Low-power, Low-cost and Low-voltage ISM Band Oscillator Using Discrete Components and a Miniaturized Resonator

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ABSTRACT

In this paper, a low-voltage and low-power 2.4 GHz LC-oscillator using discrete components on FR-4 is presented. This LC-Oscillator requires only 1.8V to operate and the optimized layout is implemented on low-cost conventional double layer PCB without using an additional layer for connection between the miniaturized resonator and transistors. The dimension of the PCB is only 32 mm x 21 mm. Measured results show the circuit consumes only 2.56 mW using a supply voltage of 1.8V, with phase noise of -118 dBc/Hz at 1-MHz offset. Further experiment shows that it can operate at 1.1 V with power consumption only 0.69 mW.

INTRODUCTION

For portable RF devices, battery life is an essential factor. In the case of RFID or wireless-powered platforms [1,2,3,4,5], batteries are not used in the receiver/transponder and energy is taken direct from the base station. Energy is salvaged using diode and then voltage is boosted by using multi-stage voltage multipliers. In such cases it is very important to have a very low power and low voltage oscillator to communicate with the base station. Commercial VCO chips usually operate on 2.7 V and more and so their voltage requirement is too high for our purpose [6,7,8]. Several papers for low-voltage and low-power oscillator have been presented using custom IC with CMOS technology [9,10,11,12]. However, a low-voltage 2.4 GHz oscillator using discrete components and low-cost FR-4 are rarely found in the literature. In this paper, a low-power, low-voltage and low-cost 2.4 GHz LC-oscillator using discrete components on double layer FR-4 is discussed. The design is simulated using Microwave Office from AWR. The prototype has been built and measured using the signal spectrum analyzer. The result shows that its performance is very competitive to custom ICs.

OSCILLATOR DESIGN

In the approach presented here, a conventional LC-coupled oscillator is designed using Microwave Office. The resonator is implemented using copper microstrip instead of lumped elements. A discrete NPN silicon RF transistor BFR360F [13] has been chosen for its low cost and availability. Due to the restriction of the package, an additional layer of interconnection is usually needed to implement the crossover connections of the LC-tank and transistors as shown in Figure 1. However, with optimized chip placement and a novel H-shaped resonator, the whole design can be implemented on a single copper layer without any crossover or the need for another layer for interconnects as shown in Figure 2. One of the transistors has been placed upside down so that it simplifies the base-collector connection of the transistors. It also minimizes the number of turns of the connections and hence reduces power loss. The H-shaped resonator is not only an LC tank, but also provides the necessary interconnect for the DC bias of the transistors. The DC supply voltage is connected with an RF-choke on the top-right of the resonator. The total length of the resonator between the transistors controls the oscillation frequency. The distances from the collector to the base and the collector have been optimized to be $\lambda/4$ for maximum signal swing. The width of the segment going into the base has been optimized differently for each transistor to control the gain of each transistor and so obtain a more symmetrical output waveform. The pad sizes are optimized not only for soldering but also aid in impedance matching the transistor whilst minimising the use of components. A 1.2 pF capacitor at the emitter is used to filter-out unwanted second harmonics. A 0.8 pF output coupling capacitor is used to output power to the load whilst minimising resonator loading and Q deterioration. The whole design is implemented on a conventional double layer FR-4 with a dielectric constant of 4.2. Since this layout eliminates the use of wire crossover, a triple layout with middle ground-plate is not required. The dimension of the PCB is only 21 mm by 32 mm and it can be reduced further easily. The miniature resonator dimension is only 8.7 mm by 17.8 mm. And three connectors are used for V_{DD} and V_{BIAS} and RF out. The actual circuit implemented on PCB is shown in Fig. 3.

