

# 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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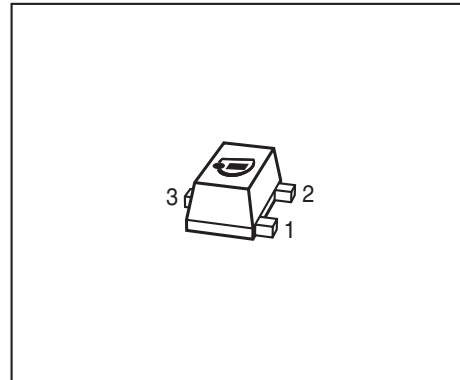
**Previous Version: 2001-05-17**

| <b>Page</b> | <b>Subjects (major changes since last revision)</b> |
|-------------|---|
| All         | Document layout change                              |
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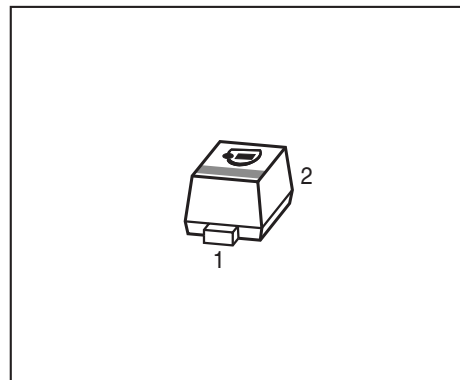
## 1 W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V

