Optimization of Gilbert Mixer for Wireless 5G communication

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CERTIFICATE

This is to certify that the report titled **Optimization of Gilber Mixer for 5G Wireless Communication submitted by Usakoyala Ram Prasad** to the Electrical Engineering Department, Indian Institute of Technology, Patna, is a bona fide record of his work under my supervision.

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Place: Patna

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OBJECTIVE:

Our project aims to create and deploy a Gilbert mixer suited for 5G wireless networks. High linearity, low noise figure, and wide bandwidth are the primary objectives this mixer will strive to attain to enable effective frequency conversion across the 5G spectrum. To satisfy the strict criteria of 5G communication standards, we also want to optimize the mixer's performance metrics, like conversion gain, isolation, and power consumption. We aim to provide a stable, dependable mixer solution that advances 5G wireless technology via careful design, simulation, and testing.

MOTIVATION:

The motivation for designing a Gilbert Mixer tailored explicitly for 5G wireless communication stems from the critical need for advanced RF components that can effectively handle the unique challenges posed by the 5G spectrum.

In the realm of RF communication systems, mixers serve as indispensable components, fulfilling a plethora of crucial functions such as frequency conversion, modulation, and detection. Traditionally, bipolar transistor-based mixers held sway, but with the rapid advancement of CMOS technology, CMOS mixers have emerged as preferred choices, boasting superior linearity over their bipolar counterparts. Among the array of mixer topologies, the Gilbert cell stands out for its double-balanced structure, offering commendable performance in noise figure, linearity, and conversion gain, particularly in down-conversion scenarios pivotal for RF communication systems.

As the wireless communication market experiences exponential growth and demands a reduction in system cost and size, the significance of RF mixers only intensifies. These mixers, whether active or passive, act as pivotal three-port devices within RF transceivers, facilitating the production of down-converted and up-converted versions of input RF frequencies. Particularly in the design of receiver front ends operating at RF frequencies, paramount considerations include achieving low power consumption, operating at low voltage, and integrating circuits seamlessly. The challenge extends to designing active mixers in advanced technologies such as the 180nm process, where the focus lies on optimizing for high gain and superior linearity while adhering to stringent power and integration constraints.

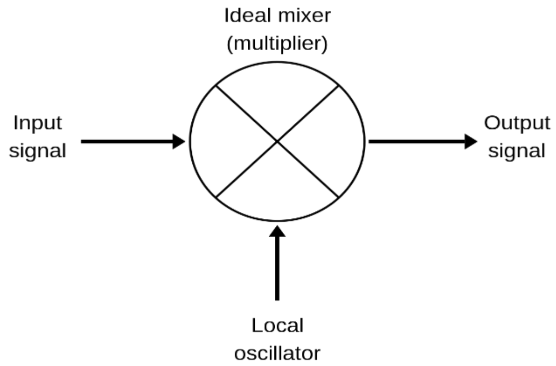
In this landscape of evolving wireless communication systems, the versatility to configure mixers in various circuit topologies remains crucial. Double-balanced mixers, among others, offer tailored solutions catering to diverse applications, including those in ultra-wideband systems necessitating low noise and variable gains. Thus, as semiconductor technology continues to progress and wireless communication systems evolve, the design and implementation of RF mixers stand at the forefront, adapting to meet the burgeoning demands of the industry while striving for optimal performance and efficiency.

Methodology:

Down Conversion Mixer:

- Basic Principle:

A mixer is used for frequency conversion in the RF transceiver. The signal processing can be done in a much lower frequency domain than RF by using mixer frequency conversion, thus reducing the cost and complexity of the circuits. As shown in the Figure below, an ideal mixer is a device that multiplies two input signals, the incoming RF signal is f1 and f2 which is the frequency of the local oscillator and IF is the complex output.



$$V_{RF}(t)=A_1\sin 2\pi f_1(t)$$

$$V_{LO}(t)=A_2\sin 2\pi f_2(t)$$

Multiplication of two signal i,e, local oscillator and transconductance yields:

$$V_{IF}(t)=V_{RF}(t)\times V_{LO}(t)$$

Therefore:

$$V_{IF}(t)=(A_1\sin 2\pi f_1 t) \times (A_2\sin 2\pi f_2 t)$$

$$V_{IF}(t)= (A_1A_2\,[\cos 2\pi(f_1-f_2)t-\cos 2\pi(f_1+f_2)t])/2$$

Where $(f_1\text{-}f_2)$, and (f_1+f_2) are the difference and sum of the frequencies respectively.

