STUDIES ON OSCILLATOR NOISE SENSING AND REDUCTION IN RF CIRCUITS

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by

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Submitted

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Dedicated

to

My Family

CERTIFICATE

This is to certify that the thesis entitled "**STUDIES ON OSCILLATOR NOISE SENSING AND REDUCTION IN RF CIRCUITS**", being submitted by **Mr. Santosh Kumar Bhagat** for the award of **Doctor of Philosophy** to the Centre for Applied Research in Electronics, Indian Institute of Technology Delhi, New Delhi, is a record of bonafide research work carried out by him under our guidance and supervision.

Mr. Santosh Kumar Bhagat has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The results contained in this thesis have not been submitted in part or in full to any other university or institute for the award of any degree or diploma.

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Santosh Kumar Bhagat

ABSTRACT

This thesis discusses new approaches for noise reduction in RF oscillator circuits, Phase Noise extraction and oscillator noise measurement using an enhanced PLL circuit.

First, an efficient low phase noise oscillator design proposed using a high *Q* resonator and harmonic suppression filter. The oscillator is designed using a combined bandpass filter (BPF), which is used as a feedback element to an amplifier. The filter consists of an embedded spur line filter in the L-shaped input and output section which encloses a perturbed square ring. All of these sections are assembled to form a combined BPF which gives an excellent suppression of second and third harmonics. Low phase noise oscillator results are evaluated at 2 V power supply. The measured results show the fundamental frequency at 2.4 GHz, total output power of 14.92 dBm, phase noise −130.7 dBc/Hz at 1 MHz offset frequency, figure of merit (FOM) −175.64 dBc/Hz, reduction in 2nd and 3rd harmonics to below −45 dBm and DC-to-RF efficiency of 51.73%.

In the second part of this dissertation work, A simple method shown for phase noise extraction using a BJT nonlinear Ebers Moll model on a Colpitts oscillator. Simulation results are consistent with Leeson's theory and the magnitude of the sidebands directly scales with the magnitude of input noise. Furthermore the VCO phase noise is analysed with respect to Power supply noise and varactor non-linearity. The simulation shows phase noise is mostly affected at small offsets and in good agreement with the experimental data.

An Enhanced Phase Locked Loop (EPLL) has been used for oscillator noise measurement. The EPLL has two feedback loops: phase locked loop (PLL) for phase estimation and amplitude locked loop (ALL) for amplitude estimation. The presented method has been also used for

estimating fundamental signals along with phase noise and amplitude noise simultaneously. The circuit simulation results were found to be close with the measured results for 100 MHz operations. The measurement results shows that in the steady-state EPLL and PLL shows comparable phase noise at close offset frequencies and at higher offset frequencies.

The EPLL is expected to be useful for on-chip use, in particular with complex systems-on-chip, where in-situ monitoring of oscillator noise is required.

सार

यह थीसिस आरएफ ऑसीलेटर सर्किट, फेज नॉइस निष्कर्षण और एक बढ़ाया पीएलएल सर्किट का उपयोग कर ऑसीलेटर नॉइस माप में नॉइस में कमी के लिए नए दृष्टिकोण पर चर्चा करता है।

सबसे पहले, एक कुशल कम फेज नॉइस ऑसीलेटर डिजाइन प्रस्तावित किया गया है जिसमे एक उच्च क्यू अनुनाद और हार्मोनिक दमन फिल्टर का उपयोग किया गया है । ऑसीलेटर को एक संयुक्त बैंडपास फ़िल्टर (बीपीएफ) का उपयोग करके डिज़ाइन किया गया है, जिसका उपयोग एम्पलीफायर के लिए एक प्रतिक्रिया तत्व के रूप में किया जाता है। फ़िल्टर में एल-आकार के इनपुट और आउटपुट सेक्शन में एक एम्बेडेड स्पर लाइन फ़िल्टर होता है जो एक क्षुब्ध वर्ग की अंगूठी को संलग्न करता है। इन सभी वर्गों को एक संयुक्त BPF बनाने के लिए इकट्ठा किया जाता है जो दूसरे और तीसरे हार्मोनिक्स का एक उत्कृष्ट दमन देता है। कम फेज नॉइस ऑसीलेटर परिणाम 2 वोल्ट बिजली की आपूर्ति पर मूल्यांकन कर रहे हैं। मापा परिणाम 2.4 GHz पर मौलिक आवृत्ति दिखाते हैं, 14.92 डीबीएम की कुल आउटपुट पावर, फेज नॉइस -130.7 dBc / हर्ट्ज 1 मेगाहर्ट्ज ऑफसेट आवृत्ति पर, योग्यता का आंकड़ा (एफओएम) -175.64 डीबीसी / हर्ट्ज, 2nd और 3rd हार्मोनिक्स में -45 डीबीएम से नीचे और 51.73% की डीसी-टू-आरएफ दक्षता में कमी दिखाते है ।