### 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.

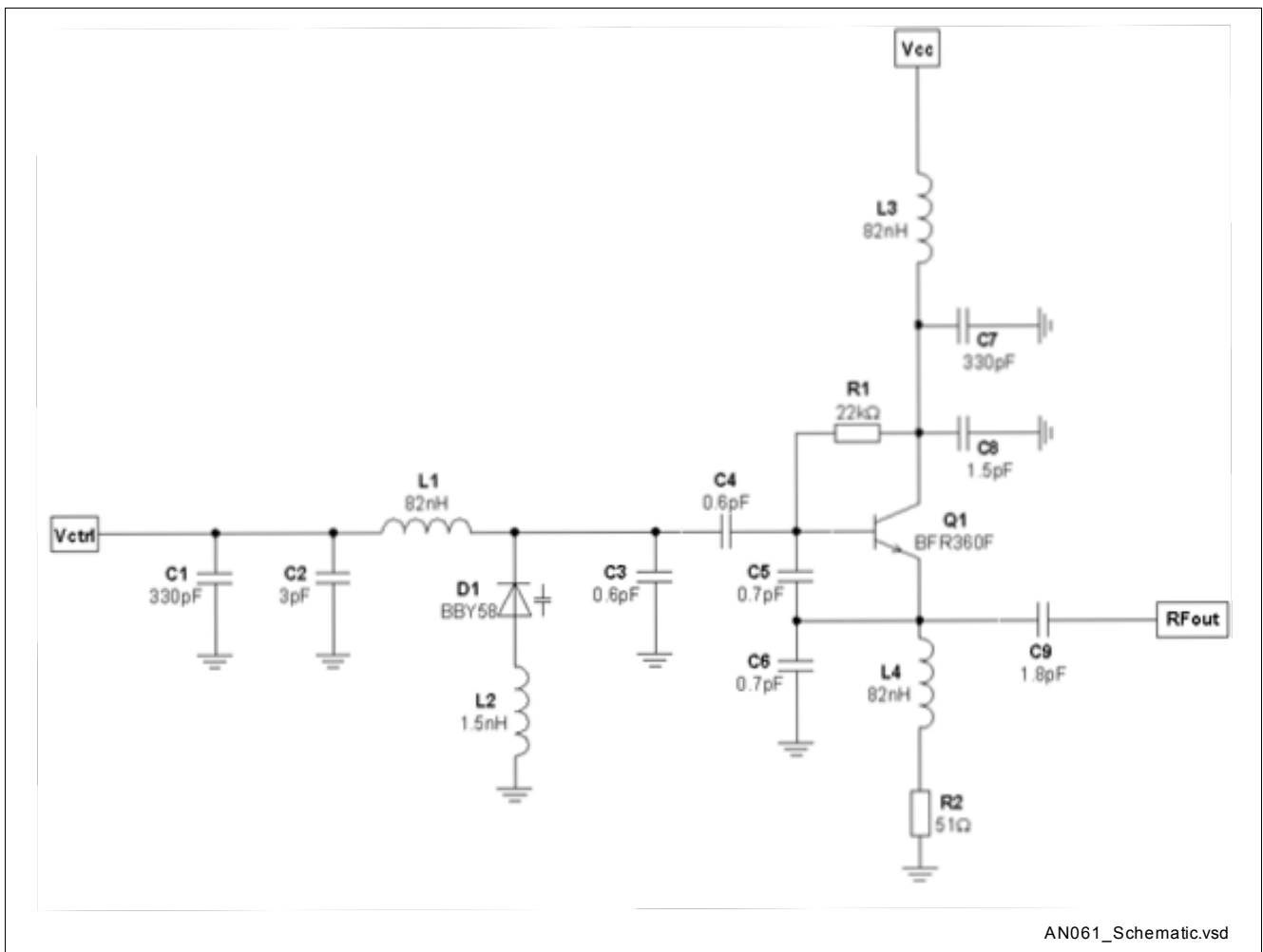
#### 1.1.2 BBY58-02V

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**

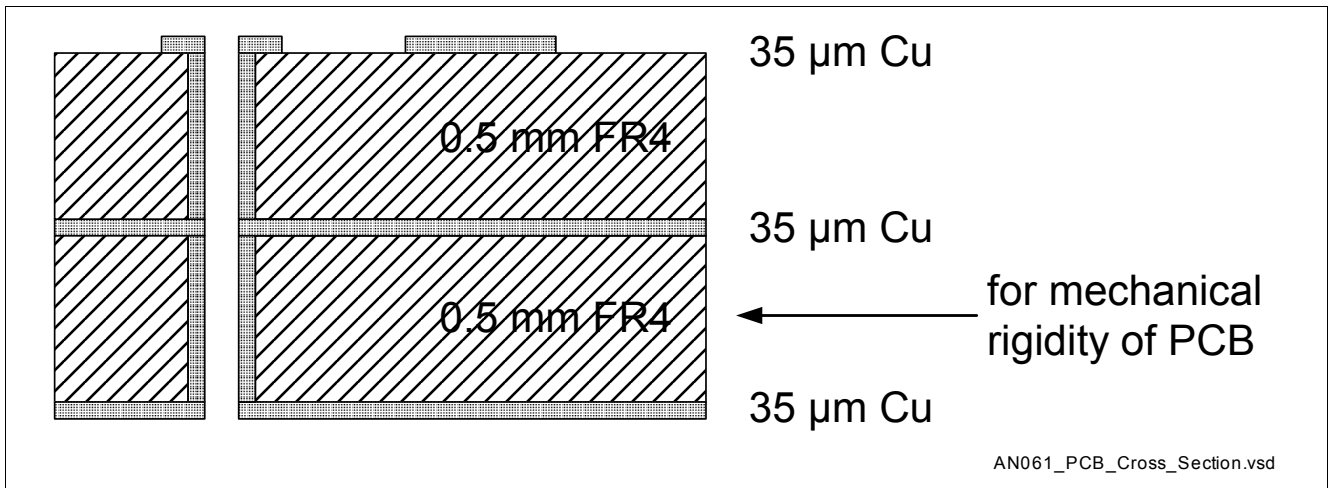
| Parameter   | Value                |
|-------------|----------------------|
| $V_{CC}$    | 3 V                  |
| $I_{CC}$    | 8.5 mA               |
| $f_{osc}$   | 2300 MHz - 2360 MHz  |
| $V_{ctrl}$  | 0.85 V - 2 V         |
| $P_{out}$   | 0 dBm                |
| Phase Noise | <-90 dBc/Hz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