From the above equation, the required intermediate frequency is obtained as:

$$V_{IF}(t)= (A_1A_2\,[\cos 2\pi(f_1-f_2)t])/2$$

$$V_{IF}(t)=A_{IF}\cos 2\pi f_{IF}$$

- ## Single Balanced Down Conversion Gilbert-Cell Mixer:

A single balanced down conversion mixer has one of its input signals either RF signal or LO signal applied to a differential circuit so that either LO or RF feed through i.e. unwanted signal at the output is suppressed but not feed through are suppressed. The below figure shows the single balanced down conversion Gilbert cell mixer. The radio frequency (RF) signal first enters the base of the M1 transistor, while the local oscillator signal is supplied to M2 and M3. The input RF signal is converted into current and mixed in with the switching LO signals in M2 and M3. The current is converted into voltage again via the load resistors R1 and R2 and the output exits from the IF output.

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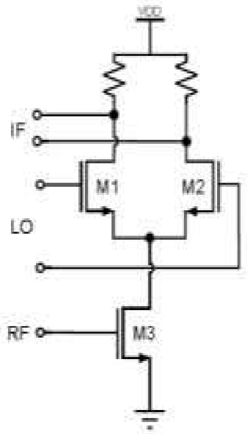
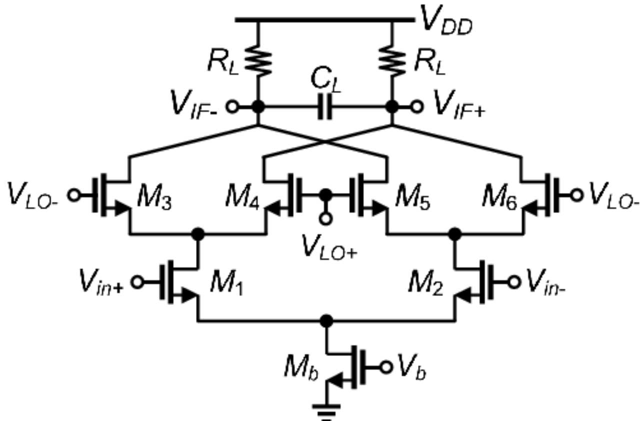


- ## Double-balanced Gilbert mixer:

A double-balanced mixer has both incoming signals i.e. inputs, RF signal, and LO signal applied to the differential circuit. The double-balanced design consists of



single-balanced mixers placed together. The differential RF input is given to the transconductance stage below which has two transistors, and the switching stage has four transistors. Each time the switches change the position the small signal current direction changes through the load resistors and mixes with the LO signal, converting the current into voltage.

The figure shown above has load resistors at the output for converting output current into voltage, we replaced them with P-MOSFET to work as resistors by applying voltages in the required range. So, if we resistors, we can get high gain, but we must use high-valued resistors, which is not preferred. So, we use the MOSFET in the Linear (Triode) region by which we can control the resistance, thus we can achieve high gain through this also, we get a low Noise Figure by using MOSFET than a resistor, as there will be thermal noise if we use resistors. We have adjusted the size of the transistors such that the gain and noise are optimized.

Designed System Diagram and Photographs:

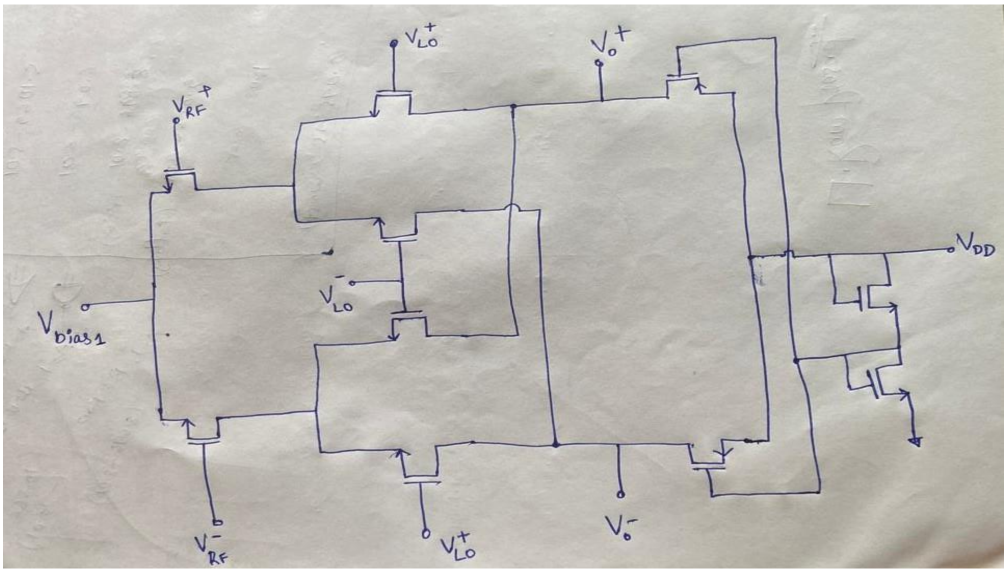
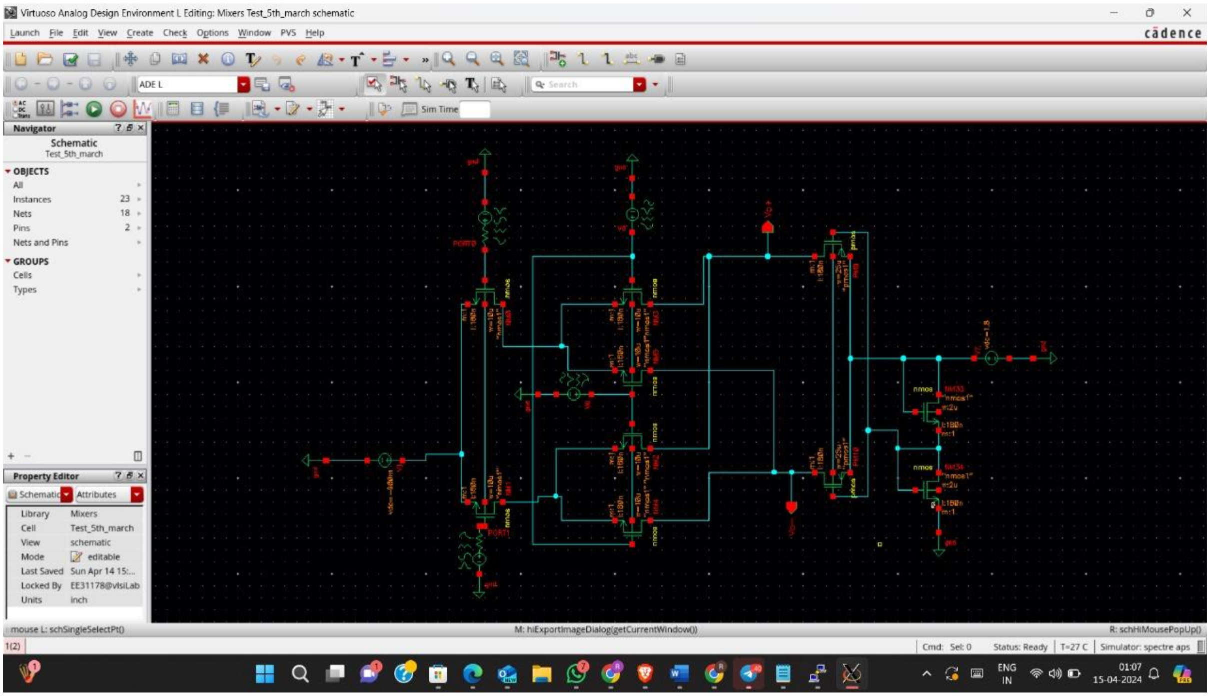


Fig1: Proposed Mixer Design



Results and Discussion:

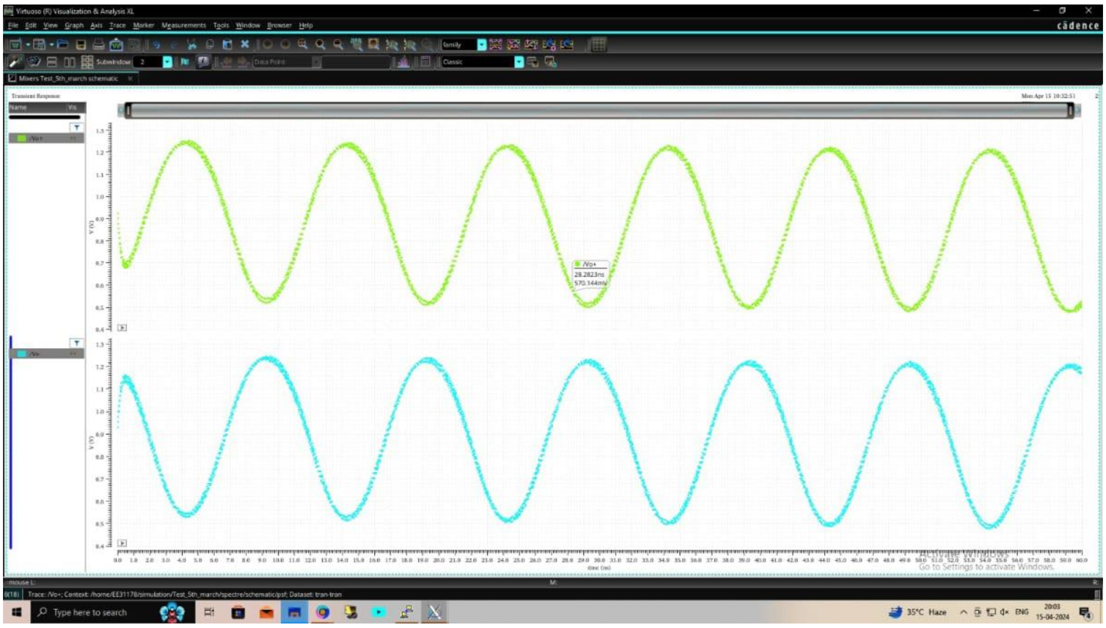


Fig2. Output of the Proposed Mixer

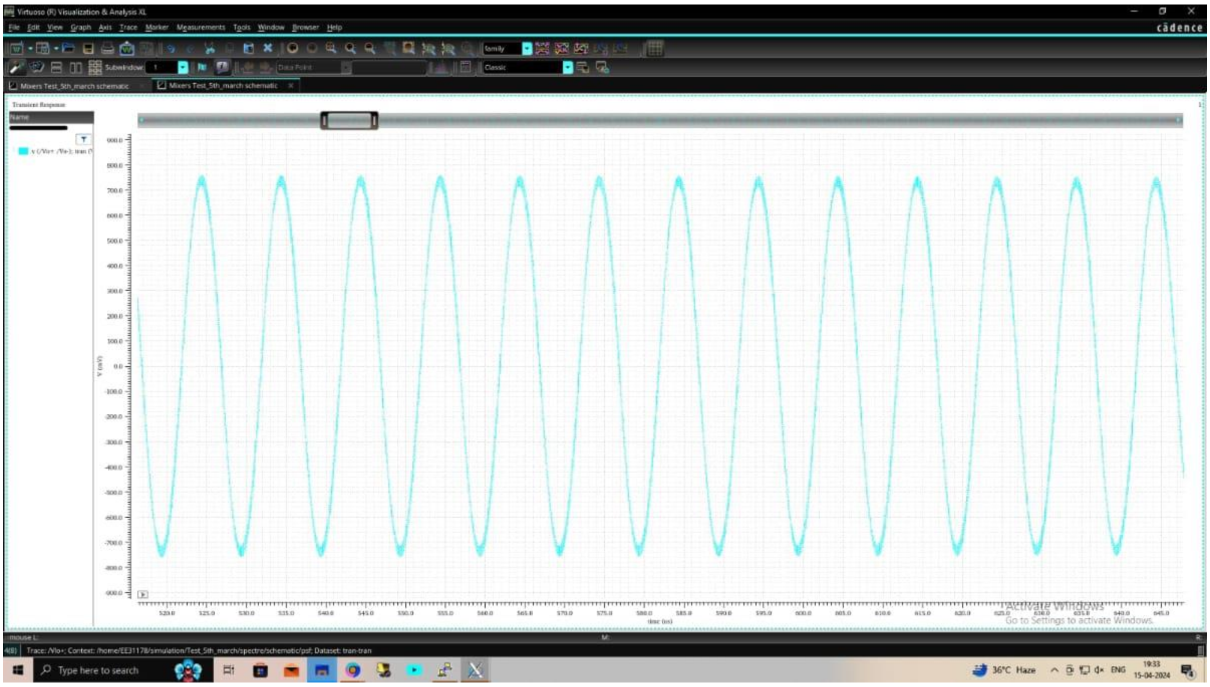


Fig3. Differential Output Voltage of the Proposed Mixer.

