

Advancements and Challenges in Sub-Harmonic Mixer Technology for High-Speed, Low-Power Communication Systems

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Abstract - The wireless communication technologies have been growing rapidly especially in the areas of 5G, IoT, and satellite communications and this has produced piles of pressure on the performance requirements of RF front-end receivers, especially to deliver high-bandwidth, broadband performance, low power. Sub-harmonic mixers can be seen as a major improvement in addressing these requirements in that they can be used to advantage over standard mixers in that they can operate at sub-multiple frequencies than the local oscillator (LO). This gives low power usage, a linearity improvement and an overall sensitivity rise in the receiver. Nonetheless, issues of retaining linearity, noise figure optimization, and low power consumption among others are important areas of future investigation. This paper presents a discussion about the design, the strengths, and weaknesses of sub-harmonic mixers used in contemporary communication systems, and the authors review different reports and compare their performance in the major parameters, conversion loss, linearity, bandwidth, and power consumption. Comparison of the role of sub-harmonic mixers in the shape of high-performance, low-power wireless communications in the future is examined, and how the mixers can be incorporated into the next-generation systems.

Keywords: Sub-harmonic mixers, RF front-end receivers, 5G, IoT, satellite communications, power consumption, linearity, noise figure, bandwidth, figure of merit (FOM).

I. INTRODUCTION

The lightning pace of communication technology has made more and more demand of the emerging technologies which will be capable of meeting the speed at which the need of speed and bandwidth and also the use of less power is getting advanced at a very fast pace. It is especially true in wireless communication networks, such as the new 5G infrastructure, the explosive increase in the Internet of Things (IoT), and satellite communications [1]. The technologies that enable these networks as they trail and expand within their

scope have to remain ahead within the more demanding needs that they are being requested to accomplish. The heart of such systems is called receivers at the front-end and they are tasked with receiving incoming data that could be in the form of radio frequency (RF) signals, converting them into intermediate frequencies (IFs) to allow processing and subsequent examinations [2].

As front-end receivers these mixers are charged with the task of such signal conversion. The traditionally used mixer technique is to apply the input RF signal and the local oscillator (LO) signal and produce the difference and sum frequencies. The kind of technology used in mixers will give it a definitive effect on the overall performance of the receiver due to the direct implication on power consumption, linearity, noise figure, and frequency response. In the current communication systems, a need arises to have mixers with higher speed of operations and with a broader bandwidth with minimum power in mobile and battery-supported gadgets [3].

Sub-harmonic mixers have become an attractive advancement in mixer technology; since they eliminate the power and performance limitations of the traditional mixers. With sub-harmonic mixers, in contrast to ordinary mixers where the ideal LO signal must have the same frequency as RF signal, a fraction of the LO signal frequency, or sub-multiple of it, is used. Some of the key advantages of this method are that they consume less power, noise figure is lower and that they are more linear. Sub-harmonic mixers are hence especially suitable with the performance requirements of a high speed, low power communications system [4].

Semiconductor technology advances have also been the catalyst to the replacement to sub-harmonic mixers, especially the use of new materials like gallium arsenide (GaAs) and silicon-germanium (SiGe) which have improved performance capability (power handling, noise figure, and linearity). These materials provide the background in creation of mixers which operate under severe conditions but are energy saving and convert the signals with high performance. The use of mixers such as these will continue to play a central role in

transforming RF front-end receivers that are capable of supporting the massive demands of the newer networks as wireless communication systems continue to grow with popularity [5].

In addition to the predominant advantage of low power, high linearity, the sub-harmonic mixers possess other performance specifications that render them most suitable in the next generation systems of communication. An example is the sub-harmonic mixers which can operate at LO frequencies lower than the conventional mixers and consume less power overall. It is especially helpful in the case of mobile and IoT devices, when the energy efficiency is a crucial point. Sub-harmonic mixers have also the capacity to provide higher conversion gain hence can be applied in systems where signal integrity needs to be provided even when the system operates at low power levels [6].

Although these advantages do exist, their integration into modern systems of communication is not without challenge. The most critical of these is maintaining high linearity when faced with non-ideal situations such as signal interference and component mismatches. While sub-harmonic mixers are generally more linear than traditional mixers, these do pose challenges to their performance. Scientists and engineers continue to work on ways to improve the linearity of such mixers by employing more advanced circuit design and signal processing techniques to reduce distortion and improve signal integrity [7].

