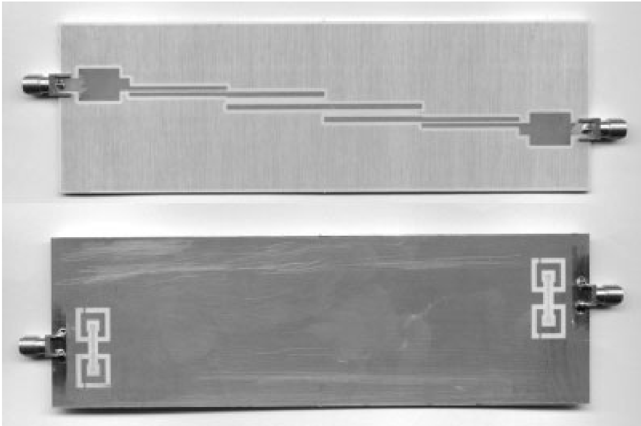

**Figure 8** Photo of the prototype filter

The above parallel-coupled-line BPF embedded with the DGS element in its input and output is simulated and its frequency response is shown in Figure 6 to compare with the structure without DGS. It is obvious that not only the spurious harmonics at 2, 3, and $4\ f_o$ are suppressed, but also the $5\ f_o$, which is mainly because of the wide rejection bandwidth of the zero at the highest frequency. As a result, this filter offers a wide stopband with more than 30 dB attenuation up to $5\ f_o$. The center frequency and bandwidth of the fundamental passband is kept as in the original filter and no significant deviation observed. The measurement results of this prototype filter have been recorded in Figure 7 and are in good agreement with the simulations. It is observed that the spurious passbands from 2 to $5\ f_o$ are suppressed with overall 30 dB attenuation. Thus, the proposed filter outweighs the conventional structure through the multispurious suppression up to five times the center frequency. As shown in Figure 8, the size of the DGS pattern is only 10 mm $\times$ 23.5 mm and is smaller than the needed defected ground size when traditional dumbbell DGS is used to achieve similar stopband performance.

## 4. CONCLUSION

The proposed open-loop outlined dumbbell-shaped DGS element offers three controllable finite transmission zeros. Using this structure for multispurious suppression of BPF, unwanted passbands up to five times the center frequency can be suppressed, without significant circuitry size increase. Also, the simulated and experimental results show good agreement between them, demonstrating the usefulness of the proposed DGS unit.


## ACKNOWLEDGMENT

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# A 24-GHz POWER-EFFICIENT MMIC PULSE OSCILLATOR FOR UWB RADAR APPLICATIONS


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**ABSTRACT:** *A 24-GHz power-efficient pulse oscillator for ultrawide-band (UWB) radar applications implemented with InGaP HBT MMIC technology is proposed. The oscillator uses a common base inductive feedback topology without output buffers. The bias current is switched on by a pulse-control voltage. The oscillator consumes power only when the 24-GHz pulse is generated, allowing high power efficiency to be obtained. A high output power of 8 dBm and a low phase noise of −120 dBc/Hz at 1 MHz offset frequency are obtained in continuous wave (CW) mode. While in pulse-mode operation, the oscillator shows a 1-ns pulse width with only 5 ps of phase jitter.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1412–1415, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22456



**Key words:** *automotive radar; pulse oscillator; ultrawideband*


## 1. INTRODUCTION

Recently, extensive studies have been carried out on ultrawideband (UWB) short-range radar sensors for automotive radar applications [1, 2]. These types of radar generate short pulses by modulating a continuous wave (CW) signal using high-speed semiconductor switches, but suffer from two kinds of key problems. One is that the finite isolation of the switches causes CW-signal leakage when the switches are turned off [2]. The leakage signal radiated from an antenna is reflected from a target and interferes with the receiver's detection. The other key problem is the low power efficiency. Although no signal is emitted to the target during a switch-off period, the CW oscillator operates continuously and much energy is consumed in vain. If the radar transmitter produces a 1-ns pulse with a pulse-repetition frequency (PRF) of 30 MHz, as shown in Figure 1, only 3% of the generated energy is transmitted through the antenna.

