MM-wave 61-62 GHz Frequency Generation for Low-power Wireless Electromyography Sensor Nodes

Aditya Gupta, *Graduate Student Member, IEEE* and Amelie Hagelauer, *Senior Member, IEEE*

***Abstract*— This project report presents a method to generate a mm-wave carrier frequency of 61-62 GHz for a low-power biomedical application, specifically for sub-mm localization of electromyography sensor nodes. The proposed method utilizes a sub-harmonic 20.33 local oscillator to generate the higher 3rd harmonic carrier frequency. Simulations demonstrate that the worst-case phase noise and output power are -80 dBc/Hz and -5 dBm, respectively. The total dc power consumption of the VCO core, tripler, and buffer is found to be 12 mW.**

***Keywords*— Millimeter wave integrated circuits, local oscillator, electromyography.**

I. Introduction

From the perspective of medicine and psychology, there is a growing need to develop patient-centric digital diagnostics and therapeutic options. This requires the remote capturing of high-resolution (sub-mm) human motion parameters non-invasively, using radio-based sensor technologies, and algorithmic reconstruction of psychological and behavioral human states based on captured motion information using body function models. This approach requires the real-time acquisition of accurate muscle activity information and its precise location source. However, current human motion analysis systems and radio-based sensor localization systems suffer from multiple design trade-offs, such as measurement accuracy, limited functionality due to form-factor and weight constraints, power efficiency for extended battery lifetime, and bio-compatibility constraints for biomedical telemetry applications. To overcome these challenges, it is necessary to design miniaturized, energy-efficient, localizable electromyography (EMG) transponders that enable real-time acquisition of surface EMG data synchronously with sub-mm range wireless localization.

One of the main challenges in designing such transponders is their energy efficiency. The power-hungry transmitter's RF front-end blocks are required to transmit high output power levels ($\sim$10 dBm) for any practical medium-range ($\sim$10 m) indoor localization environment. Recent work in [1], [2] has demonstrated that mm-accurate sensor localization measurements are achievable with phase-difference based angle-of-arrival (PDOA) based localization methods using narrowband carrier signals. This approach trades the high carrier bandwidth requirement with a large receiver antenna array aperture size to achieve mm-accurate localization. For a given receiver antenna array aperture size, the localization accuracy can be enhanced further by increasing the carrier transmission frequency.

In this project, we aim to design a narrowband, low-power 61-62 GHz carrier signal generator in a 22nd FDSOI CMOS process for a direct-conversion transmitter that will be embedded inside such a an EMG sensor. Table 1 provides the system-level transmitter specifications for this design.

Table 1. Transmitter system-level specifications

Specifications	Description/ values
Carrier frequency	61-62 GHz (ISM band)
Data-rate	5 MSPS
Channel spacing	40 MHz
Modulation format	2-level ASK
Carrier bandwidth	10 MHz
Tx ON/OFF period	10 us / 90 us
Technology	22nm FDSOI CMOS
Output power	10 dBm
Supply voltage	0.8 V
XTAL frequency	13.33 MHz
RMS phase error	10°

II. Project Description

According to the transmitter system-level integrated root mean square (RMS) phase error requirement of 10°, the phase noise for the 61 GHz carrier signal must be below -78 dBc/Hz at a 1 MHz frequency offset. In millimeter-wave direct-conversion transmitters, employing a frequency synthesizer operating at a lower frequency than the carrier proves beneficial. This approach alleviates local oscillator frequency pulling issues, eases the operating frequency constraints for the divider chain within the feedback loop, reduces phase noise due to decreased parasitic effects, and proves more energy-efficient compared to synthesizers operating at fundamental millimeter-wave frequencies [3], [4], and [5]. In the present study, the 61 GHz carrier signal (f_0) is generated from a 20.33 GHz local oscillator ($f_0/3$) by employing a frequency tripler, which suppresses the fundamental tone and second harmonic tone while amplifying the third harmonic.

The block-level diagram of the circuit is illustrated in Fig. 1. The local oscillator employs an NMOS cross-coupled topology. Owing to the narrowband operation of the transmitter, fine-tuning of the oscillator is accomplished using NMOS varactors designed for a nominal KVCO (at $f_0/3$) value of 1 GHz/V. This design minimizes the varactor's contribution to phase noise (due to the AM-PM phenomenon) and reduces sensitivity to supply noise. Furthermore, switched capacitor-based structures are incorporated into the LC-VCO

