

Application Note No. 061

W-CDMA 2.3 GHz VCO using BFR360F and
BBY58-02V

RF & Protection Devices



Never stop thinking

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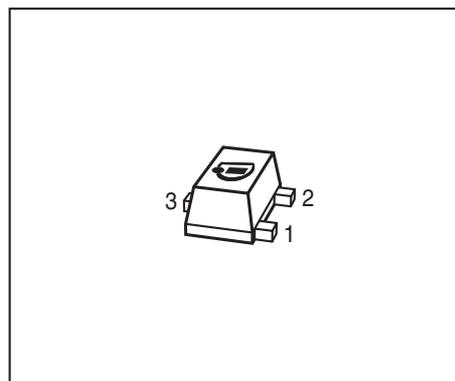
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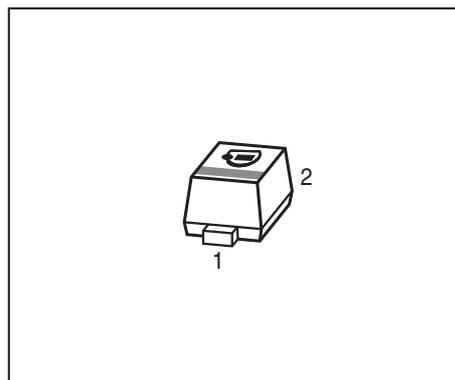
1 W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V

Features

- Low phase noise of < -90 dBc / Hz at 10 kHz using a low Q resonator
- 0 dBm output power at low current consumption
- Highly linear oscillation frequency versus control voltage curve



Package: TSFP-3



Package: SC79

1.1 Introduction

1.1.1 BFR360

The BFR360F is a silicon bipolar transistor housed in a small outline TSFP-3 package. A member of Infineon's new 3+ generation transistor family, the BFR360F is a 14 GHz transition-frequency device which takes advantage of the latest manufacturing techniques requiring fewer processing steps than other devices in its class, thereby offering excellent performance and device-to device consistency at extraordinarily low cost. With a noise figure of 0.95 dB at 2 V / 5 mA, this device is a good solution for cost-sensitive LNA designs. In addition, the BFR360F is an ideal choice for VCO applications due to its low flicker noise ($1/f$ noise) corner frequency of 15 kHz.

