Oscillator Radiated Susceptibility Analysis By Estimating the Added Phase Noise

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***Abstract*—In this paper the radiated susceptibility of oscillators is investigated in electromagnetic polluted environment. Oscillator is one the most important constituting block in every RF communication device and its operation dramatically defines the total system performance. The radiated susceptibility of oscillator has been analyzed in term of added phase noise to the intrinsic phase noise of the output spectrum, due to external electromagnetic wave illumination. As a source of threat, the electromagnetic radiation output of WiMax antenna is considered and the output oscillation spectrum is investigated. The method is verified by full wave simulations of a PCB mounting a real oscillator in CST software environment. In addition, analytic verification is done to prove the sensitivity of the oscillator while it has its normal operation.**

Keywords: **Electromagnetic Interference (EMI), Printed Circuit Board (PCB), phase noise, radiated susceptibility.**

I. INTRODUCTION

ELECTROMAGNETIC interference (EMI) is defined as unwanted current, voltage, and electromagnetic field which can degrade, obstruct, or limit the effective system operation. Development of using communication systems and resulted electromagnetic spectrum pollution in commercial and home environment necessitate the EMC/EMI investigation of performance degradation on electronic/electrical systems. The performance of a digital/analog systems directly is related to the quality their clock/oscillator signals. These signals act like a beating heart for the systems.

The radiated susceptibility of electronic system implemented on printed circuit board (PCB) should be studied by a measurable quantity. Some studies have been done about the review of subjects in the field of electromagnetic compatibility (EMC) at the IC level in [1], susceptibility of the voltage-controlled oscillator (VCO) is studied as a standalone circuit before being integrated into the PLL in [2]. The amount of EMI on a specific mobile board is measured by a presented method in [3].

Phase noise and jitter play substantial role in RF communications as it can make malfunction in mix circuits. Phase noise can be described as short-term random frequency fluctuations of a signal. It is measured in the frequency domain, and is expressed as a ratio of signal power to noise power measured in a 1 Hz bandwidth at a given offset from the oscillation frequency.

In this paper, we select WiMax spectrum as EMI source that exists in typical environment. This spectrum is illuminated to the oscillator on a PCB and the added phase noise on the output of oscillator are extracted. This result is obtained while the oscillator is working. Also, the superposition of external EMI and working oscillator are considered, simultaneously.

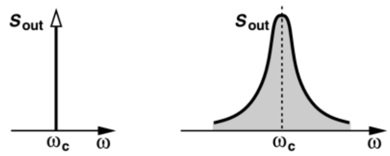
The paper is organized as follows. In Section II the analytic derivation for problem definition is presented. WiMax spectrum and its induced voltage on PCB trace are discussed in this section. Simulation setup and results are done in Section III. Finally, paper ends with conclusion and future works.

II. PROBLEM DEFINITION

The output of an ideal sinusoidal oscillator may be expressed as [4],

$$V_{out}(t) = A\cos[\omega_c t + \varphi] \quad (1)$$

where, A is the amplitude, ω_c is the frequency, and φ is an arbitrary, fixed phase reference. Practically, φ is a time dependent function which is named phase noise. Output voltage spectrum of an oscillator in both ideal and real situation is shown in Fig. 1.



(a) (b)

Fig. 1. Output spectra of (a) an ideal, and (b) a noisy oscillator

The expression (1) may be modified as,

$$V_{out}(t) = A\cos[\omega_c t + \varphi_n(t)] \quad (2)$$
$$V_{out}(t) = A\,(\cos\omega_c t\ \cos\varphi_n(t) - \sin\omega_c t \sin\varphi_n(t)) \quad (3)$$
$$V_{out}(t) \approx A\, cos\omega_c t - A\varphi_n(t)\sin\omega_c t \quad (4)$$

In the mentioned expression, it is assumed $\varphi_n(t) \ll 1$.

Similarly in digital systems alternative definition of phase noise in time domain is clock jitter. Fig. 2 shows eye diagram of digital clock that zero-crossing variation is indicated.

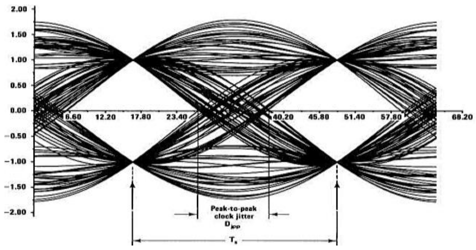


Fig. 2. Signal eye diagram of digital clock[9]

The clock signal synchronizes gates and building parts of digital systems. Similarly, oscillator extract the noisy signal and plays the role of modulation and frequency shifting. Both of these parts act like a beating hearts.