A residual-carrier-free burst oscillator consisting of two parts, a cross-coupled LC oscillator and a current switch, was proposed to solve the CW-leakage problem [3]. This oscillator operates only when a control pulse is applied to the current switch, and does not experience CW leakages. However, the oscillator is still power-inefficient, the output buffers and current source continuously

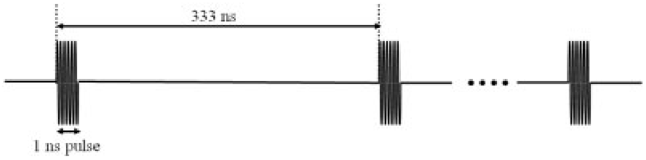



**Figure 1** Timing chart of the transmitted pulses

consume current even when the oscillator is not working. Another pulse oscillator, in which the power supply is directly switched on by the control pulse, was designed on a RO4003 PCB as a hybrid-integrated circuit [4]. The power supply of the oscillator is turned off when it does not work. Thus, the oscillator is power-efficient but the oscillation start-up is very slow [3], mainly because the transistor operates in a saturation region.

In this letter, a power efficient MMIC pulse oscillator, using InGaP/GaAs heterojunction bipolar transistor (HBT) technology, is proposed. The oscillator uses common base inductive feedback topology without output buffers, and a bias current is switched on and off with pulse-control voltages. The oscillator does not use the bias current when it does not work, which leads to high power efficiency. A rapid start-up is achieved by constantly operating all transistors in active-forward and cut-off regions, thus avoiding storage time delays in the saturation region.

## 2. CIRCUIT DESIGN

The oscillator is based on the common-base inductive feedback configuration, which allows high output power when matched to an optimum output load [5], as shown in Figure 2. The oscillation occurs when the following conditions are satisfied:

$$Re(Z_R) < |Re(Z_{in})|/3 \quad (1)$$

$$Im(Z_R) = -Im(Z_{in}) \quad (2)$$

If the following output matching condition is satisfied, the maximum power can be transferred to the output load.

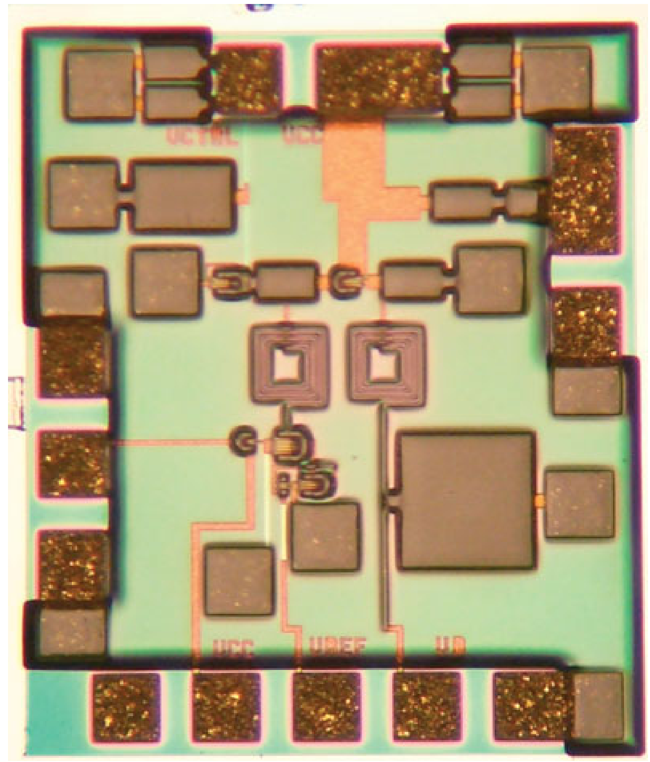


**Figure 3** Photograph of the fabricated pulse VCO. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

$$\Gamma_{OUT} = \Gamma_T \quad (3)$$

A common-base HBT with a microstrip line series inductor ($L_{fb}$) in the base provides negative resistance, making $Re(Z_{in}) < 0$. The length and width of the microstrip inductor are chosen to make the negative resistance large enough to satisfy Eq. (1). An HBT

