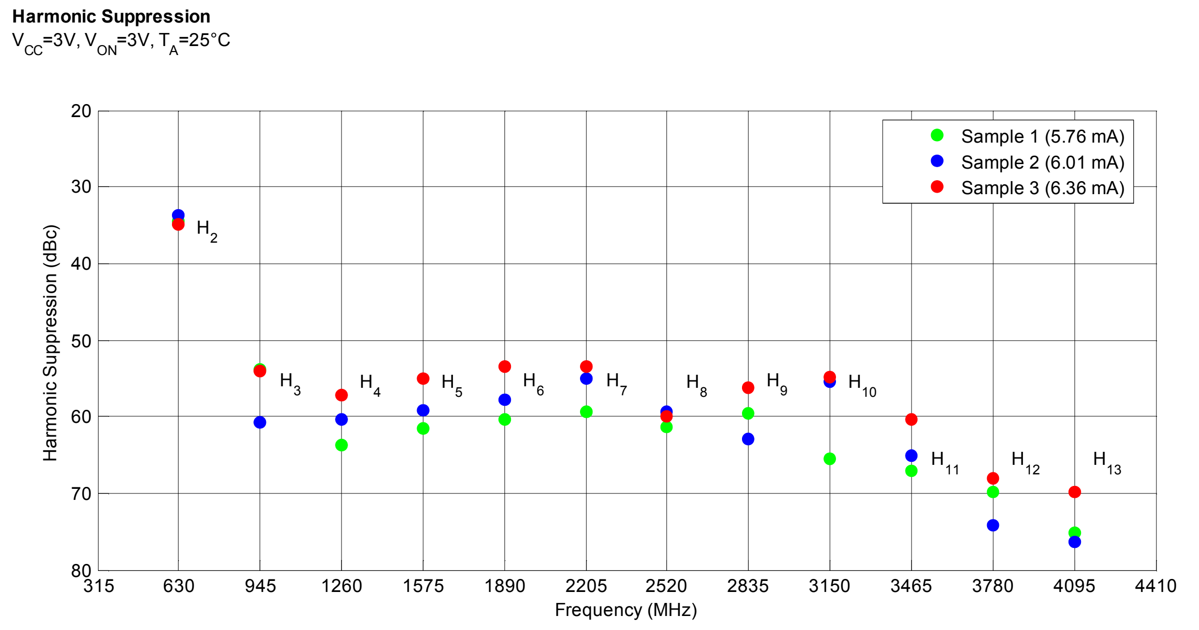


Figure 4 Harmonic Suppression from Second to Thirteenth Harmonic

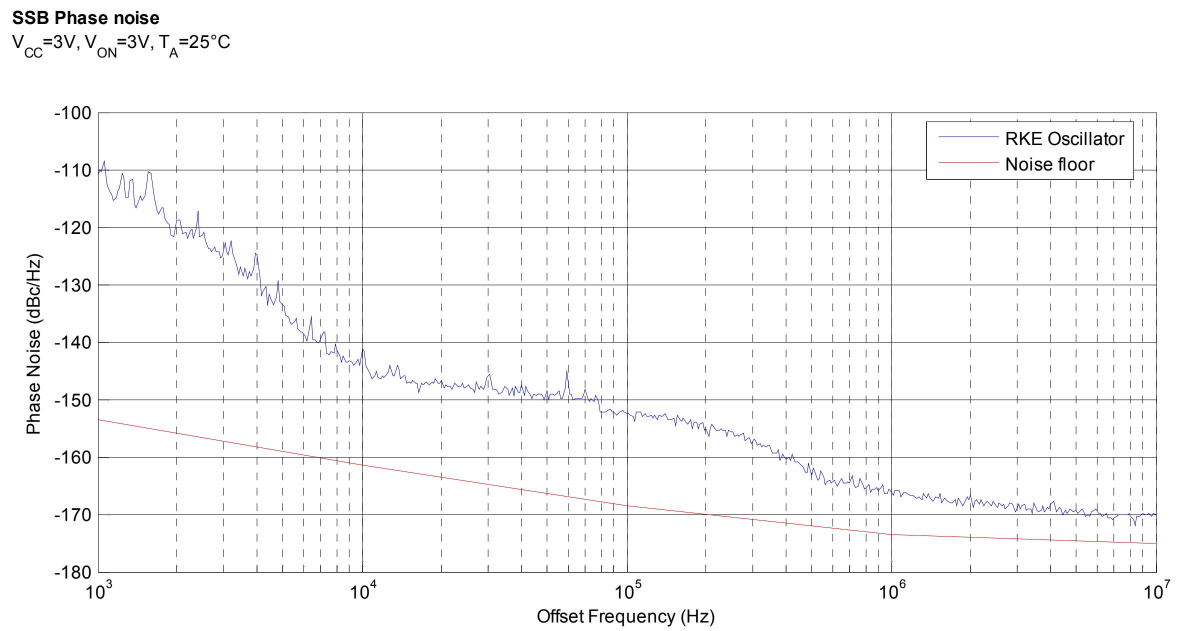
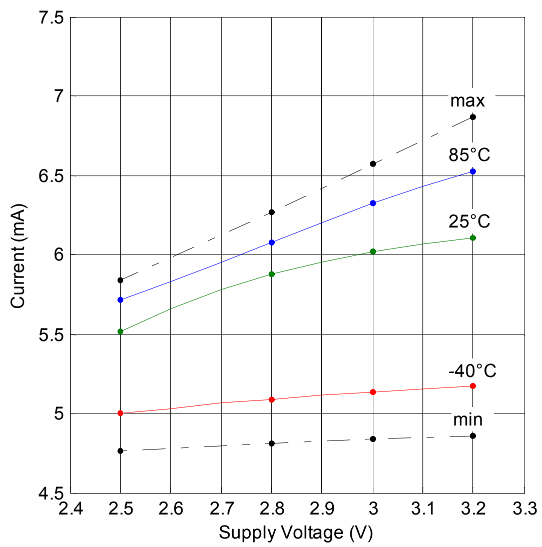


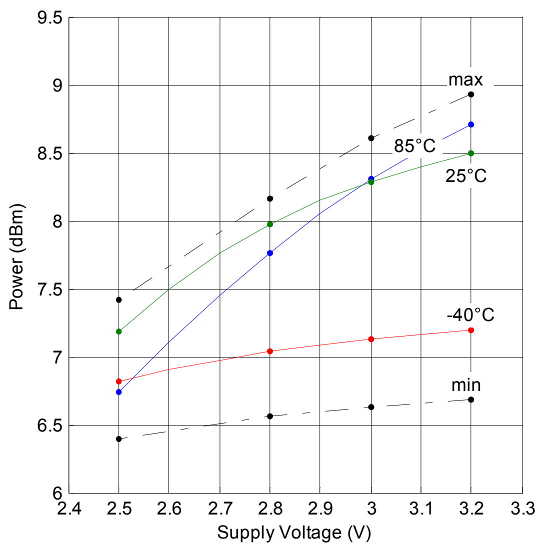
Figure 5 SSB Phase Noise of RKE Oscillator and Noise Floor of Signal Source Analyzer

Typical Characteristic vs. Supply Voltage (verified by 6 samples)

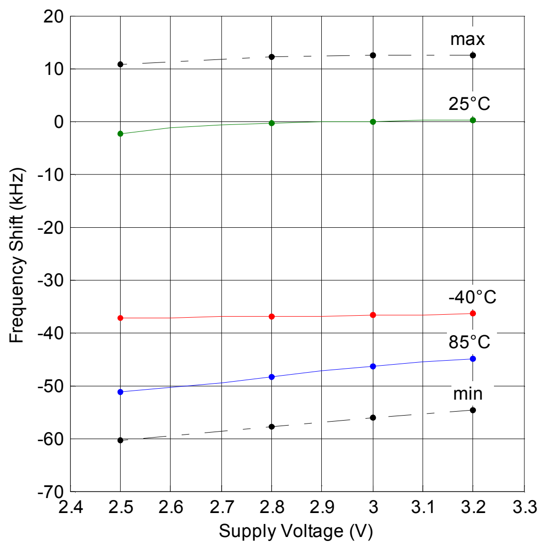
Collector Current $I_C = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter



Output Power $P_{OUT} = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter



Oscillation Frequency Shift $\Delta f_{OSC} = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter

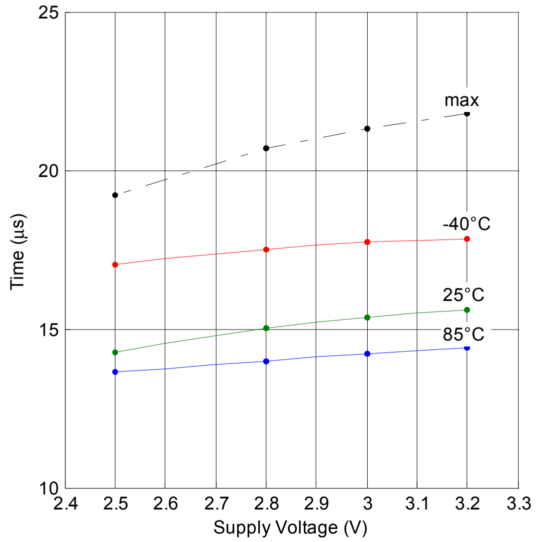


Note:

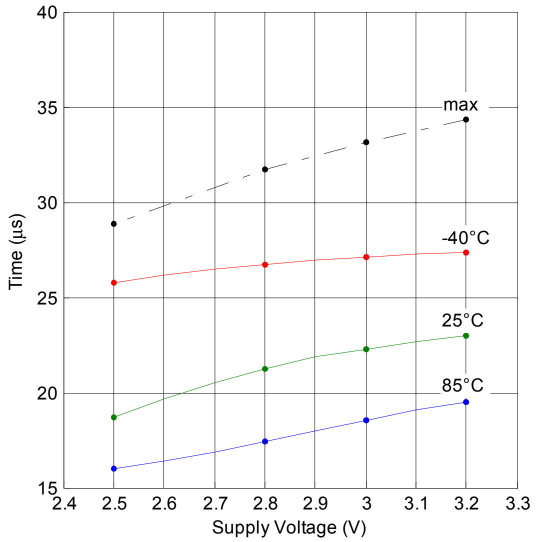
1. *The min/max curves show the minimum/maximum measured values and must not be taken to mean guaranteed minimum/maximum limits.*
2. *The shift in frequency of oscillation relates to the typical frequency of oscillation at 25°C and 3V.*

Typical Start-up Time vs. Supply Voltage (verified by 6 samples)

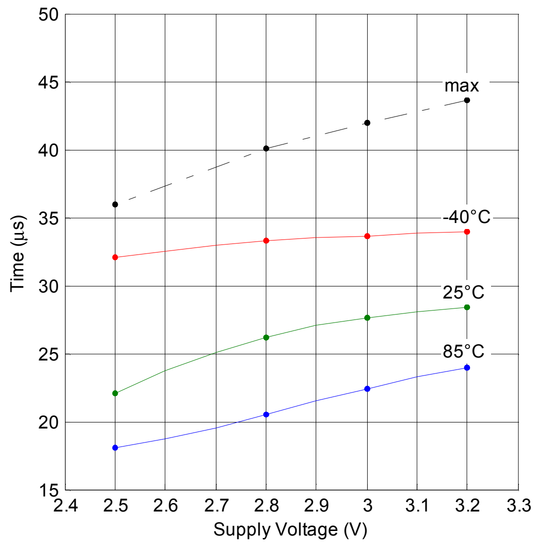
Start-up Time $t_{ON,3dB} = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter



Start-up Time $t_{ON,1dB} = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter

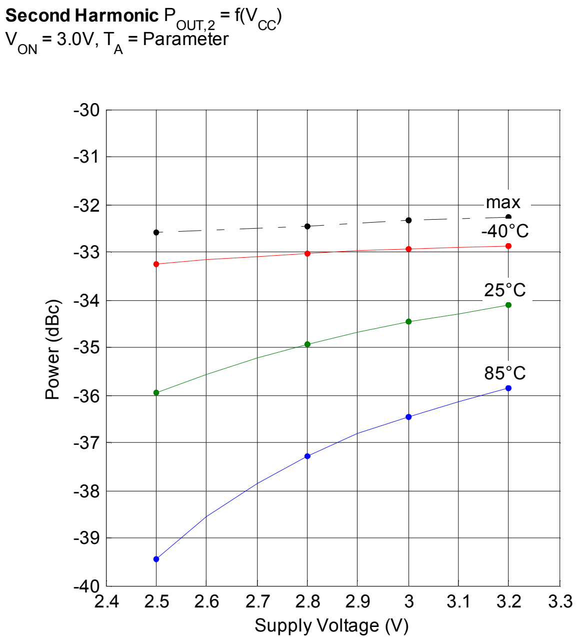


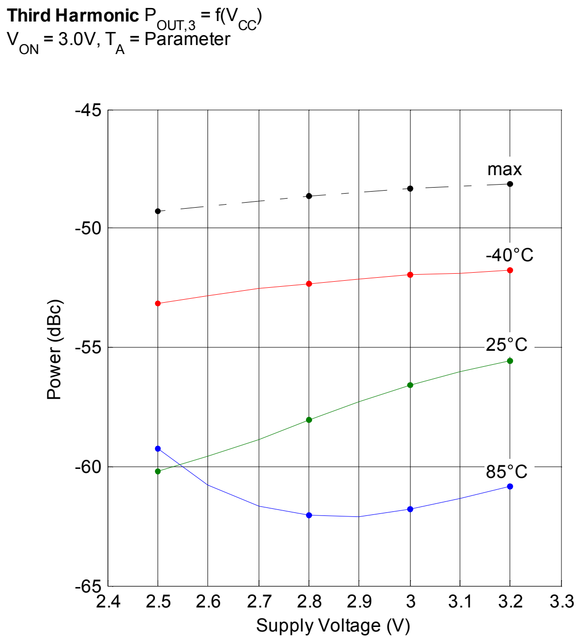
Start-up Time $t_{ON,1/2dB} = f(V_{CC})$
$V_{ON} = 3.0V$, T_A = Parameter



Note: The max curve shows the maximum measured values and must not be taken to mean guaranteed maximum limits.

Typical Characteristic of Second and Third Harmonic vs. Supply Voltage (verified by 6 samples)

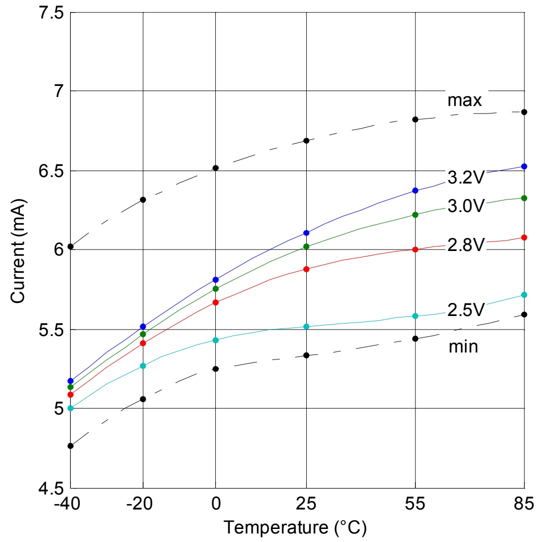




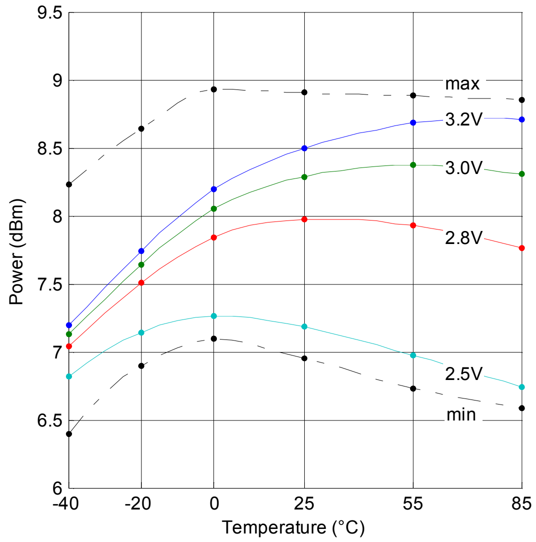
Note: The max curve shows the maximum measured values and must not be taken to mean guaranteed maximum limits.