General architecture of a RF receiver is shown in Fig. 3. The generated EMI from Wi-Max antenna and its radiated susceptibility can be represented with the system noise figure parameter. The EMI induced phase noise on oscillator and performance degradation are studied in next section.

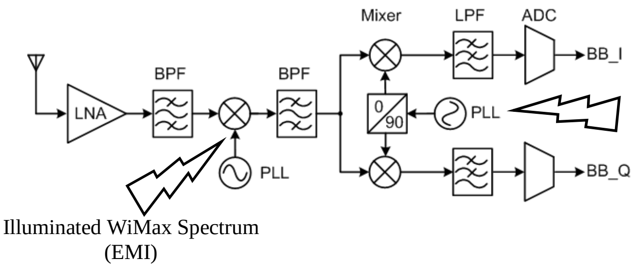


Fig. 3. General architecture of RF receiver [5]

There are several researches about the concept of phase noise and how to model the phase noise [6]. This definitions can help us toward measure the phase noise due to EMI illumination. Output WiMax spectrum that is used to explore the induced phase noise on oscillator is shown in Fig. 4.

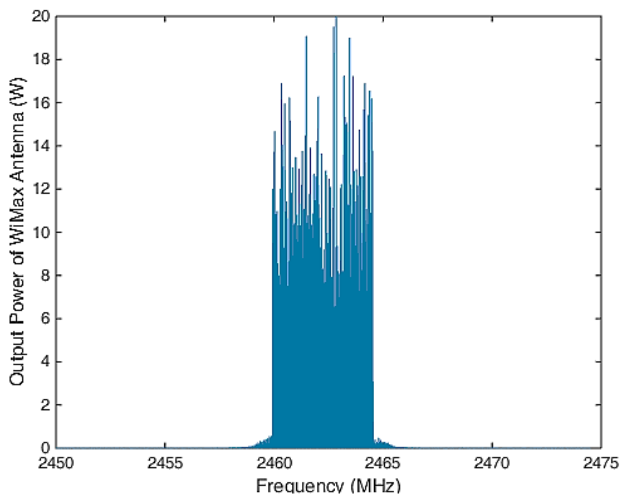


Fig. 4. Output power of WiMax antenna [7]

Fig. 4 shows output power of WiMax spectrum in terms of frequency. The analytical equation for converting the voltage to electrical field can be expressed as,[5]

$$E = \frac{\sqrt{60.G.P}}{r} \quad (5)$$

where, G is the gain of antenna, P is the output of transmitting antenna, and r is the distance between antenna and device under test (DUT).

III. Simulation

The concentration of working frequency of most important communication protocols such as WiMax, WiFi, 3G, and 4G are around 2.45GHz.This congestion of protocols encourage us to select a WiMax spectrum as unwanted EMI signal which is normally exist in civil, hospital, office area.

A predefined system include of an oscillator and driver with precise measures and materials selected as DUT as shown in Fig. 5. This circuit is designed in CST STUDIO SUITE for full wave simulations.

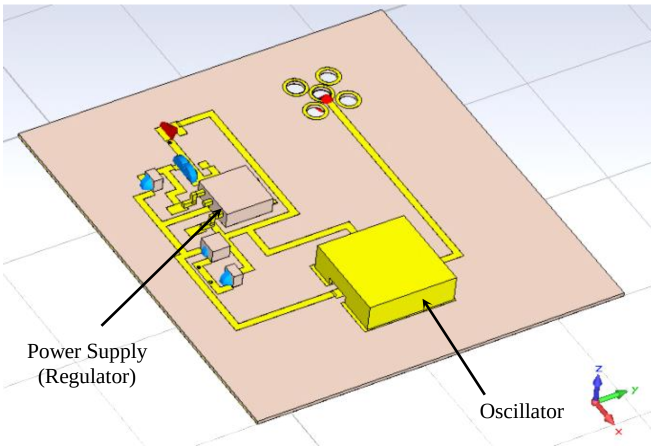


Fig. 5. Device under test include of an oscillator, power supply and SMA connector