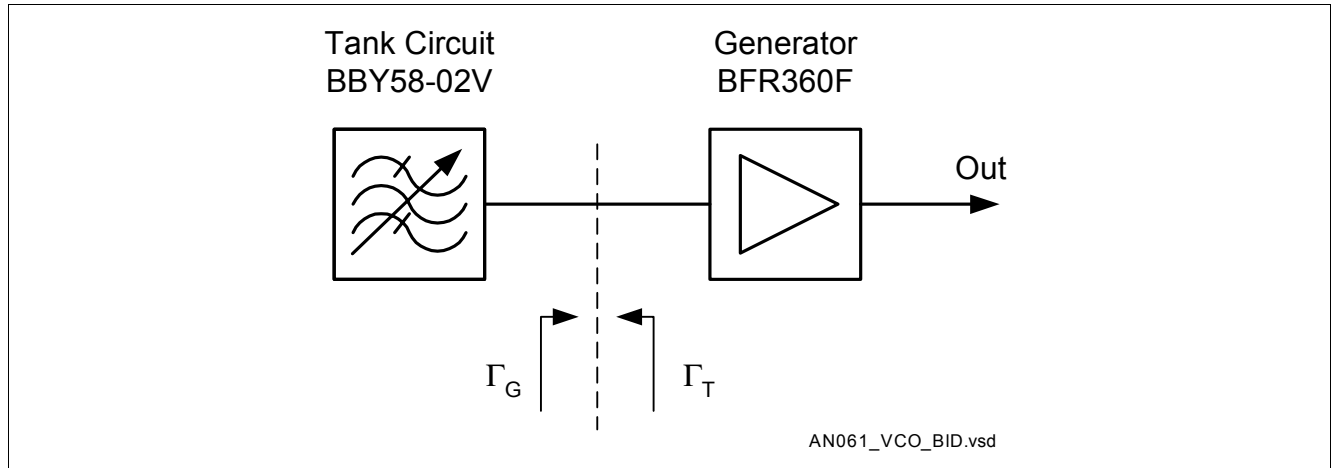
| Name | Value     | Package | Manufacturer   | Function                     |
|------|-----------|---------|----------------|------------------------------|
| C1   | 330 pF    | 0402    | Various        | RF Decoupling                |
| C2   | 3 pF      | 0402    | Various        | RF Decoupling                |
| 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.

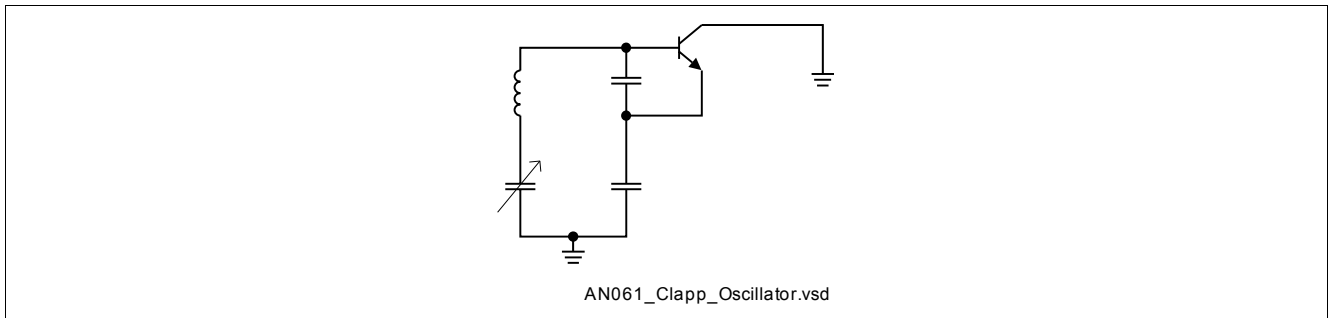
The BBY58-02V diode serves as a voltage controlled capacitor in the tank circuit to enable tuning of the oscillation frequency.

