60 GHz FMCW RADAR-on-Chip

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System level study of a 60 GHz FMCW RADAR-on-Chip was carried out in order to evaluate the parameter trade-offs and define specifications for a short-range low-power application. A RADAR architecture is proposed for addressing the limitations regarding phase noise, flicker noise and DC offset.

Radio detection and ranging (RADAR) systems, which have been developed since the 1930s, have in recent years found their way into consumer electronics thanks to miniaturization. One example where RADARs can be found today is in the automotive industry as part of adaptive cruise control systems. However, there is still a gap in the market due to the lack of low-power, low-cost and fully integrated RADAR-on-Chip (RoC) solutions. This is a research opportunity, considering that there is still substantial room for improvement, in particular, targeting short-range applications, such as gesture recognition and vital signs monitoring. RADARs may be pulsed, continuous-wave (CW) or frequency-modulated continuous-wave (FMCW), the latter is best suited to fully integrated solutions. Pulsed-RADAR uses a transmitted pulse with a duration that is inversely proportional to the desired radial resolution (*e.g.*, 0.15 ns for 22 mm): the average transmitted energy being strongly limited by the relatively low maximum voltage of CMOS technology. Pulsed-RADARs also require a power-hungry, fast ADC, which is often replaced in practice by sample-and-hold circuits for time sweeping of the sampling instant, which tends to lower the speed and overall power efficiency. CW RADARs are limited to Doppler (*i.e.*, velocity) measurement as the ranging capability is missing and the absence of distance discrimination, except for very specific applications, significantly degrades the signal available for processing. The FMCW RADAR scheme provides the minimum peak-to-average transmitted power ratio, with a rather lowfrequency baseband signal that is the sum of beat frequencies proportional to the distance to the reflectors (*e.g.*, 6.7 kHz for 1 m with 1 GHz/ms sweeping slope).

The trend in RADARs is to operate at higher frequencies where larger bandwidths are available. This is advantageous because the radial resolution and accuracy are inversely proportional to occupied bandwidth. Higher frequency operation also corresponds to smaller antennas, as well as, better radial resolution per effective antenna surface area, for steerable or multiple-antenna systems. These are the main reasons for designing our RoC to operate in the millimeter wave (mmWave) frequency range: The license-free 57-64 GHz band is allocated to short range devices (SRD), offering a range resolution of 22 mm. The range accuracy is limited by the SNR due to noise in the receiver chain (*e.g.*, thermal, flicker and phase noise).

Designing at mmWave frequencies imposes a challenge with respect to phase noise. However, the use of a RADAR with a single frequency synthesizer alleviates the problem. Contrary to communications, where one device transmits and the signal is received in another device, RADARs receive the same signal that they transmitted, after reflection off of the target. If the received signal is down converted using the same synthesizer which generated the transmitted signal, the phase noise is correlated. The strength of the correlation depends on the range at which the target is located; the closer the target, the shorter the Time-of-Flight (TOF), the more correlated the signals. Experimental results were obtained using one and two PLLs [1,2]. A comparison of the phase noise at the down-converted Intermediate Frequency (IF) is shown in Figure 1. The measured IF phase noise for the two PLL setup is lower than the calculated value because they were not completely separated: they shared the frequency reference. The measured phase noise for the single PLL case is a good match with the calculated phase noise for high frequency offsets.

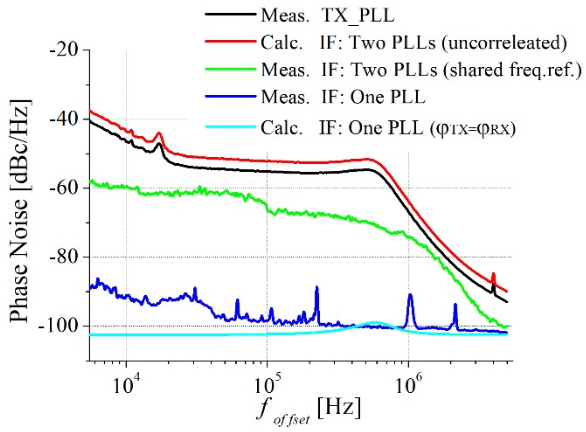

Figure 1: Calculated and measured values of the correlated phase noise.

The SNR attributable to thermal noise is dependent on the transmitted power, as well as, the noise figure (NF) of the receiver chain. Flicker noise optimization and DC offsets are especially important in short-range applications; since the TOF is short, the beat frequency, in practice, falls below 1/f corner frequency. This limitation is addressed by implementing phase modulation, such as BPSK, which translates the beat frequency higher. The RoC architecture and specifications are shown in Figure 2. The first integration in GF 22 nm FDSOI is been planned in Q4 2019.

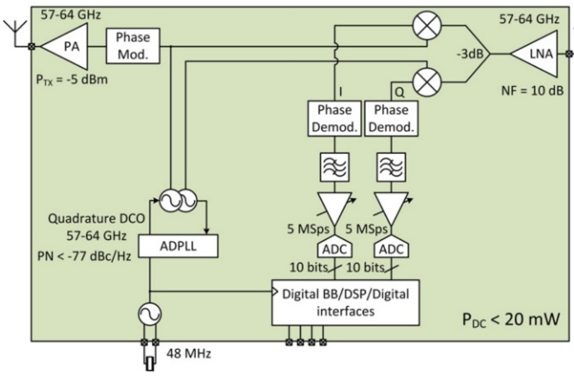

Figure 2: Block diagram of the RADAR architecture.

[1] M3TERA (EU project under GA No 644039) https://m3tera.eu

[2] E. Daskalaki, *et al*., "Measurement principles and hardware considerations for remote vital signs monitoring with a FMCW radar," IEEE Trans. Microw. Theory Tech. Submitted.