In the simulation process, for illumination the unwanted EMI signal to the PCB as excited signal, we need to convert the output voltage of WiMax spectrum to electrical field. In this regard, the output power of antenna in WiMax spectrum for a typical one is 43dBm (20Watts). Also, it is assumed $G = 1$ and $r = 100m$. Therefore, with using expression (5), [5]. The corresponding electric field of the WiMax spectrum, using (6) is shown in Fig. 6.

$$E_{WiMax} = \frac{\sqrt{60P_{WiMax}}}{100} \quad (6)$$

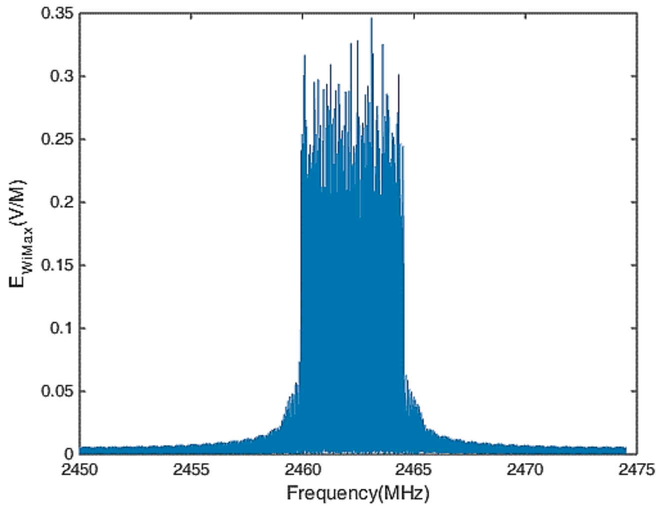


Fig. 6. Output electrical field of WiMax spectrum

The calculated electrical field (E_{WiMax}) should be fitted to obtain the function of electrical field. Illumination is needed to be in form of time to use in CST STUDIO SUITE, that is why we get Fourier transform. The fitted WiMax spectrum for electric field in frequency domain and its time domain are,

$$E_{WiMax}(f) = a \times exp\left(-\frac{(f-f_c)^2}{c^2}\right) \quad (7)$$

$$E_{WiMax}(t) = \frac{1}{\sqrt{\pi}} \times exp(-\pi(ct)^2 + j2\pi f_c t) \quad (8)$$

It is assumed, $f_c = 2462.25$ MHz. Coefficients of equations (7) and (8) are shown in Table 1.

Table 1 Estimated index of fitted function of electrical field

Index	Value
a	35.2 mV/m
c	2.755e6

This excitation signal illuminated to the PCB of Fig. 5. The induced voltages on the output of oscillator is extracted while the oscillator was working. Therefore, the result is the superposition of both induced voltages and the oscillator output signal.

In order to obtain the induced voltage on oscillator analytically, electrical field must be derived as (9), [5]

$$V_{induced}(t) = k\frac{d}{dt}(E(t)) \quad (9)$$

Where, k is a coefficient that is related to PCB physical dimension, trace length, and wave parameters. With using (9), and curve fitting application of MATLAB for extraxting the fitted function of induced electrical field in CST, the induced voltage can be written as (10)

$$E_{WiMax}(t) = a \times exp\left(-\frac{(t-b)^2}{c^2}\right) \times \cos(\omega_c t) \quad (10)$$

$$V_{induced}(t) = ak \times exp\left(-\frac{(t-b)^2}{c^2}\right)\left[-\frac{2(t-b)}{c^2}\cos(\omega_c t) - \omega_c \sin(\omega_c t)\right] \quad (11)$$

From the output data that extracted from simulation of PCB in front of WiMax electrical field with using curve fitting, the fitted index has been derived as shown in Table 2,

Table 2 Extracted index of voltage function in time domain

Index	Value
a	−0.6957 V/m
b	3.643e6 (s)
c	-0.6301e6 (s)

In order to obtain frequency domain of induced voltage at the oscillator output, (10) and (11) are inverted in frequency domain. Therefore,

$$E_{WiMax}(f) = \left({}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f-f_c))^2 - j2\pi(f-f_c)b\right) + {}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f+f_c))^2 - j2\pi(f+f_c)b\right)\right) \quad (12)$$

$$V_{induced}(f) = k(j2\pi f)\left({}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f-f_c))^2 - j2\pi(f-f_c)b\right) + {}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f+f_c))^2 - j2\pi(f+f_c)b\right)\right) \quad (13)$$

We select the oscillator (ROS-2550-519+) for our simulation. The physical structure and its electrical characteristics are obtained from its datasheet. To consider the intrinsic phase noise of the oscillator, different phase noise at four offsets are extracted. The approximate function is obtained as (14), also the phase noise at offset of the oscillator is shown in Fig. 7.

$$P_{output} = -b \times \left|-\left((f-f_0) \times 10^{-3}\right)^a\right| + 4.25 \quad (14)$$

We have fitted the phase noise of the oscillator from the datasheet and the result is shown in Table 3.