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

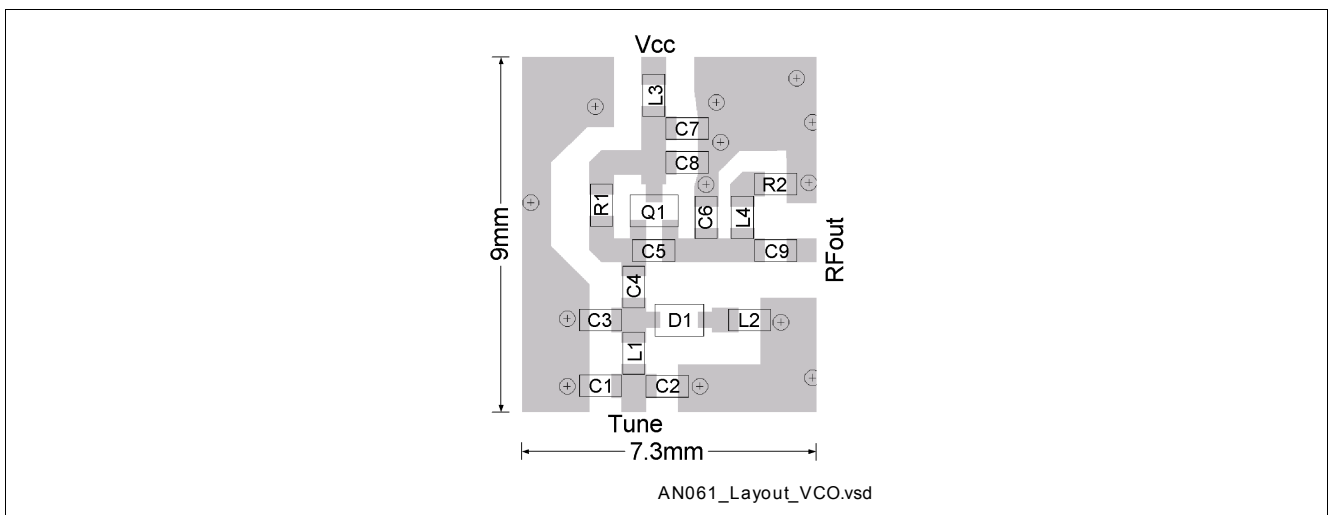
## W-CDMA 2.3 GHz VCO using BFR360F and BBY58-02V


**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



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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