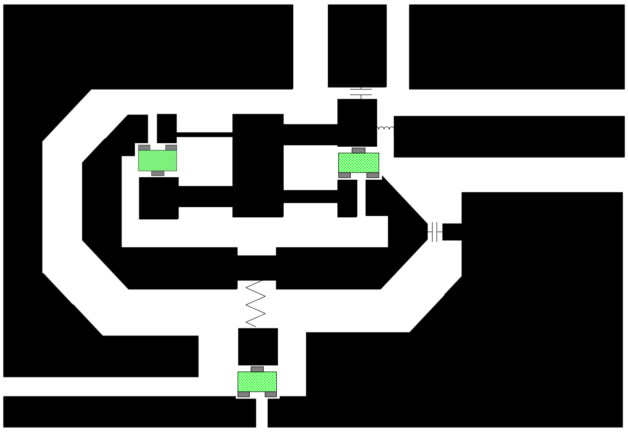


Fig. 2. PCB layout for the LC Oscillator

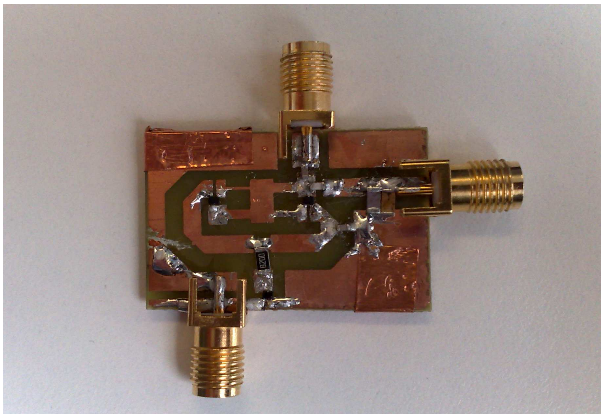


Fig.3 The actual oscillator circuit on FR-4.

The schematic has been simulated using Microwave office with supply voltage 1.8 V. Fig. 4 shows the upper-side-band phase noise performance is -119.7 dBc/Hz at an offset of 1 MHz.

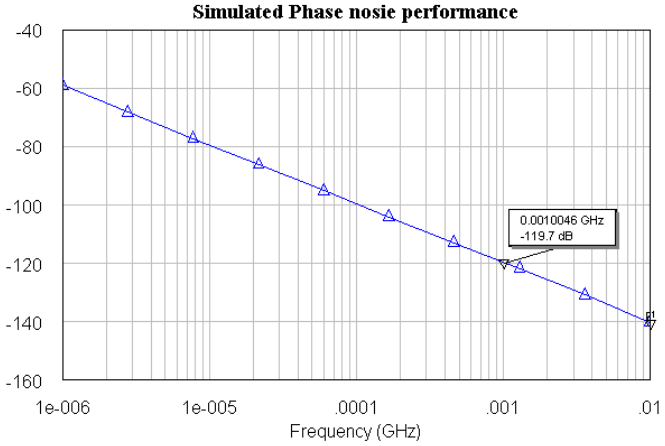
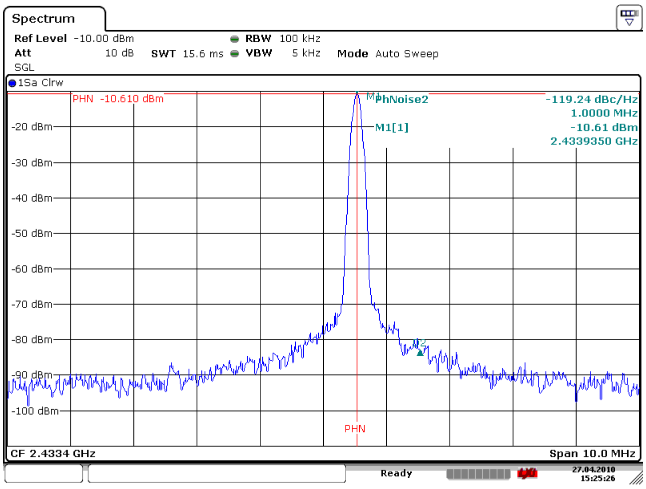


Fig 4. Simulated phase noise performance

MEASUREMENT RESULTS

The Rohde & Schwarz FSV signal and spectrum analyzer was used to measure the phase noise of the oscillator. Figure 5 shows measured phase noise for the oscillator with 1 MHz offset. With a supply voltage of 1.8 V and V_{BIAS} of 0.82 V, the circuit oscillates at 2.43 GHz with a maximum current drawn of only 1.42 mA. This equates to a mean power consumption of 1.8V * 1.42 mA = 2.56 mW. The phase noise for this condition is -119.24 dBc/Hz with 1-MHz offset. The output power is -10.61 dBm as shown in Figure 5.