Table 3 Estimated index of output power of oscillator

Index	Value
a	1.041×10^{-3}
b	67.6265
f_0	2.4688 GHz

Fig. 7(a) depicts intrinsic output power of oscillator which is plotted by MATLAB and Fig. 7(b) represents fitted diagram of output power of oscillator in order to use the related function datas.

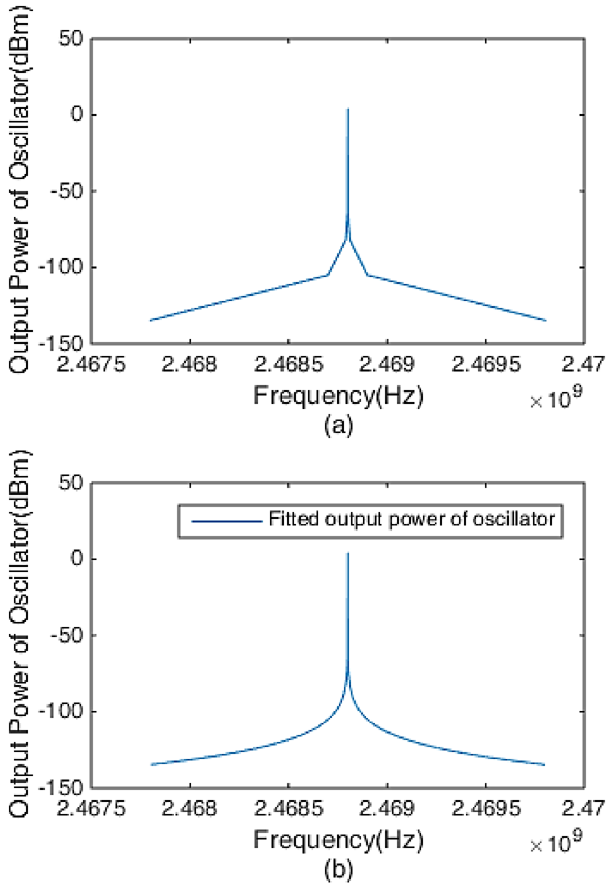


Fig. 7. Output power of oscillator at different offsets

Fig. 8 shows the output of oscillator when it is working without WiMax spectrum illumination.

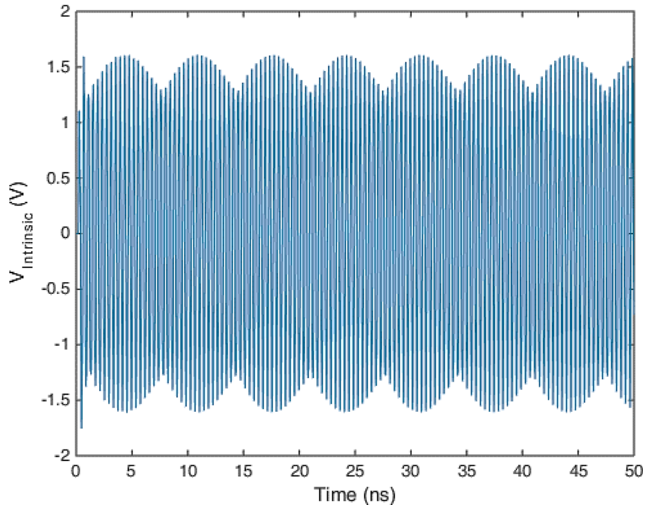


Fig. 8. The intrinsic oscillator output on a 50ohm load

Fig. 9 shows induced voltage of oscillator due to WiMax radiated on PCB when the oscillator does not work.