Typical Characteristic vs. Temperature (verified by 6 samples)

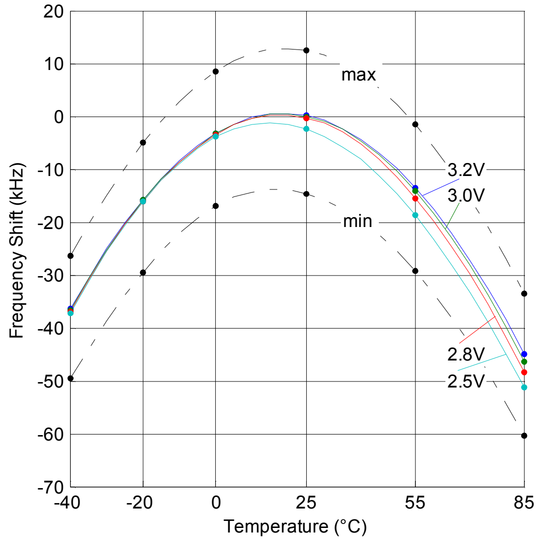
Collector Current $I_C = f(T_A)$
$V_{ON} = 3.0V$, V_{CC} = Parameter



Output Power $P_{OUT} = f(T_A)$
$V_{ON} = 3.0V$, V_{CC} = Parameter



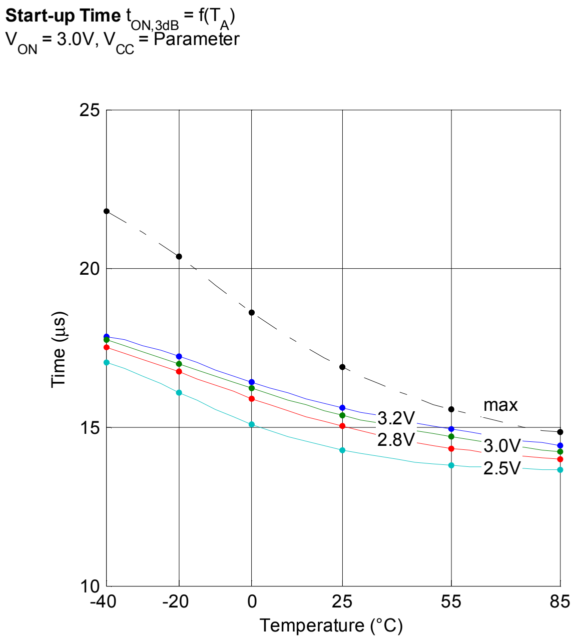
Oscillation Frequency Shift $\Delta f_{OSC} = f(T_A)$
$V_{ON} = 3.0V$, V_{CC} = Parameter