The second challenge is the noise figure of the sub-harmonic mixers, a critical parameter in the overall receiver sensitivity. Although sub-harmonic mixers are proven to provide lower noise figures than usual mixers, ultra-low noise is always preferred in high-performance applications. Various techniques like integration of low-noise amplifiers and noise-canceling circuitry are under investigation in order to reduce noise further and enhance overall performance of these mixers [8].

Power consumption remains an important consideration in the design of sub-harmonic mixers since their application to communication systems cannot occur at the cost of power use efficiency. Although sub-harmonic mixers are more efficient in power consumption compared to conventional mixers, other system components such as power amplifiers and signal processors can affect their real power consumption. To achieve this, existing research focuses on combining sub-harmonic mixers with other low-power components and optimizing signal processing algorithms so that there is minimal power consumption but high performance [9].

Additionally, the miniaturization of communication devices and systems requires that mixers, such as sub-

harmonic mixers, are mounted in increasingly smaller form factors. Advances in microelectronic and integration technologies, like system-on-chip (SoC) designs, are now making it possible to create small, high-performance sub-harmonic mixers that can easily be integrated into small, light devices. This is particularly important in mobile device applications, IoT sensors, and wearable technology applications, where space and power are at a premium [10].

With advancing communication systems, sub-harmonic mixers are poised to be central to high-speed, low-power RF front-end receiver design. Their capability of operating at lower LO frequencies with high linearity and conversion gain efficiency makes them well-suited to meet the requirements of next-generation wireless networks. However, linearity, noise figure, and power consumption are all ongoing research areas. With semiconductor materials, integration techniques, and signal processing algorithms getting better day by day, sub-harmonic mixers should act as a key enabler of future high-performance and low-power communication systems [11].

In brief, the role of sub-harmonic mixers in modern communication systems cannot be overstated. As the need for low-power and high-speed solutions has been rising, these mixers have the potential to be the solution to meeting the cutting-edge requirements of modern wireless communication networks. With the challenges of their implementation having been addressed, sub-harmonic mixers stand poised to revolutionize the performance of RF front-end receivers and aid in the design and development of 5G, IoT, satellite communications, and many others.

II. SUB-HARMONIC MIXER

The sub-harmonic mixer system displayed in Figure (1) is a special architecture deployed to fulfill the demanding requirements of modern RF communication systems. Sub-harmonic mixers are particularly valuable in systems where high performance with less power consumption is important. These sub-harmonic mixers exploit the notion of mixing signals at the sub-multiples of the local oscillator (LO) frequency to enable effective conversion of high-frequency signals to intermediate frequencies (IFs) in particular for high-speed, high-bandwidth communication systems such as 5G, satellite communications, and IoT networks [12].

A. Detailed Operation of Sub-Harmonic Mixers

Sub-harmonic mixers differ in operation from typical mixers, where the LO frequency is equal to or higher than the RF signal frequency. Sub-harmonic mixers, on the other hand, work with a fraction of the LO signal frequency, typically half the frequency, a quarter, or some other sub-multiple of the frequency of the RF signal. This allows it to reduce the

frequency of necessary LO and can result in considerable power savings in systems, and this is necessary in low-power communication systems such as IoT devices or satellite systems [13].

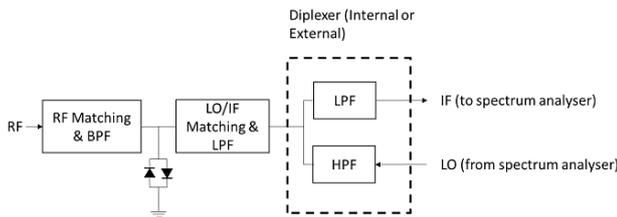


Figure 1: Sub-Harmonic Mixer

When the RF and LO signals cross each other at the mixer, there are produced new frequency components, the sum and difference frequencies. The sub-harmonic nature of the LO allows the system to down-convert the RF signal to an IF signal, which is easier to process. This is crucial because it makes high-frequency signals accessible to a frequency range that is more manageable for subsequent processing stages, such as filtering, amplification, and analysis [14].

The greatest advantage of using sub-harmonic mixers in these applications is that they are capable of decreasing the power consumption requirement of the LO oscillator. This results in the overall power consumption of the system being less, which is most vital in battery-powered systems or energy-constrained systems. In addition, since the LO runs at a sub-harmonic frequency, the operation frequency range can be lowered, and this might make it easier to design certain RF front-end components, especially for those devices which should be compact or function at lower frequency ranges [15].