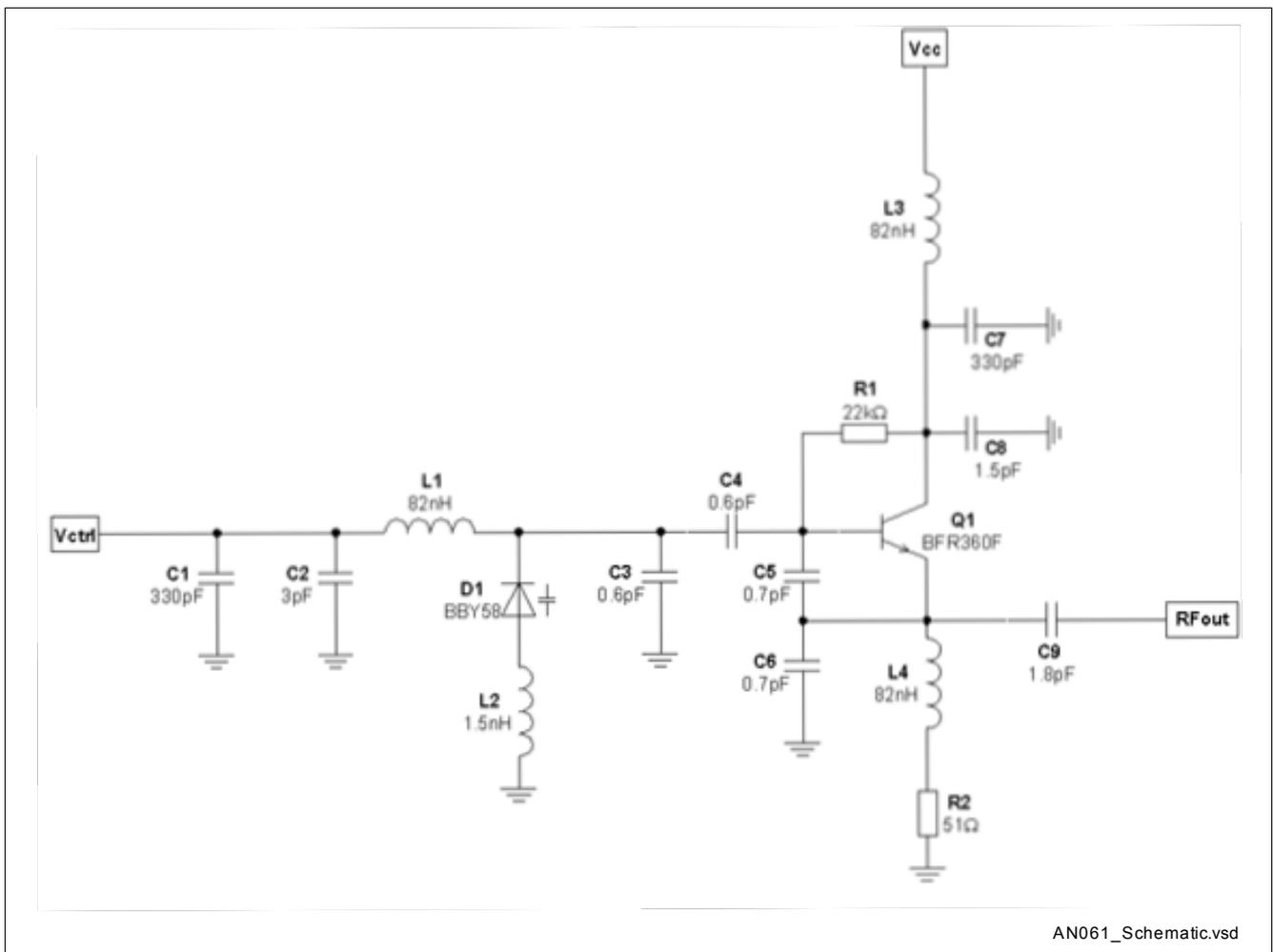
1.1.2 BBY58-02V

The BBY58-02V is a hyper abrupt silicon varactor diode designed for low tuning voltage operation in VCOs employed in mobile communications equipment. It offers excellent linearity accompanied by a high quality factor and low series inductance. Other features are a high capacitance ratio and very low capacitance spread. The BBY58-02V is housed in a small outline SC79 package.

1.1.3 Application Circuit

Table 1 Typical Parameters of the Application Circuit

Parameter	Value
V_{CC}	3 V
I_{CC}	8.5 mA
f_{osc}	2300 MHz - 2360 MHz
V_{ctrl}	0.85 V - 2 V
P_{out}	0 dBm
Phase Noise	<-90 dBc/Hz @ 10 kHz
Sensitivity	49 MHz / V


Figure 1 Schematic Diagram

W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V

Table 2 Bill of Materials

Name	Value	Package	Manufacturer	Function
C1	330 pF	0402	Various	RF Decoupling
C2	3 pF	0402	Various	RF Decoupling
C3	0.6 pF	0402	AVX ACCU-P	Tank Circuit
C4	0.6 pF	0402	AVX ACCU-P	Tank Circuit, DC Block
C5	0.7 pF	0402	AVX ACCU-P	Feedback
C6	0.7 pF	0402	AVX ACCU-P	Feedback
C7	330 pF	0402	Various	RF Ground
C8	1.5 pF	0402	Various	RF Ground
C9	1.8 pF	0402	Various	DC Block
D1	BBY58-02V	SC79	Infineon	Varactor Diode, Tank Circuit
L1	82 nH	0402	Toko LL1005-FH	RF Choke
L2	1.5 nH	0402	Toko LL1005-FH	Tank Circuit
L3	82 nH	0402	Toko LL1005-FH	RF Choke
L4	82 nH	0402	Toko LL1005-FH	RF Choke
Q1	BFR360F	TSFP-3	Infineon	Si BJT
R1	22 kΩ	0402	Various	Biasing
R2	51 Ω	0402	Various	Biasing