Spectrum

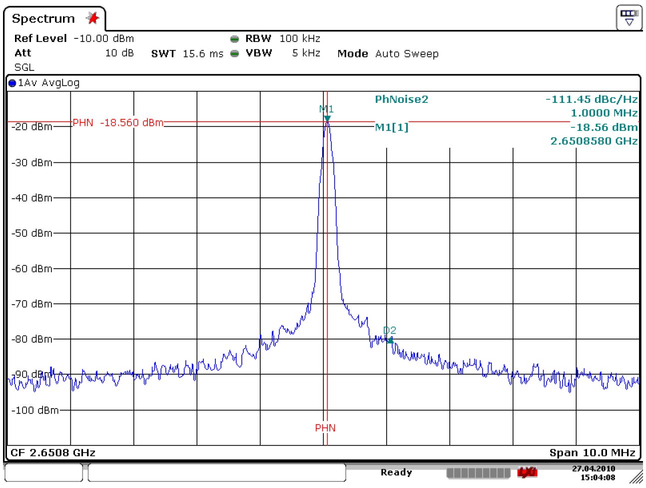
Ref Level -10.00 dBm RBW 100 kHz
Att 10 dB SWT 15.6 ms VBW 5 kHz Mode Auto Sweep
SGL
1Sa Clrw

PHN -10.610 dBm
PhNoise2 -119.24 dBc/Hz
1.0000 MHz
M1[1] -10.61 dBm
2.4339350 GHz

CF 2.4334 GHz Span 10.0 MHz
Ready 27.04.2010 15:25:26

Fig. 5. Measured output spectrum of the 2.43GHz oscillator

The supply voltage is then reduced further to 1.1 V with the same V_{BIAS}. The maximum current drawn is then only 0.63 mA and so the power consumption is less than 0.69 mW with an output power of -18.56 dBm. The phase noise is -111.45 dBc/Hz with 1-MHz offset as shown in Figure 6. However, the frequency drifts to 2.65 GHz due to the change in the DC bias conditions. Future study will be concentrated on further reducing the power consumption with frequency tuning capability. The results are summarized in Table 1[14-15].



Spectrum

Ref Level -10.00 dBm RBW 100 kHz
Att 10 dB SWT 15.6 ms VBW 5 kHz Mode Auto Sweep
SGL
1Av AvgLog

PHN -18.560 dBm
PhNoise2 -111.45 dBc/Hz
1.0000 MHz
M1[1] -18.56 dBm
2.6508580 GHz

CF 2.6508 GHz Span 10.0 MHz
Ready 27.04.2010 15:04:08

Fig 6. Measured output spectrum of the 2.65GHz oscillator

A widely used figure-of-merit (FOM) for comparing VCO performance is defined as

$$FOM = L\{f_m\} + 10\log\left[\left(\frac{f_m}{f_o}\right)^2 P_{DC}\right]$$

where L{f_m} is SSB phase noise at the offset frequency of f_o from the oscillation frequency of , and the P_{DC} represents DC power dissipation in mWs. The FOM of the proposed oscillator is –182.86 dB and the result is competitive to custom ICs.

TABLE I

Measurement Results For Different Conditions

Ref.	V_{DD} [V]	Freq. [GHz]	Power [mW]	PN[dBc/Hz] @ 1MHz	FOM [dB]
This work	1.8	2.43	2.56	-119.24	-182.86
This work	1.1	2.65	0.69	-111.45	-181.52
[14]	-	2.00	3.15	-118.9	-186
[15]	-	2.03	10	-117.0	-177.5

CONCLUSION

The 2.4GHz oscillator presented is a low-voltage, low-power and low-cost implementation using widely available PCB processing equipment and discrete components with supply voltage 1.8 V and power consumption 2.56 mW. Experiment shows that the supply voltage and power consumption can be further reduced to 1.1 V and 0.69 mV. The optimized resonator reduces the overall size and complexity of the layout and allows conventional double layout FR-4 PCB to be used for the design. It shows relatively low-phase noise with low power consumption and low supply voltage which is suitable for RFID or wireless-powered systems without using custom ICs.

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