B. Sub-Harmonic Mixers System Components

The sub-harmonic mixer system is dependent on the various components that are essential in proper conversion of a signal and a good performance of a system. The RF matching and band-pass filtering are necessary to make sure that only the wanted frequencies will be transmitted to the mixer with minimum signal destruction. Effective signal conversion depends on proper LO/IF matching, and the IF signal must be cleaned, eliminate unwanted high-frequency components, by low-pass filtering. The diplexer guarantees good separation of signal between RF and LO so as to avoid interference. Lastly, the IF and LO signals are cleaned using more low-pass and high-pass filters to be analyzed and measured correctly [16]. Table (1) is an overview of the functions of the following components in the system.

Table 1: Sub-Harmonic Mixers System Components

Component	Function	Key Role
RF Matching & Band-Pass Filter (BPF)[17]	Ensures only relevant RF signal frequencies pass to the mixer, matching impedance to reduce reflection and signal loss.	Improves system efficiency and prevents signal degradation from out-of-band noise.
LO/IF Matching[11]	Aligns LO and IF signals in frequency and impedance to ensure efficient signal conversion.	Ensures optimal performance of the sub-harmonic mixer by allowing efficient signal conversion.
Low-Pass Filter (LPF)[18]	Filters the IF signal to block higher frequencies that could result from the mixing process.	Ensures that only the desired low-frequency IF signal is passed to the next stage for analysis.
Diplexer (Internal or External)[19]	Separates RF and LO signals to direct them to the appropriate components without interference.	Preserves the integrity of both RF and LO signals, preventing unwanted interaction before mixing.
High-Pass Filter (HPF)[19]	Filters out low-frequency components from the LO signal, ensuring only relevant high-frequency components pass through.	Ensures that the LO signal received by the spectrum analyzer is clean and free of low-frequency noise.
Low-Pass Filter (LPF) - for IF signal[18]	Cleans up the IF signal by passing only relevant low-frequency components and blocking high-frequency noise.	Prepares the IF signal for accurate analysis and prevents contamination from high-frequency noise.

C. Key Advantages of Sub-Harmonic Mixers

Sub-harmonic mixers have a number of unique benefits, which makes them an almost necessary part of the modern day communication system. The first advantage is that they are power efficient since they consume less power compared to other power-sensitive applications such as mobile phones, satellite communications, and IoT devices since they operate in LO frequencies, which are sub-multiples of the RF signal.

Moreover, these mixers also offer better linearity which decreases signal distortion, and is key in high-performance system including 5G and satellite communication systems [18]. They can also operate with lower LO frequencies which also helps in miniaturization since more integrated designs can be achieved in space limited applications. Lastly, the versatility of the sub-harmonic mixers is also a significant benefit since mixers can be used in various frequencies; hence their use in a wide range of applications, such as 5G networks and satellite communications, as well as radar blocks [20]. These are the main benefits as shown in Table (2).

Table 2: Key Advantages of Sub-Harmonic Mixers [8]

Advantage	Description	Key Benefit
Power Efficiency	Operate at sub-multiple LO frequencies, reducing power consumption in the LO.	Highly suitable for power-sensitive applications such as mobile devices, satellites, and IoT sensors.
Improved Linearity	Provide better linearity than traditional mixers, reducing distortion and improving signal quality.	Essential for systems requiring high-quality signals, such as 5G networks and satellite communications.
Miniaturization	Utilize lower LO frequencies that simplify RF front-end designs, enabling more compact solutions.	Ideal for space-constrained applications like mobile phones and small IoT devices.
Versatility	Capable of operating across a wide range of frequencies, supporting different communication standards and bands.	Suitable for a variety of applications, from 5G networks to satellite communications and radar systems.

D. Applications in Modern Communication Systems

Sub-harmonic mixers are gaining more importance in several sophisticated communication and detection networks. They assist in supporting large bandwidth/fast speed demand of these systems in 5G networks by assisting with power-efficient signal conversion without sacrificing quality of signal. This also adds a lot to the efficiency of 5G base stations as well as mobile handsets and makes the communication smoother and faster. Sub-harmonic mixers have a major role in establishing an effective communication

system in satellite communications, ensuring a quality signaling and power-efficient communication channels which form the major criteria of effective communication with the satellites [21].

Sub-harmonic mixers, a low power solution, are applicable to RF signal conversion in IoT (Internet of Things) applications where large numbers of devices use limited battery power. They are low-power and small, which makes them a perfect choice to be inserted in small and battery-powered IoT devices, and hence improve the overall energy efficiency of the system. In the same vein, sub-harmonic mixers are very linear and low power consuming thus becoming useful radar systems. They are especially significant when it comes to radar, where it is vital to process and detect signals on different distances. Sub-harmonic mixers make the system more efficient and offer the optimum performance [22]. Table below gives an overview of the sub-harmonic mixer applications within these systems.