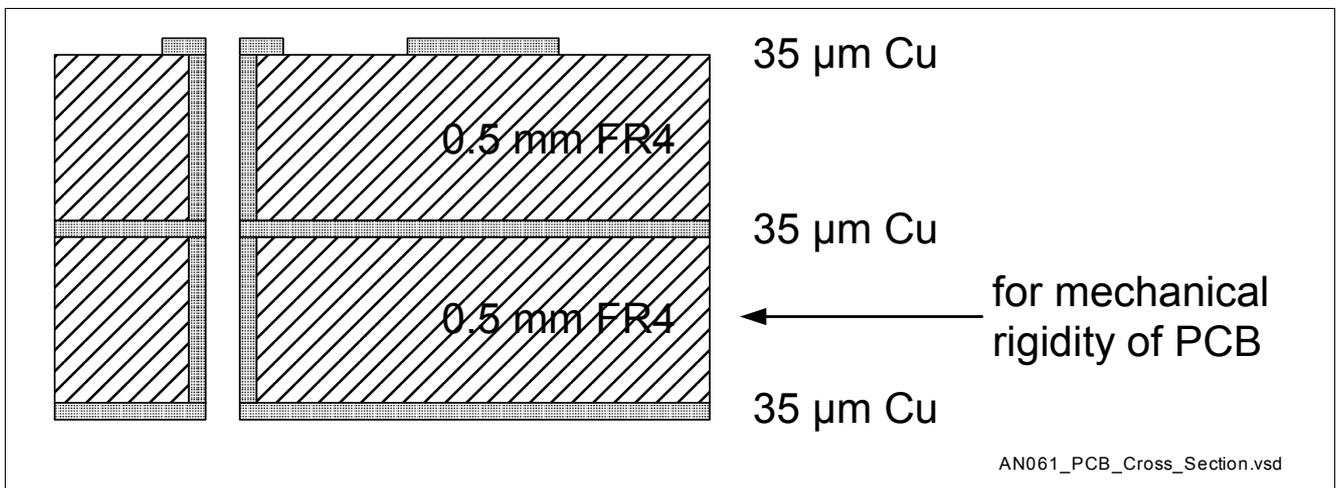


Figure 2 PC Cross Section

1.2 Overview

This application note describes the design of a voltage controlled oscillator.

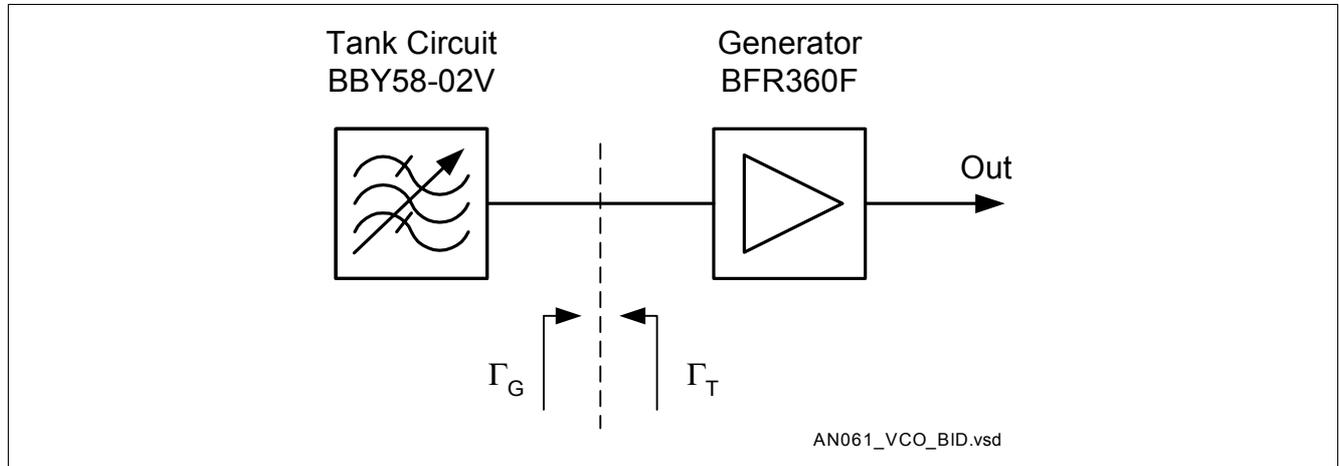


Figure 3 VCO Block diagram

Traditionally, all oscillators are classified as either a negative resistance oscillator (a.k.a. reflection oscillator) or a feedback oscillator. The criterion is whether there is an “obvious” feedback circuit. At RF and microwave frequencies, it becomes difficult to construct a feedback circuit without introducing excess phase shift. Therefore almost all oscillators in this frequency range are classified as a negative resistance oscillator. **Figure 3** shows a block diagram of a negative resistance oscillator. In the negative resistance model, oscillators are represented as a combination of an active element (generator) and a passive element (tank circuit).