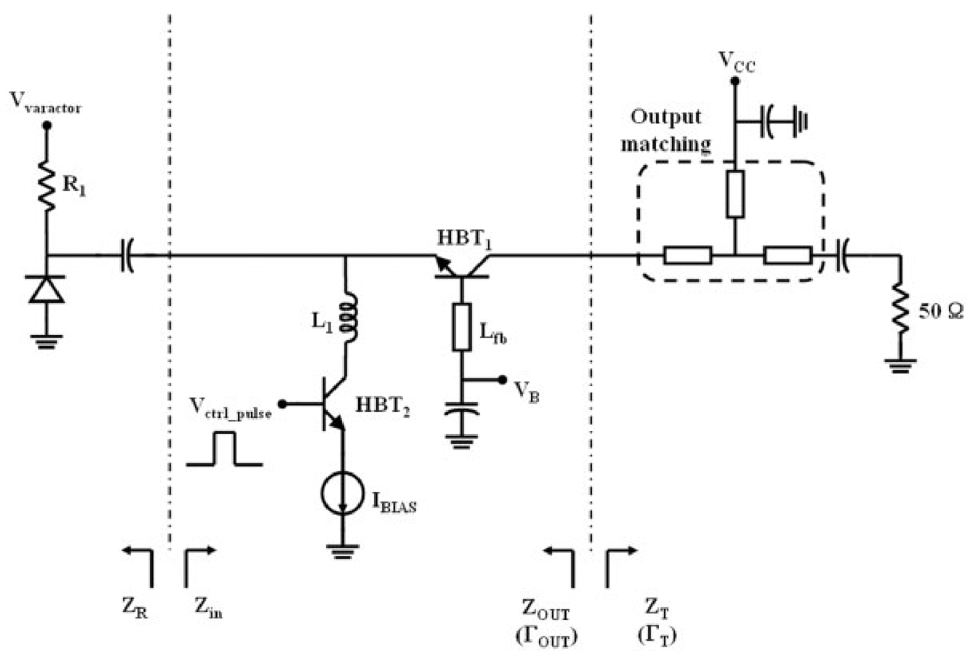



**Figure 2** Schematic diagram of the pulse VCO

collector-base junction capacitor is utilized as a varactor and $Im(Z_R)$ varies with a varactor control voltage $V_{varactor}$. The oscillation occurs at a frequency, which satisfies Eq. (2). The output matching is designed to meet Eq. (3) and the high output power is delivered to the 50-Ω load. A spiral inductor, $L_1$, is inserted between the $HBT_1$ emitter and the bias current switch ($HBT_2$). This inductor provides high impedance near the oscillation frequency, preventing the switch from affecting the operation of the oscillator. In contrast, the inductor provides low impedance at a low frequency, and does not affect the switching and biasing. $HBT_2$ is utilized as the switch responsible for a high speed switching of the bias current $I_{BIAS}$. When the input signal to $HBT_2$ is low, $HBT_2$ is turned off and no bias current flows. On the other hand, when the input signal to $HBT_2$ goes high, the bias current starts to

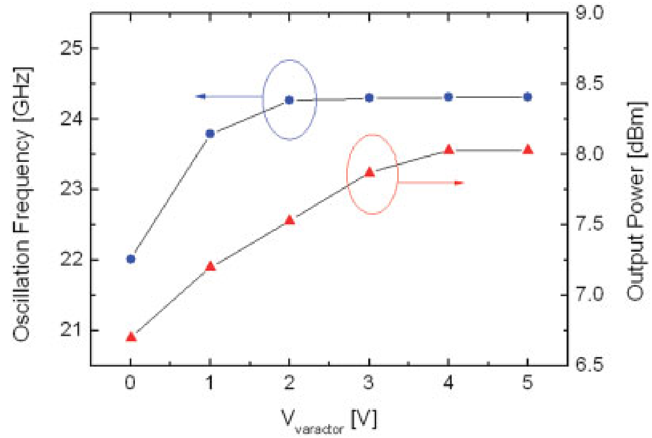
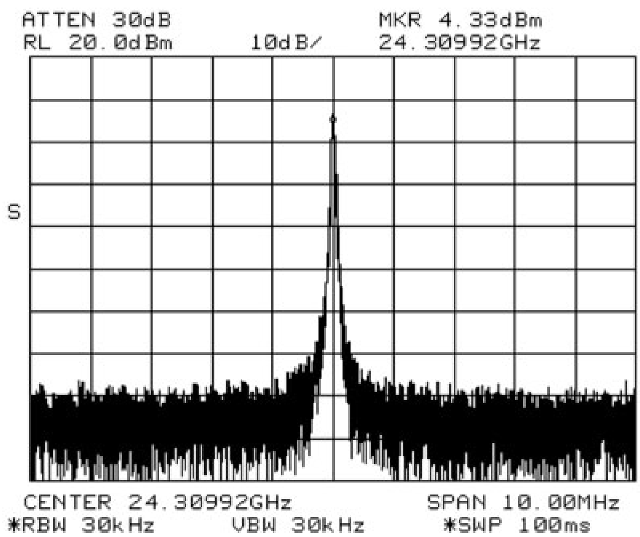
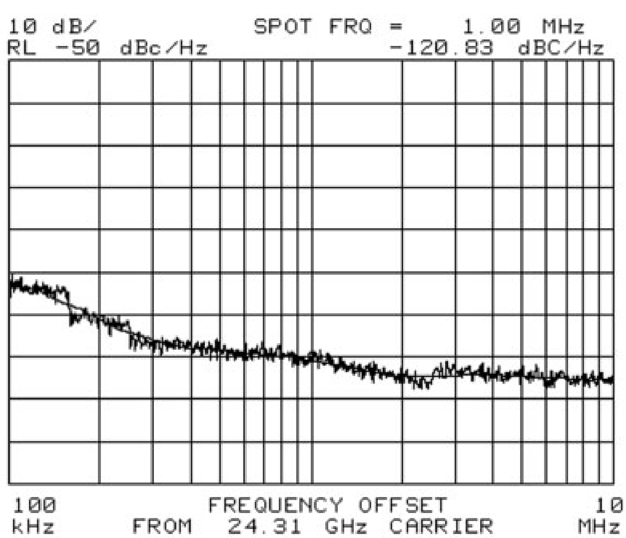