Table 3: Applications in Modern Communication Systems

Application	Description	Key Benefit
5G Networks[23]	Sub-harmonic mixers enable high-bandwidth and high-speed operation by reducing power consumption while maintaining signal quality.	Enhances the operational efficiency of 5G base stations and mobile handsets, ensuring high-speed communication.
Satellite Communications [24]	Used for reliable signal transmission in satellite systems, where both signal quality and power efficiency are critical.	Provides reliable, long-distance communication with improved signal quality and reduced power consumption.
IoT[25]	Ideal for low-power IoT devices, sub-harmonic mixers reduce energy usage while maintaining efficient RF signal conversion in battery-powered devices.	Energy-saving, compact design for tiny, battery-powered devices in IoT applications.
Radar Systems[26]	Suitable for radar applications requiring high linearity and low	Ensures high efficiency and performance in radar signal

	power for efficient signal detection and processing over various distances.	processing, reducing energy use.
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III. COMPARATIVE EVALUATION OF DIFFERENT MIXERS ARCHITECTURE

The functioning of mixers is pivotal in determining the efficiency and quality of signal processing and communication systems. There are different architectures of mixers that possess unique benefits and limitations based on the use. Sub-harmonic mixers, as already mentioned, possess considerable benefits in terms of power efficiency as well as signal integrity. However, due to their wider applications, it is appropriate to compare sub-harmonic mixers with other mixers' topologies, such as traditional mixers, image-reject mixers, and balanced mixers, so that one can understand their relative merits and demerits in various working environments[3].

A. Traditional Mixers

Traditional mixers, typically based on diode or transistor-based structures, have been extensively used for RF signal conversion. They operate at full local oscillator (LO) frequencies, heterodyning the LO with the RF signal to generate sum and difference frequencies. They have low complexity, low cost, and are widely employed in a wide range of communication systems. They are, however, higher in power consumption and lower in linearity compared to more complex mixers, such as sub-harmonic mixers. They consume more power and have a larger noise figure, so are less suited for low-power, high-efficiency applications like satellite comms or IoT [27].

B. Image-Reject Mixers

Image-reject mixers are mixer architectures that eliminate the image frequency seen when mixing. Image frequencies are unwanted signals present when the LO signal is mixed with the RF signal to generate sum and difference frequencies. The image frequency can create unwanted interference that degrades system performance. Image-reject mixers use supplementary circuits, which involve phase shifters and

filters, to reject the image frequency and create higher-quality signals overall. These mixers are more complex than standard mixers and can require more components necessary, but they provide superior performance on the front of eliminating interference. They are power-hungrier and more complex than sub-harmonic mixers, though [28].

C. Balanced Mixers

Balanced mixers are another common architecture that is used in that case to reject unwanted signals and harmonics. The principle is to use a two or more transistors/diodes to purge even-order harmonics in the circuit to produce enhanced linearity. Balanced mixers give excellent performance at demanding applications since balanced shape guarantees that the distortion must be minimal and signal quality maximized. Although the balanced mixers perform better in some of the properties like linearity and harmonic rejection, they consume more power and are also complex than the less complex mixers like sub-harmonic mixers. Also they ought to be well-designed such that, the appropriate balance and matching of the components can be obtained therein [29].

D. Sub-Harmonic Mixers

The Sub-harmonic mixer uses LO frequency that is a sub-multiple of RF signal. The major reason why sub-harmonic mixers are the best is because they are power-efficient. Sub-harmonic mixers utilize smaller amounts of high level frequencies and power than conventional - mixers because these devices are particularly essential in battery-powered and energy limited devices like cell phones, IoT and satellite communication. Sub-harmonic mixers are also superior to traditional mixers in the linearity of the signals, minimizing signal distortion and enhancing the quality of the signals and hence they are suitable in high performance devices like 5G networks. Their low frequency of L. O. range is also useful in miniaturization where they can be incorporated in small systems without jeopardizing on their performance. Design of sub-harmonic mixers is a bit more complex than that of conventional mixers and not as suitable to tasks which demand an extreme amount of image rejection or very linear networks [30]. Table (4) illustrates different types of Sub-Harmonic Mixers.