The active element generates negative resistance and drives the passive element, which is usually a resonator. When the negative resistance is of sufficient magnitude to overcome all losses in the resonator and associated circuitry, an oscillation starts and builds up, rapidly achieving a steady-state condition.

The oscillator design discussed in this application note is in Clapp configuration (**Figure 4**). The BFR360F is employed in the generator circuit to provide negative resistance.

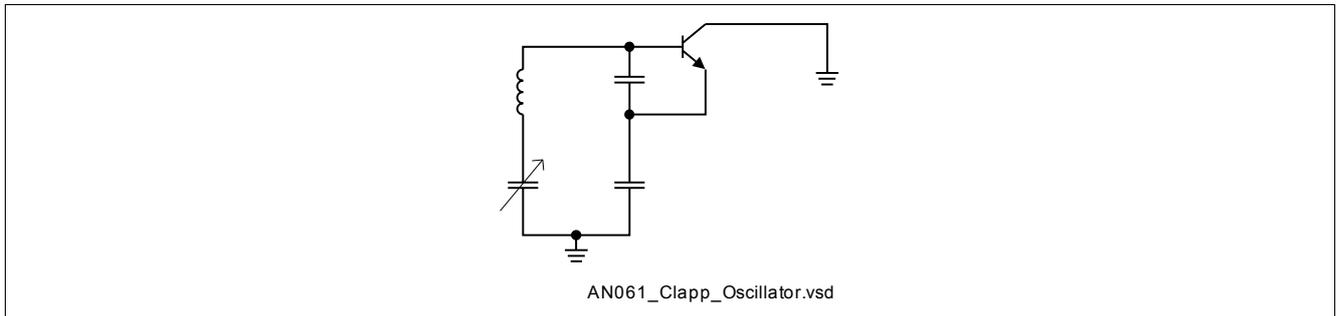
The BBY58-02V diode serves as a voltage controlled capacitor in the tank circuit to enable tuning of the oscillation frequency.

The phase noise of an oscillator depends strongly on the $1/f$ noise performance of the transistor used, and even more so on the loaded Q-factor of the tank circuit. The Q-factor of the inductor element used in the tank circuit is especially critical.

If the BFR360F transistor and the BBY58-02V tuning diode are used in an oscillator circuit, it is possible to achieve good phase noise performance, even with a low Q inductor.

The oscillator design in this application note uses a standard 0402 chip inductor as the tank circuit inductive element. The chip coil used has a modest unloaded Q approximately 70 at 2.3 GHz. Despite this limitation, the oscillator’s phase noise is still better than -90 dBc / Hz at 10 kHz offset, with oscillator output power being a respectable 0 dBm / 1 mW

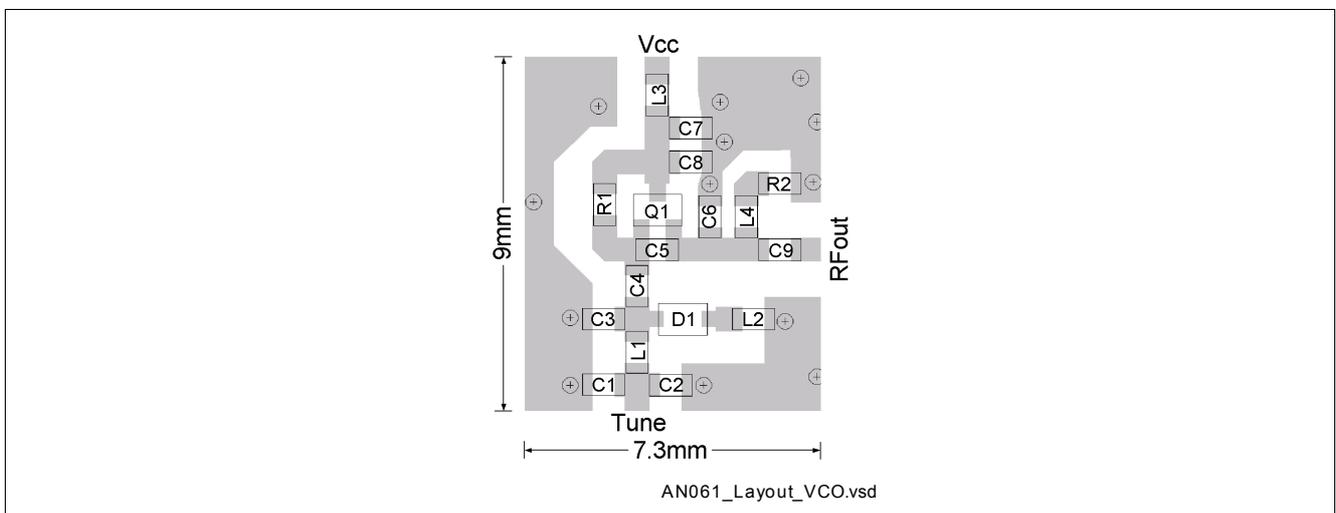
W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V


Figure 4 Clapp Oscillator

1.3 Circuit Topology

Table 1 shows the topology that is used for this VCO design.