**Figure 5** CW-oscillation frequency and output power of the VCO with the varactor tuning voltage. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]




(a)




(b)

**Figure 4** Measured spectral characteristics of the pulse VCO (a) Measured 24 GHz output spectrum, (b) Phase noise vs. offset frequency

flow and the oscillation occurs, and thus the power saving is achieved.

The pulse oscillator was fabricated using InGaP/GaAs HBT technology of Knowledge* on foundry. An HBT with 2 emitter fingers (2 × 10 $\mu m^2$ each) was used as a negative resistance device. This device has a cut-off frequency ($f_T$) of 50 GHz and a maximum oscillation frequency ($f_{MAX}$) of 80 GHz. Figure 3 shows a photograph of the fabricated MMIC chip. The chip size is 1 × 1.17 $mm^2$.

## 3. MEASUREMENTS OF PULSE OSCILLATOR

The output spectrum and the phase noise performance of the oscillator were obtained by an HP 8564E spectrum analyzer, as shown in Figure 4. The power supply voltage was 5 V and the bias current was 11 mA. The losses of the microprobe, cable, and connectors are measured to be 3.7 dB at 24 GHz. The loss-compensated output power is 8 dBm and the phase noise is −120.83 dBc/Hz at a 1 MHz offset frequency. The oscillator exhibited excellent phase noise performance, compared with the state-of-the-art K-band oscillators using III–V device technology [6]. Figure 5 shows the CW-oscillation frequency and the output power versus the varactor tuning voltage. The frequency tuning range is from 22.01 to 24.32 GHz and the output power variation is within 1.3 dB.

A time domain waveform of the pulse oscillation was obtained with the use of an Agilent 86100C sampling oscilloscope. Figure 6 shows the measurement of a 24 GHz pulse. The input pulse width fed to the switch device $HBT_2$ was 1 ns and the PRF was 62.5 MHz. The pulse oscillator generates very coherent pulses with a phase jitter of ~5 ps. Figure 7 shows the output spectrum of the oscillator in pulse mode. The center frequency is 24 GHz and no LO CW leakage was detected.

## 4. CONCULSION

A 24-GHz power efficient pulse oscillator using InGaP/GaAs HBT technology is presented. This oscillator uses common base inductive feedback topology. The high power efficiency is obtained by switching the bias current off while the oscillator is not in use. The oscillator shows very excellent performance both in the CW mode and pulse-mode operations. In the CW mode, a high output power of 8 dBm, a low phase noise of −120.83 dBc/Hz, and a frequency tuning range of 2.3 GHz are measured. In the pulse mode, the oscillator shows a 1-ns pulse width and 5 ps of phase jitter. The