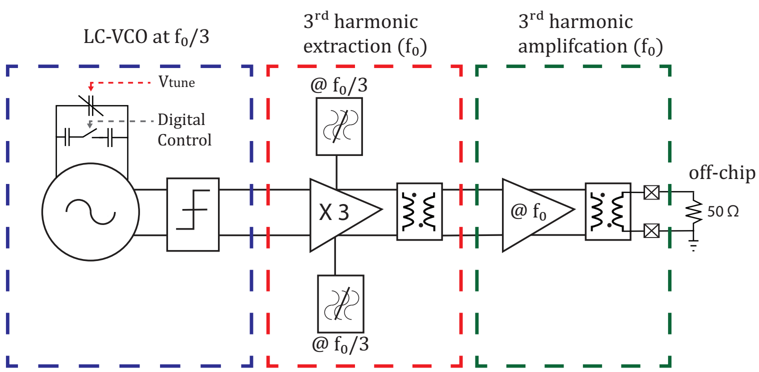

Fig. 1. Block diagram of the 60 GHz frequency generator

Table 2. 61 GHz frequency generator performance summary

Parameters	**Values**
Technology node	22 nm
Output frequency f_0	61-62 GHz
$PN(f_0)$ @ 1 MHz offset	< -78 dBc/Hz
Tuning range	1 GHz
V_{DC}	0.8V
P_{DC} (LC-VCO core + Tripler + Buffer)	12 mW
Output power @ f_0	> -5 dBm

tank to compensate for potential extreme process variations during fabrication.

Non-linear inverter stages are introduced at the output of the LC-VCO to enhance the third-order non-linearity of the output signal without compromising its phase noise. The frequency tripler stage extracts the third harmonic tone at 61 GHz while suppressing the fundamental tone at 20.33 GHz using notch filters. The second harmonic tone at 40.66 GHz is suppressed by implementing a differential topology. A buffer/amplifier stage is integrated at the output to further amplify the extracted third harmonic signal, ensuring a usable voltage swing for subsequent stages following the carrier generator. This buffer stage also facilitates the measurement of the carrier generator output without loading the tripler circuit.

Fig. 2 demonstrates the impact of process corner variations (FF - Fast, Typ - Typical, SS - Slow) on the VCO's frequency response (i.e., pre-trim behavior) and confirms that the desired response is achieved after trimming across the corners. Fig. 3 presents the phase noise performance and generated output power of the 61 GHz carrier signal as a function of the tuning voltage V_{tune}. The phase noise is measured at a 1 MHz carrier frequency offset. The results indicate that the phase noise remains below the desired specification of -78 dBc/Hz throughout the tuning range. Additionally, the output power at 61 GHz exceeds -5 dBm across the tuning range. A summary of the frequency generator's performance is provided in Table 2.

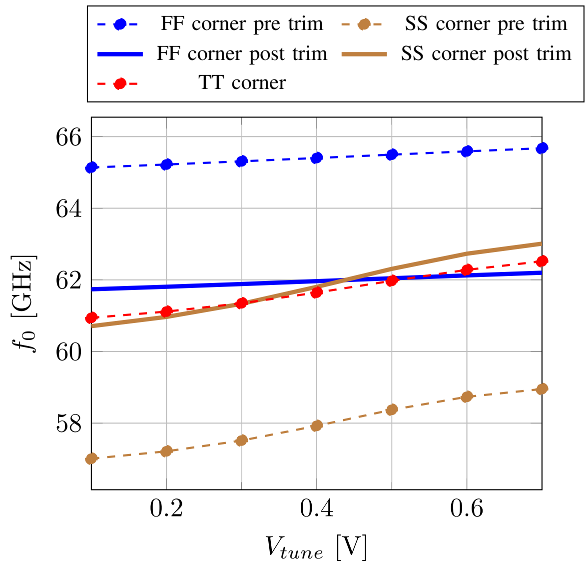

Fig. 2. Frequency generator's response over process variations before and after trimming

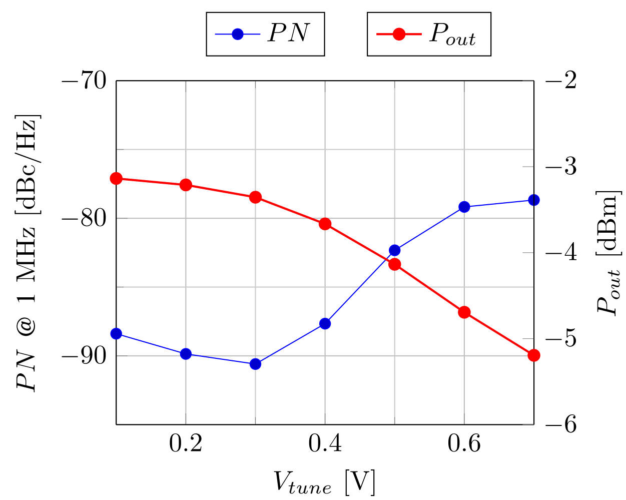

Fig. 3. Phase noise and output power behaviour against the tuning voltage

III. Conclusion

In this project report, a design topology is presented for millimeter-wave 61 GHz carrier signal generation using a 20.33 GHz LC-VCO. By operating the VCO at a lower frequency, this approach enables the development of a low-power integrated frequency synthesizer functioning at 20.33 GHz for phase-locking the carrier signal with an off-chip crystal reference oscillator. In subsequent steps, the measurement results of the proposed design will be obtained, and additional components (phase-frequency detector, charge-pump, divider chain) of the frequency synthesizer will be designed.

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