Q_1 , the Infineon BFR360F transistor, is used in a common collector configuration and utilizes the feedback voltage divider $C_1 - C_5$ to provide appropriate phase-shift and feedback to enable oscillation to occur. The impedance that will be seen by the resonator on Q_1 's base will be negative and the system is classified as a reflection oscillator. The system's thermal noise will create a signal build-up between the generator and the resonating tank circuit that will build to an oscillation at a frequency determined by the resonator. L_4 is chosen as an RF choke to provide a high impedance in the emitter circuit and to ensure that most of the oscillator power is fed back to the base of Q_1 instead of being dissipated in R_2 . R_2 is used for current feedback, providing a stable DC operating point that is less dependent on variations in transistor h_{FE} . C_7 and C_8 serve as RF bypass capacitors and provide an RF ground at the BFR360F's collector


Figure 5 Layout of the VCO

The tank circuit is comprised of C_3 , C_4 , L_2 and D_1 , the varactor diode BBY58-02V. These elements determine the VCO's frequency of oscillation. It is lightly coupled to the BFR360F's base through C_4 , the light coupling serving to maximize the loaded Q of the resonator. L_1 is used as an RF choke, while C_1 and C_2 serve as RF bypass capacitors.

C_9 is the coupling capacitor that taps some of the energy out of the VCO. The less energy drained out of the oscillator circuit, the higher the loaded Q factor will be, and therefore the better the phase noise performance. However, the drawback is a low output power from the complete circuit.

The loaded Q of the tank circuit can be augmented by increasing C_6 or reducing C_4 . However, doing so reduces the loop gain in the oscillator, and sufficient loop gain has to be maintained to guarantee oscillation start-up under all conditions of temperature, supply voltage, ect. C_4 determines the amount of coupling between the active device

W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V

and the resonator. The lighter the coupling (a lower value of C_4 yields lighter coupling), the better the loaded Q of the resonator, which results in better phase noise performance. The trade-off is reduced VCO output power and as the coupling becomes lighter and lighter, the likelihood of the VCO to fail to achieve start-up increases. For this reason it is prudent to test the VCO for start-up at the maximum anticipated operating temperature and lowest specified operation voltage, to ensure sufficient gain margin to guarantee oscillator start-up under adverse conditions.