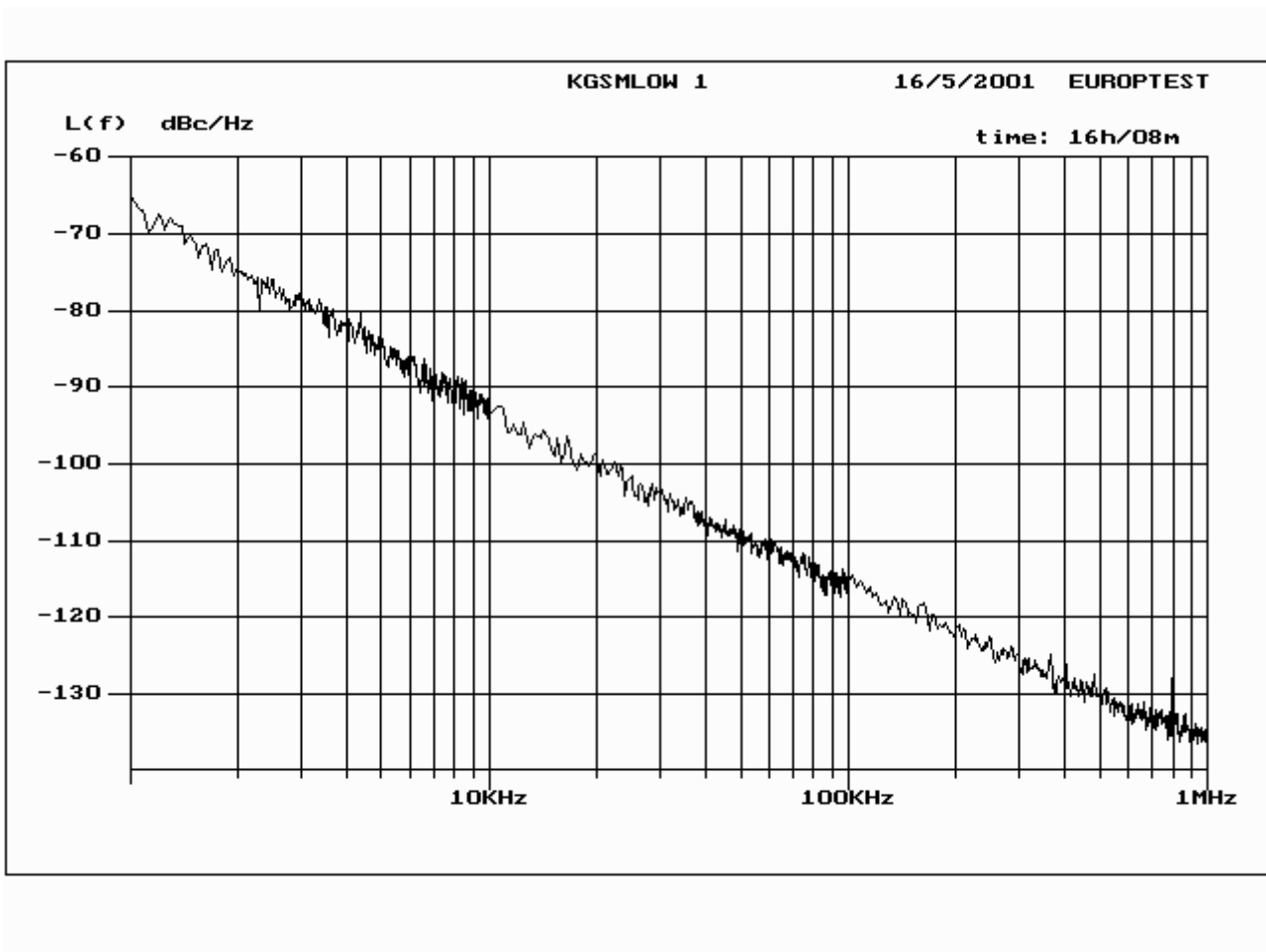


Figure 6 Measured Phase Noise

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

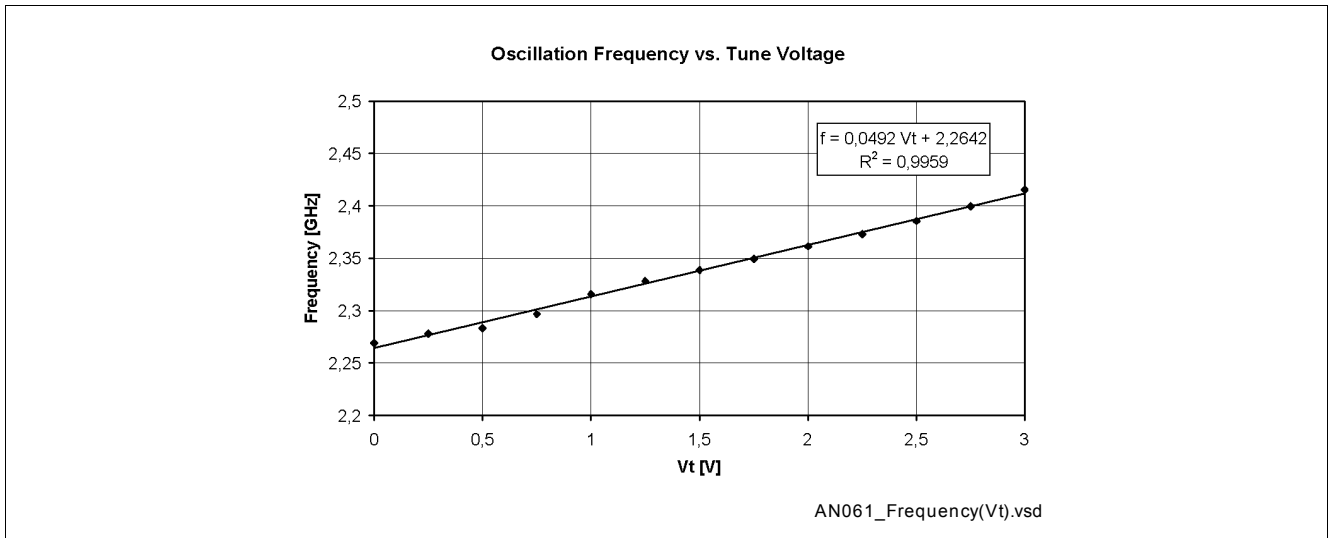


Figure 7 Measure Frequency of Oscillation vs. Tune Voltage