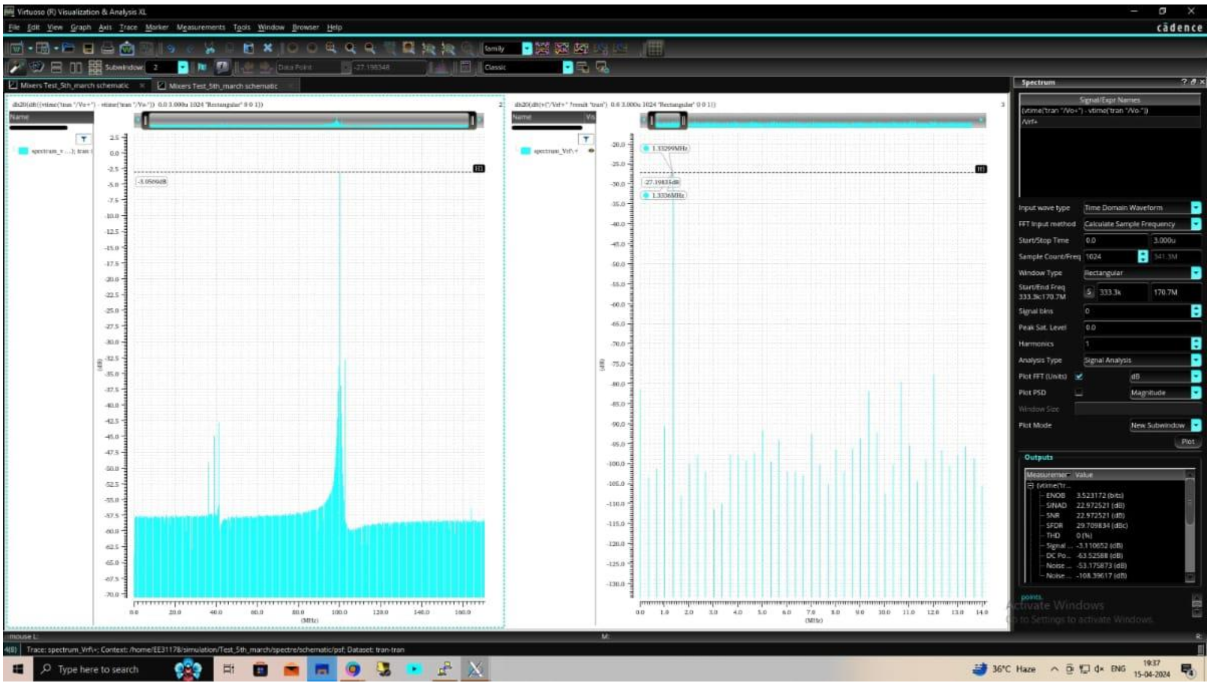


Fig4. FFT of the Proposed Mixer.