1.4 Measurement Results

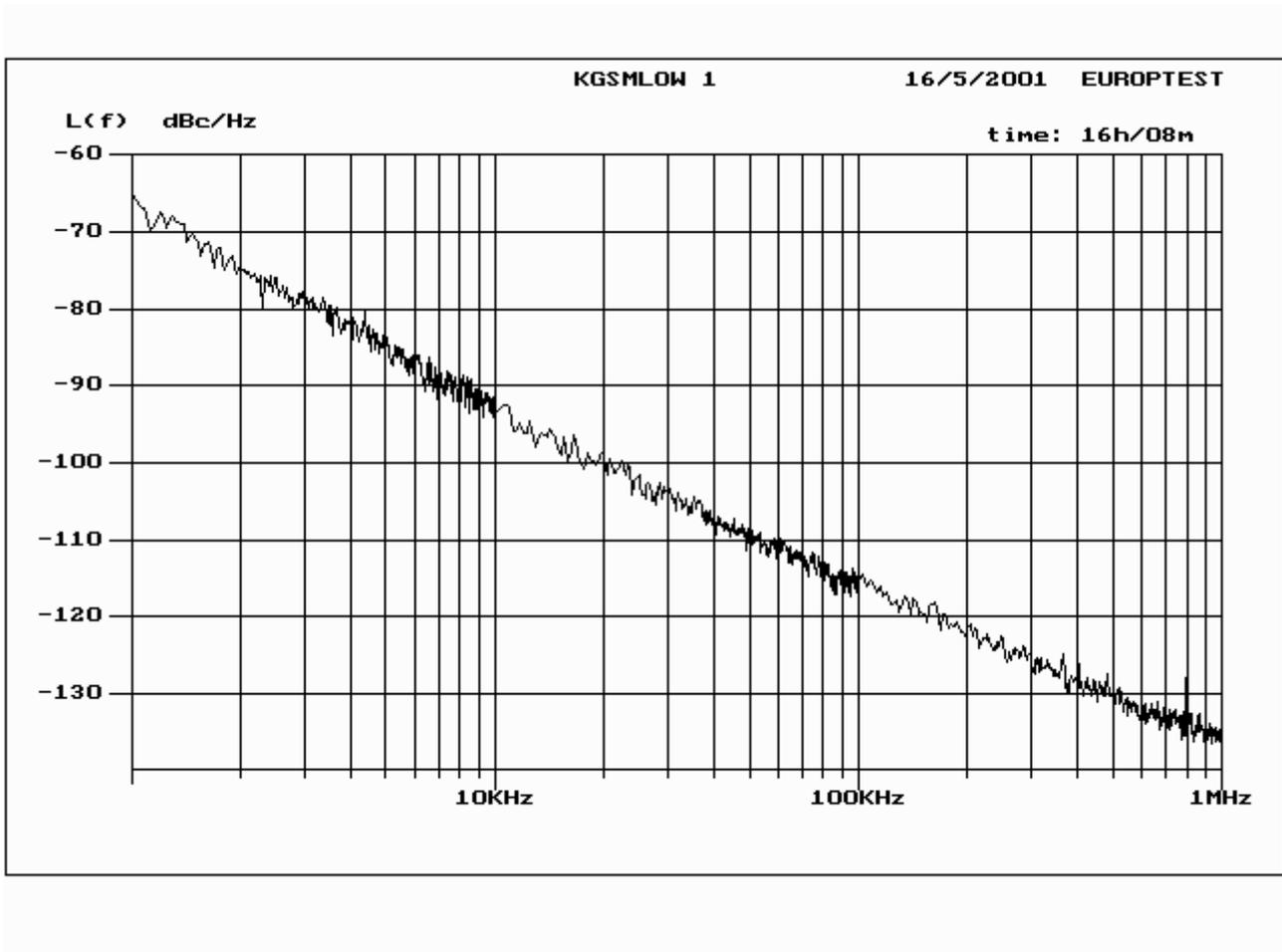
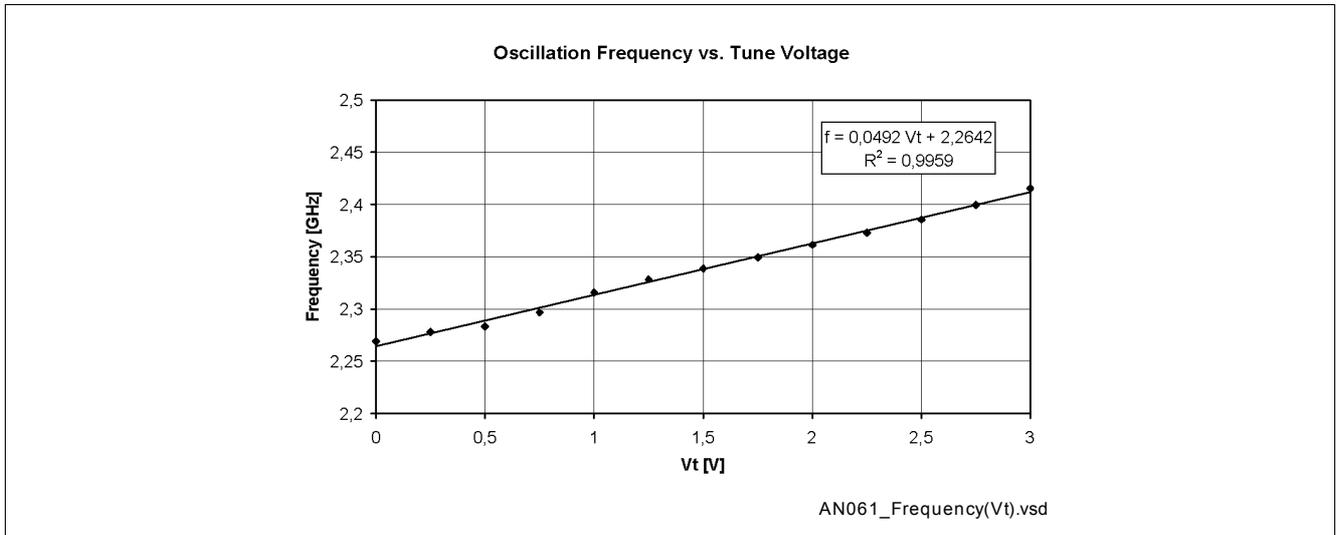
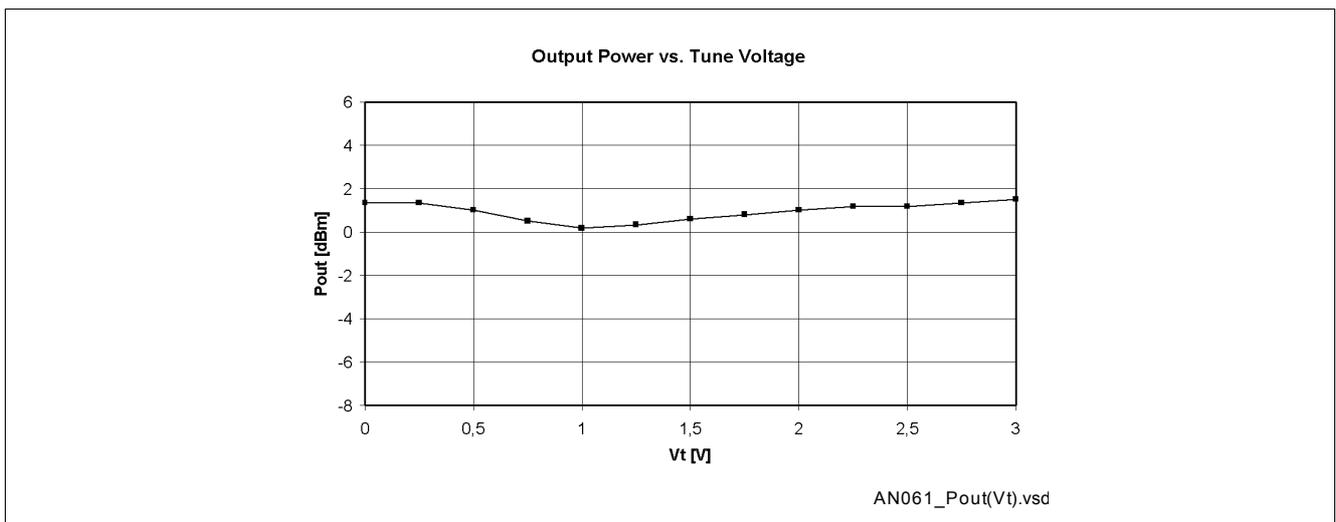