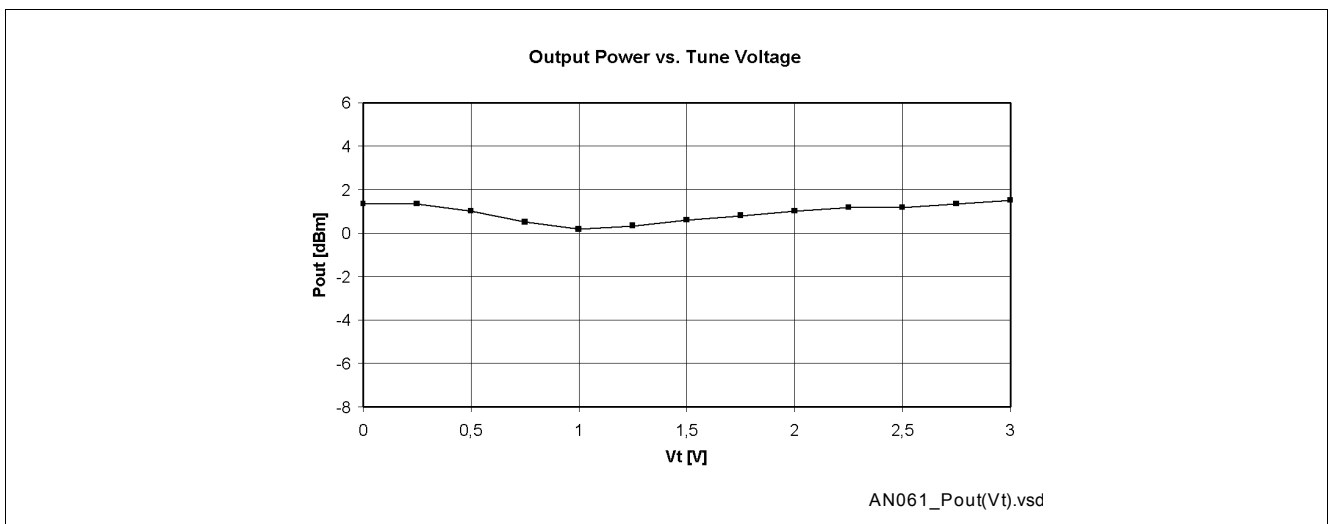


Figure 8 Measured Output Power vs. Tune Voltage

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  $\pm 0.3$  nH, which corresponds to  $\pm 20$  % 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.