11.4 A Regenerative Semi-Dynamic Frequency Divider for Mode-1 MB-OFDM UWB Hopping Carrier Generation

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Multi-band orthogonal frequency division multiplexing (MB-OFDM)-based ultra-wideband (UWB) system partitions the 7.5GHz UWB band into 528MHz sub-bands and transmits signals on hopping carriers [1]. The system calls for high agility to hop from one band to the other in 9ns. The PLL approach for carrier generation is not applicable in this case because of the settling time limitation of the loop. On the other hand, direct frequency synthesis has been used for agile frequency generation, such as satellite transponders. In this paper, the frequency ratio among the 3 carriers in the Mode-1 MB-OFDM operation is studied to directly synthesize the hopping carriers using frequency dividers and single-sideband (SSB) mixers.

A divide-by-7.5 regenerative divider is proposed that produces the required deviation for frequency translation. As shown in Fig. 11.4.1, the proposed synthesizer architecture employs a fixed 3.96GHz sinusoid and generates the deviation of 528MHz, the same frequency of the baseband clock signal in MB-OFDM UWB system [1], to translate the carrier frequency in an SSB mixer. It features the semi-dynamic frequency divider that provides a non-power-of-2 ratio and has the I and Q outputs with symmetric waveforms.

In the Mode-1 operation, the carrier hops among 3.432GHz, 3.96GHz, and 4.488GHz, where there exists a common factor of 264MHz. One simple approach is to set the base frequency at 16 times the common factor, namely 4.224 GHz, and use a series of divide-by-2 dividers and SSB-mixers for the creation of the desired deviation [1]. This translation scheme is to shift 792MHz downwards or 264MHz upwards/downwards the base tone to achieve the desired center frequencies by a SSB-mixer. This architecture uses a cascade of SSB-mixers and the image tone will be at the adjacent sub-band center when the deviation 264MHz is used. Strict orthogonality between the I/Q signal paths and sharp band-pass filtering are required to eliminate the inter-band interferences.

Choosing the base tone at 3.96GHz can alleviate the image contamination problem. The output stage does not need to execute frequency translation when the hopping code is set to the second sub-band. The center frequencies of the other two sub-bands entail the same amount of 528MHz deviation in different directions. It necessitates a divide-by-7.5 frequency divider that has I/Q outputs with symmetric waveforms for SSB mixing.

The regeneration loop is used to realize a semi-dynamic frequency divider. Conventionally, frequency dividers, aside from those with a power-of-2 ratio, are configured as a series of D flip-flops with the signal flow controlled by auxiliary programmed logic circuits. The output waveform loses symmetry from the switching signal paths. As shown in Fig. 11.4.2, the proposed divider is derived from the dynamic Miller frequency divider [2]. To eliminate the extraneous zero crossings, the suppression of the frequency addition term after the mixer needs to be more than 9.5dB with respect to the subtraction term [3]. In the proposed work, the mixer and low-pass filter network are replaced by a SSB-mixer to avoid the challenging task of high-frequency filter design. The feedback signals for the SSB-mixer switching pairs are drawn from the static dividers that further block the inter-

modulation and harmonic terms. The inclusion of N stages of static frequency dividers in the loop facilitates the regenerative modulation of the input sinusoidal signal from f_0 to $\frac{2^N}{2^N+1}f_0$.

The succeeding k_{th} divider will then has the I/Q symmetric waves at the frequency of $f_k = \frac{2^N}{2^N+1}f_0$.

With the regenerative operation, the undesired signals caused by nonlinear and parasitic effects of the circuits will be rejected. In this design, a cascade of divide-by-3 and divide-by-2.5 dividers are used to acquire the desired ratio of 7.5.

The divide-by-3 stage employs an active lower-band SSB mixer together with a current-mode logic (CML) static divider as illustrated in Fig. 11.4.3a. The transconductance stage operates at 3.96GHz and does not require high-swing input signal, which is a challenge in conventional dividers. On-chip spiral inductor is used for the load to drive the CML divider at 2.64GHz. After generating large-swing 1.34GHz I/Q signals, the divide-by-2.5 stage is used to compose the 528MHz frequency deviation as shown in Fig. 11.4.3b. The passive mixer is used in this stage because of its lower power consumption. Two cascaded CML dividers form the feedback path of the regenerative loop. The I/Q 528MHz deviation signals are obtained from the first CML divider. The hopping carrier generator is a SSB-mixer with the multiplexed transconductance stage shown in Fig. 11.4.4. The frequency deviation signal feeds the SSB-mixer in altering polarities controlled by the time-frequency hopping code. When the second sub-band is selected, the switch turns the mixer into an amplifier by replacing one half of the transconductance stages with a fixed tail current and shutting down the other half. On-chip inductors work with switched capacitors as the load to form a programmable band-pass filter that further suppresses image signals caused by unavoidable circuit mismatches.

The carrier generator is realized in a 0.18μm CMOS technology with the core area of 0.8×0.85mm². Figure 11.4.5 shows the die micrograph. Prudent layout techniques are used to balance the parasitic capacitors among the I/Q differential signal paths. The interconnections have round angle bending to avoid parasitic inductor effects. The measurement uses on-wafer GSGSG differential inputs at 3.96GHz injected to the on-chip poly-phase 90° phase shifter to generate quadrature phases. Figure 11.4.6 shows the spectra of the single-ended output when the frequency translation is performed to acquire 3.432GHz and 4.488GHz carriers. The LO leakage causes the adjacent sub-band interference at 3.96GHz. However, based on the double-balance mixer configuration, the differential circuitry mitigates this problem and reduces the adjacent sub-band coupling. The second adjacent sub-band interference is due to the image signal when the SSB frequency translation is conducted. The measured image tone is around -20dBc, which can be further improved by fine-tune mechanism in the programmable bandpass filter. The chip uses a 1.8V supply and consumes 18mW in each sub-band.

Acknowledgments:

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References:

- [1] IEEE 802.15 High Rate Alternative PHY Task Group (TG3a) merged proposal-1, <http://grouper.ieee.org/groups/802/15/pub/TG3a.html>
- [2] R. L. Miller, "Fractional-Frequency Generators Utilizing Regenerative modulation," *Proc. Inst. Radio Eng.*, vol. 27, no. 7, pp. 446-456, July, 1939.
- [3] J. Lee and B. Razavi, "A 40-GHz Frequency Divider in 0.18μm CMOS Technology," *IEEE J. Solid-State Circuits*, vol. 39, no. 4, pp. 594-601, April, 2004.

Figure 11.4.1: Direct frequency synthesizer with semi-dynamic dividers.

Figure 11.4.2: Semi-dynamic regenerative frequency divider.

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Figure 11.4.3: (a) Divide-by-3 circuit (b) divide-by-2.5 circuit.

Figure 11.4.4: Hopping carrier generation output stage.

Figure 11.4.5: Die micrograph.

Figure 11.4.6: Single-ended measurements of the hopping carrier generator when the frequency is translated to 3.432GHz and 4.488GHz.