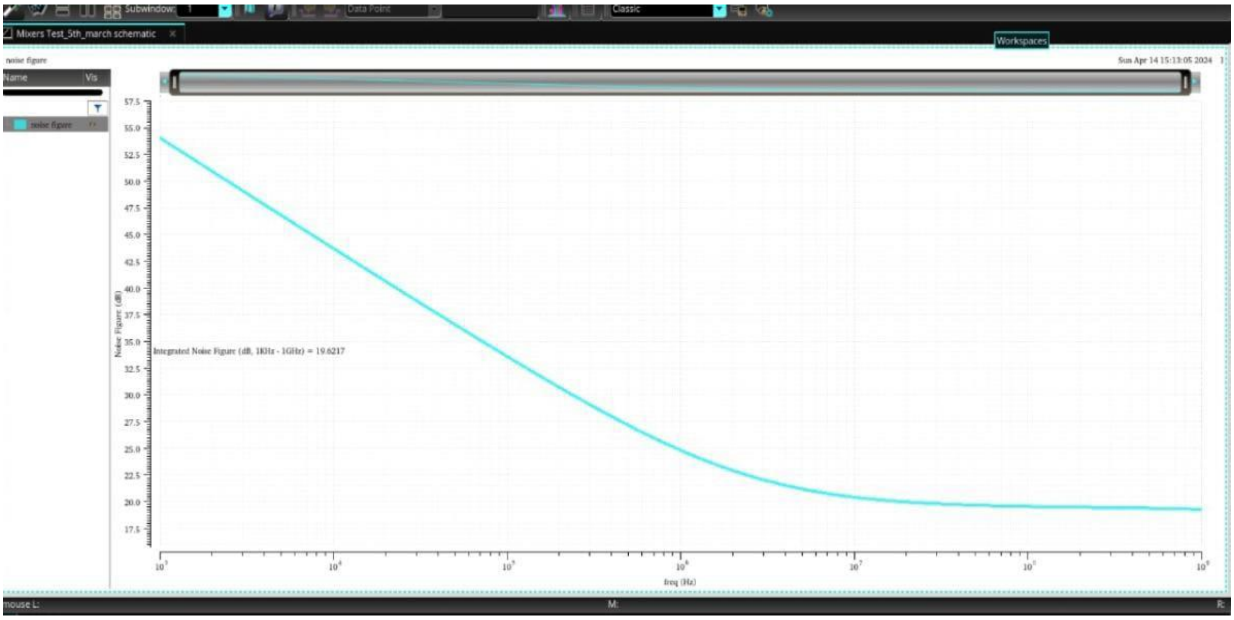


Fig5. Noise Figure of the proposed Mixer

I/p Voltage (V pp)	O/p Voltage (V pp)	Gain (in dB)	Noise Figure
720mv	3.82v	14.682	19.784
360mv	2.73v	18.093	19.784
180mv	2.45v	23.195	19.784
90mv	1.45v	24.1198	19.784

Simulation Results:

The proposed schematic of double balanced Gilbert cell frequency mixer is represented in Fig 1. The conversion gain i.e. voltage conversion gain is measured to be around 24.1198dB as shown in Fig 5. Fig shows the plot of the noise figure of the proposed mixer which is 19.784dB.

The schematic of the proposed double-balanced Gilbert-cell mixer is carried out in 180nm CMOS technology is shown in Figure 1. The virtuoso schematic editor of the Cadence tool is used for schematic design. The schematic is successfully checked, and the results are computed.

Conclusion:

A CMOS double-balanced down conversion Gilbert-cell frequency mixer with input Radiofrequency of 9.9GHz and LO frequency of 10 GHz is designed in 180nm CMOS technology. The Cadence Spectre simulator is used for simulation. The mixer is operated at a low voltage of 1.8V supply. The voltage conversion gain of the proposed double-balanced Gilbert cell mixer is 24.1198dB and the noise figure is around 19.78 dB . Hence the mixer is appropriate in use for the development of the radio frequency receiver front-end application.

Future Scope of Extension:

The future scope for the extension of a Gilbert Mixer optimized for 5G wireless communication is vast and promising, aligning with the ongoing evolution of wireless communication technologies and the continuous pursuit of improved performance, efficiency, and functionality. Here are several potential avenues for extending and enhancing the initial design:

1.6G and beyond : As the industry progresses towards the development of 6G and future wireless communication standards, there will be a need for mixers capable of operating at even higher frequencies, wider bandwidths, and enhanced linearity. Extending the design to support these upcoming standards will be crucial.

2. Advanced Integration: Integrating the Gilbert Mixer with other RF front-end components, such as low noise amplifiers (LNAs), power amplifiers (PAs), and filters, into a single chip or module can streamline system design, reduce footprint, and improve overall performance. Exploring advanced integration techniques such as system-on-chip (SoC) or system-in-package (Sip) architectures could be a future direction.

3. Multi-Standard Support: With the coexistence of multiple wireless communication standards (e.g., 5G, Wi-Fi, Bluetooth) in modern devices, there's a growing need for RF components that can seamlessly support multiple standards. Extending the Gilbert Mixer design to be compatible with various frequency bands and modulation schemes would enhance its versatility and market relevance.

4. Millimetre Wave (mm-Wave) Optimization: As Mm-Wave frequencies become more prevalent in 5G and future wireless networks, optimizing the Gilbert Mixer design for these higher frequencies while maintaining performance and efficiency will be crucial. Future extensions could focus on enhancing the mixer's performance at mM-wave bands and addressing associated challenges such as signal attenuation and interference.

5 Low-Power Operation: Continued emphasis on energy efficiency and battery life in wireless devices necessitates the development of low-power RF components. Future extensions could explore innovative circuit techniques, such as subthreshold operation or dynamic power management, to further reduce the power consumption of the Gilbert Mixer without compromising performance.

6. Advanced Signal Processing: Integration of digital signal processing (DSP) functionalities directly into the mixer architecture could enable advanced signal conditioning and manipulation, such as digital pre-distortion for nonlinear distortion compensation or adaptive filtering for interference cancellation. Future extensions could explore incorporating DSP capabilities into the Gilbert Mixer design to enhance its adaptability and performance in dynamic communication environments.

Overall, the future scope for extending a Gilbert Mixer optimized for 5G wireless communication is characterized by ongoing technological advancements, evolving standards, and the need for increasingly integrated, efficient, and versatile RF solutions to support the growing demands of wireless connectivity.

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