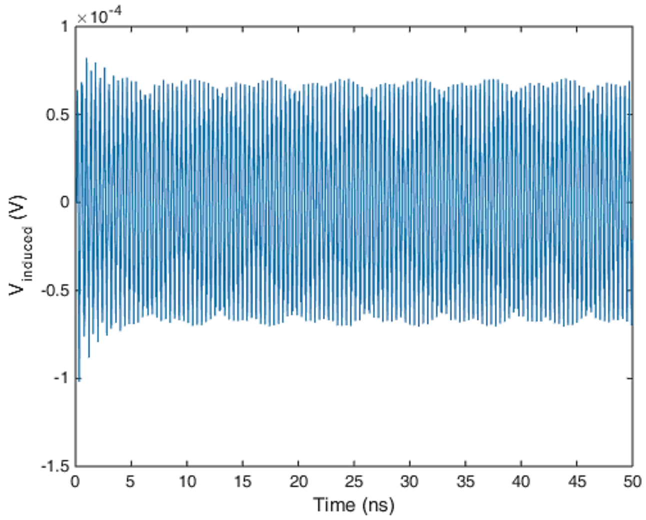


Fig. 9. Induced voltage on the oscillator output

To estimate the added phase noise due to the EMI effect of WiMax illumination on the PCB, the output voltage on output port is converted to the power on the load of the output trace. The load is assumed to be 50Ω. Therefore the output power will be calculated with using

$$P = \frac{V^2}{2R} = \frac{(V_{Inherence}+V_{Induced})^2}{2\times50} = \frac{V^2_{Superposition}}{100} \qquad (15)$$

In general form, the superimposed voltage on the output of the oscillator can be written as,

$$V_{Superposition} = V_{Intrinsic}(f) + V_{Induced}(f) \qquad (16)$$

$$V_{Superposition}(f) = \sqrt{\left(10^{\left(-b\times\left|-((x-f_0)\times10^{-3})^{a}\right|+4.25\right)/10}\times 10^{-3}\right)\times 2\times 50} + k(j2\pi f)\left({}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f-f_0))^2 - j2\pi(f-f_0)b\right) + {}^{1}\!/_{2}\, ac\sqrt{\pi}\, exp\left(-(\pi c(f+f_0))^2 - j2\pi(f+f_0)b\right)\right) \qquad (17)$$

It is needed to convert superposition voltage in frequency domain ($V_{Superimpose}(f)$), in order to compare the output power with oscillator power output and WiMax power output as it depicted in Fig. 10.

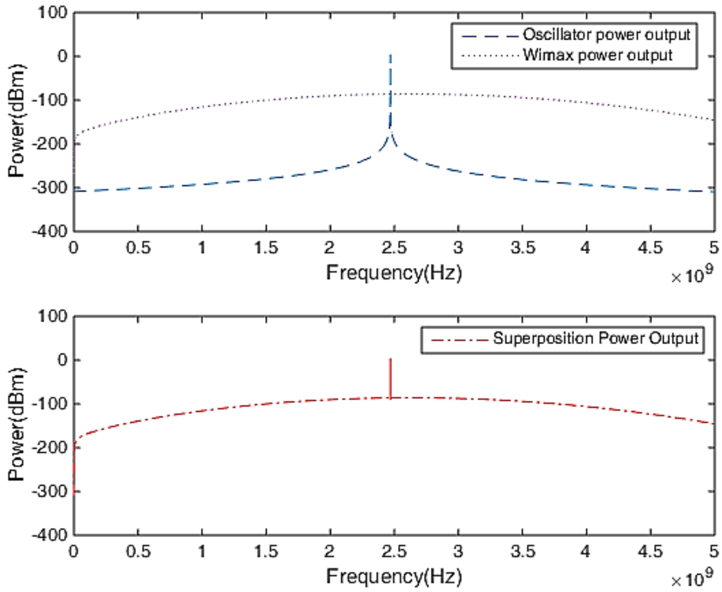


Fig. 10. Superposition output power with WiMax illuminated

Fig. 10 illustrates WiMax spectrum makes an impressive change on oscillator power output. It should be noticed that this result is valid for an oscillator with mentioned specific above and when oscillator is running.

IV. Conclusion and Future Works

In this paper, susceptibility of oscillator against EMI is concerned. Phase noise degradation due to the EMI signal was selected as research topic. WiFi, WiMax, 3G, and 4G communications could be considered as EMI source. Technically, WiMax spectrum has been selected as noisy environment that electronic systems can be affected from this spectrum. Firstly, intrinsic phase noise of oscillator when it was working is simulated. Secondly, oscillator phase noise illuminated by WiMax spectrum has been extracted. Finally, using superposition theory both of mentioned situation was applied in order to find the amount of changes in phase noise. In future works, the amount of changes on output for several types of oscillators in form of equation will be analytically classified.

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