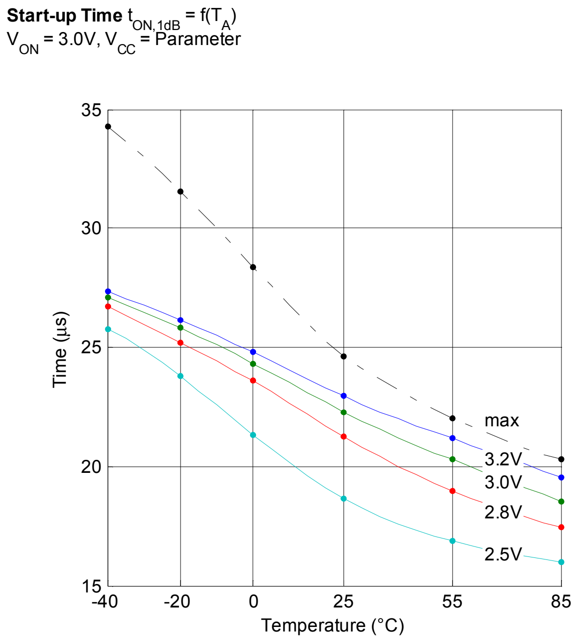


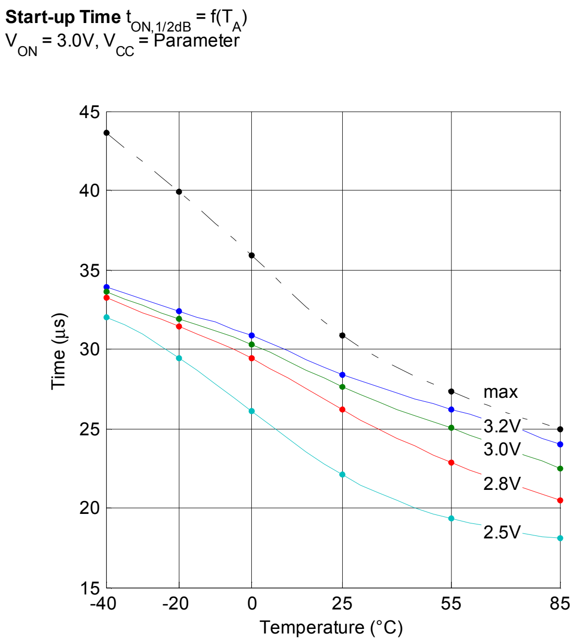
Note:

3. *The min/max curves show the minimum/maximum measured values and must not be taken to mean guaranteed minimum/maximum limits.*
4. *The shift in frequency of oscillation relates to the typical frequency of oscillation at 25°C and 3V.*

Typical Start-up Time vs. Temperature (verified by 6 samples)

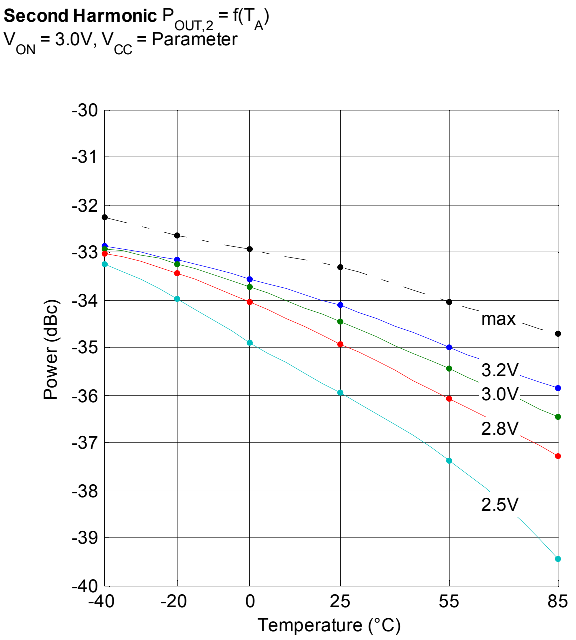


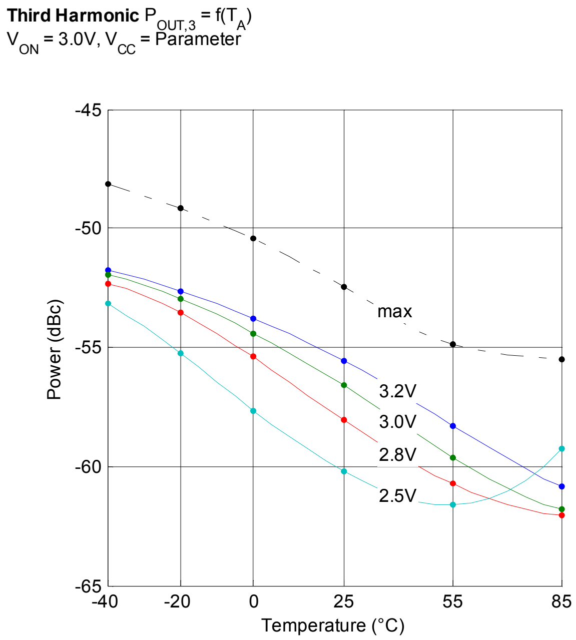




Note: The max curve shows the maximum measured values and must not be taken to mean guaranteed maximum limits.

Typical Characteristic of Second and Third Harmonic vs. Temperature (verified by 6 samples)





Note: The max curve shows the maximum measured values and must not be taken to mean guaranteed maximum limits.

References

[1] John Kraus, Ronald Marhefka, “Antennas for All Applications,” 3rd Edition, McGraw-Hill, Dec. 2001, ISBN 0-071-12240-0