Figure 6 Measured Phase Noise

W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V


Figure 7 Measure Frequency of Oscillation vs. Tune Voltage

Figure 8 Measured Output Power vs. Tune Voltage
Table 3 Test Results

Parameter	Units	Measured Performance
Supply Voltage	V	3
Supply Current	mA	8.5
Control Voltage Range	V	0.85 - 2
Operating Frequency Range	MHz	2300 - 2360
Control Voltage Sensitivity	MHz / V	49
Output Power into 50 Ω	dBm	0
Phase Noise at 10 kHz	dBc / Hz	-90
Phase Noise at kHz	dBc / Hz	-113
Frequency Pushing ($V_{CC} = 3 V \pm 0.25 V$)	kHz	± 450
Harmonics	dBc	-13

2 Summary and Remarks

Infineon's newly introduced 3+ generation BFR360F bipolar transistor and BBY5x-02V varactor diodes offer a high performance, compact and low-cost solution for voltage controlled oscillator (VCO) designs.

This application note describes a VCO design for WCDMA applications. The circuit offers a low phase noise of less than -90 dBc/Hz @ 10 kHz despite the fact that a standard, low-cost, low Q chip inductor is used in the resonator circuit. Of course one can not expect this VCO design to have tightly toleranced, highly repeatable frequency of oscillation since the tolerance of the inductor used in the tank circuit are ± 0.3 nH, which corresponds to ± 20 % of the nominal 1.5 nH value. The main purpose of this application note was not to present an oscillator suitable for mass production but to point out the excellent potential of the BFR360F transistor for low-cost, low phase noise VCOs.

Evaluation boards for the VCO application described in this application note are available from Infineon Technologies.