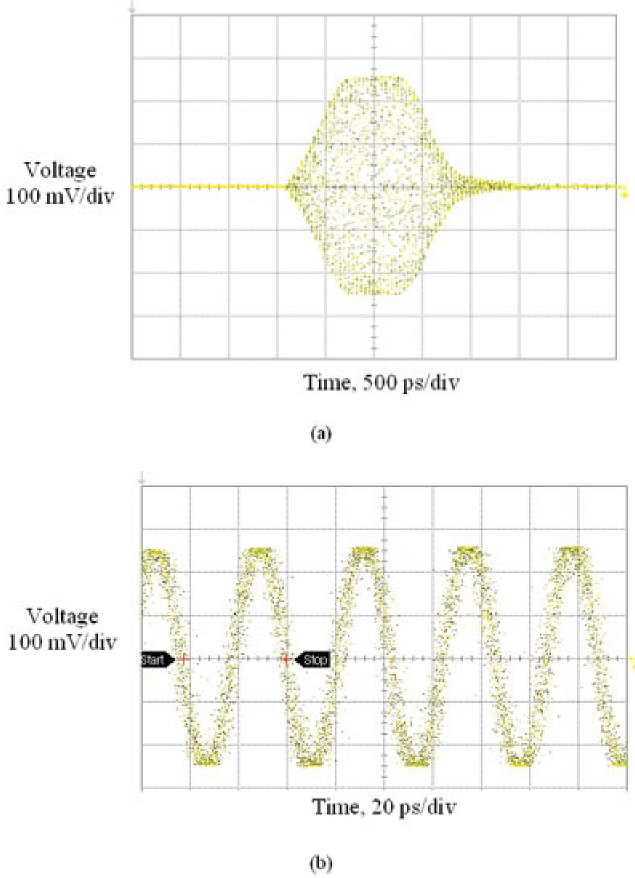



**Figure 6** A 24 GHz pulse waveform (The signal amplitude was intentionally attenuated to show the entire waveform in an oscilloscope window. The real amplitude is approximately 1.4 Vpp). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

proposed oscillator was developed for automotive UWB short-range sensors and can be widely utilized for the sensor system requiring low-power operation.

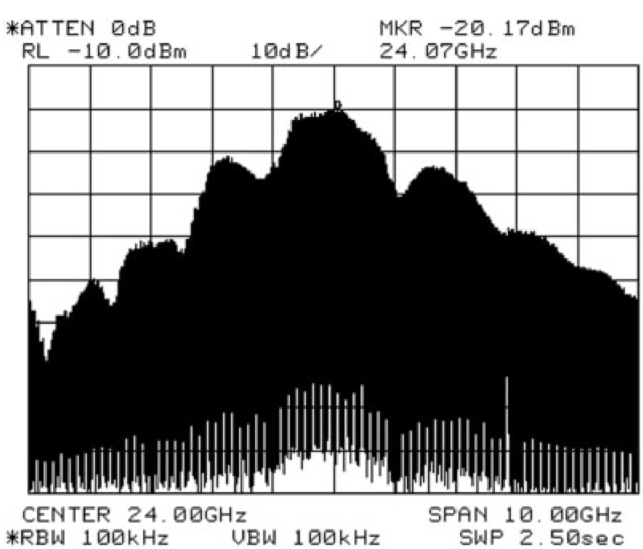



**Figure 7** Output spectrum of the pulse oscillator in pulse mode

**ACKNOWLEDGMENT**

We thank Knowledge* on for offering the InGaP/GaAs HBT foundry services.

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# DESIGN AND FABRICATION OF THE CIRCULARLY POLARIZED MICROSTRIP PATCH ANTENNA

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**ABSTRACT:** *In this article, circularly polarized microstrip patch antenna with a 5.8 GHz frequency for the Industrial Scientific Medical is designed and fabricated. The proposed modified cross-slots antenna composed four separate slots by removing the intersection of the cross-slot in conventional structure. The proposed antenna improved characteristics of the gain, radiation pattern, and impedance bandwidth than the conventional cross-slots antenna. As a result, the proposed antenna obtains impedance bandwidth of 240 MHz (VSWR < 1.5) and maximal gain of 5 dBi.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1415–1418, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22441

**Key words:** *cross slot; aperture coupled; microstrip; circularly polarization; antenna*

## 1. INTRODUCTION

The application of wireless communication is expanding in today's diverse information society. In particular, development with a view to wireless communication is increasing rapidly within industrial and medical fields. Today, wireless frequencies, such as 2.4 and 5 GHz, are jointly used in wireless LAN and medical fields. A microstrip antenna has been selected, amongst many other alternative antennas, for use in a number of fields, since it is lightweight, small with strong surface adhesion, is economical