इस शोध प्रबंध कार्य के दूसरे भाग में, कोलपिट्स ऑसीलेटर पर बीजेटी नॉनलाइनियर एबर्स मोल मॉडल का उपयोग करके फेज नॉइस निष्कर्षण के लिए एक सरल तरीका दिखाया गया है । सिमुलेशन परिणाम लीसन के सिद्धांत के अनुरूप होते हैं और साइडबैंड की तीव्रता सीधे इनपुट नॉइस के परिमाण के साथ आनुपातिक होती है। इसके अलावा वीसीओ फेज नॉइस का विश्लेषण बिजली आपूर्ति शोर और वैरेक्टर गैर-रैखिकता के संबंध में किया गया है। सिमुलेशन से पता चलता है कि फेज नॉइस ज्यादातर छोटे ऑफसेट पर प्रभावित होता है और प्रयोगात्मक डेटा के साथ अनुसार मिलता है।

ऑसीलेटर नॉइस माप के लिए एक उन्नत फेज लॉक लूप (EPLL) का उपयोग किया गया है। EPLL में दो प्रतिक्रिया लूप हैं: फेज अनुमान के लिए फेज लॉक लूप (PLL) और आयाम अनुमान के लिए आयाम लॉक लूप (ALL)। प्रस्तुत विधि का उपयोग फेज नॉइस और आयाम नॉइस के साथ-साथ मौलिक संकेतों का आकलन करने के लिए भी किया गया है। सर्किट सिमुलेशन परिणाम 100 मेगाहर्ट्ज संचालन के लिए मापा परिणामों के साथ करीब पाए गए है। माप परिणामों से पता चलता है कि स्थिर स्टेट में EPLL और PLL निकट ऑफसेट आवृत्तियों पर और उच्च ऑफसेट आवृत्तियों पर तुलनीय फेज शोर दिखाता है।

उम्मीद की जाती है कि EPLL चिप के उपयोग के लिए उपयोगी होगा, विशेष रूप से जटिल प्रणालियों-ऑन-चिप के साथ, जहां ऑसीलेटर शोर की इन-सीटू निगरानी की आवश्यकता होती है।

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LIST OF ABBREVIATIONS

SSB	Single sideband
VCO	Voltage controlled oscillator
SNR	Signal to noise ratio
BER	Bit error rate
Q	Quality factor
BPF	Band Pass filter
LTI	Linear time invariant
LTV	Linear time variant
DAE	Differential algebraic equation
PD	Phase detector
PLL	Phase locked loop
DUT	Device under test
ADC	Analog-to-digital converter
EPLL	Enhanced Phase Locked loop
LPF	Low pass filter
FOM	Figure of merit
BJT	Bipolar Junction Transistor
CSRR	Conventional square ring resonator
SMBPF	Single-mode BPF
DMBPF	Dual-mode BPF
BSF	Bandstop (notch) filter
f_0	Fundamental frequency,
IL	Insertion loss
P_{DC}	Total dc power

Δf	Offset frequency
RBW	Resolution Bandwidth
ODE	Ordinary Differential Equation
DSO	Digital storage oscilloscope
MHz	Mega Hertz
PN	Phase Noise
NM	Not Measures
SA	Spectrum Analyzer