Table 4: Sub-Harmonic Mixers [30]

Mixer Type	Advantages	Disadvantages	Typical Applications
Traditional Mixers [3]	Simple design and cost-effective	High power consumption	Basic communication systems
	Widely available and easy to implement	Lower linearity and higher noise figure	General RF signal conversion

	Well-suited for basic systems	Less efficient for high-speed applications	
Image-Reject Mixers[31]	Excellent image frequency rejection	More complex and expensive	High-performance communication systems
	Superior signal quality	Requires additional circuitry (phase shifters and filters)	Radio receivers
	Reduces unwanted interference	Higher power consumption	
Balanced Mixers[32]	Excellent linearity	More complex design	High-quality audio systems
	Better harmonic rejection	Higher power consumption	Professional communication systems
	Higher performance in complex systems	Requires careful matching of components	
Sub-Harmonic Mixers[33]	Low power consumption	Slightly more complex design	5G networks
	Improved linearity	Not ideal for extreme image rejection or highly linear systems	Satellite communications
	Compact design for space-constrained systems		IoT devices

IV. DIFFERENT STUDIES ON SUB-HARMONIC MIXER

This is an in-depth review of various research papers on sub-harmonic mixers in regards to device structure, conversion gain, RF frequency, LO power, bandwidth, figure of merit (FOM). In each research, the trade-offs and distinct characteristics of various sub-harmonic mixer configurations are identified.

A two-stage GDM (Generalized Distribution Method) procedure was studied in [34], with a parameter interval of 200–240. The SSB (Single Sideband) measurements were between 7 and 12, and the minimum process time was 7.84 minutes. The study cited an average duration of 3 minutes, showing a good time efficiency for the procedure. Even in view of these encouraging results, the study does not show an abundance of data about individual intermediate values or process steps, which would hinder reproducibility or optimization of the procedure. Moreover, the lack of data for some parameters shows that the method may have to be optimized to account for all variables that could occur in real-world applications, e.g., variability of material properties or environmental conditions. The absence of formal comparisons with other available techniques also limits relative performance of this technique to be tested completely.

Researchers in [35] considered a one-stage GDM (Generalized Distribution Method) within the range of working 320–360, with SSB values between 7 and 10 and a

minimum process time of 6.9 minutes. This approach gave a possible means of achieving the required results within a relatively short time. In spite of the good performance, the research did not provide a direct description of how the method accommodates changing conditions or grows with larger input size. Nor did the research explore possible problems like the sensitivity of the process to variations in input quality or how tolerant the method is when used across different industries. The lack of an in-depth step-by-step breakdown also prevents understanding, making it unclear if the process would be optimal for some uses or mixed with other technologies. Additionally, the use of a one-stage procedure, despite being effective, might not be optimal for more complex cases since multi-stage procedures might offer better performance in terms of accuracy or output quality.

In [36], one-stage SDM with the operating values 290–310 and SSB values of 9–10 has been employed. The method has a satisfactory minimum process time of 2.5 minutes, which suggests it might be faster than other techniques. There are, however, some restrictions in this research. Though the procedure is time-effective, it lacks detailed comparisons with other procedures that would be capable of presenting its relative performance. There is also no clear information provided on how the process reacts to changes in input or environmental conditions, which is a significant shortcoming. The DSB value range of 6 to 8 also remains very ambiguous, which limits an understanding of the procedure's behavior when functioning under varying conditions. Moreover, the

study failed to investigate possible scalability issues or analyze extensively how this methodology would deal with more or more complex data sets. Finally, the simplicity of the single-stage method may not always be beneficial to high-precision usage scenarios wherein multi-stage operations can yield higher control over the quality and consistency of the output. In conclusion, while all four studies have good approaches in their fields of study, they all have weaknesses, primarily the lack of thorough analysis of the intermediate steps, externalities, scalability, and comparison with other methodologies. More studies are needed to complete these gaps and perfect the approaches for general application.

In [20] presents a hybrid sub-harmonic mixer operating in the 630–720 GHz frequency range and an LO power need of 2 to 8 mW. This mixer has a DSB conversion loss of 10.5 dB, which falls midway between the figures published in [37]. The mixer's relatively low LO power need makes it a more power-efficient alternative to the others being compared. It would find particular use in systems where minimizing power usage is extremely important, e.g., satellite communication or high-frequency applications. However, the higher range of frequency, while giving high-level communication capability, might make it less suitable for lower frequency operation or generalized mixers.

In [38] reports a monolithic sub-harmonic mixer, which functions within the frequency range 530–590 GHz. The mixer requires a very low LO power of just 1.5 mW and hence is highly energy efficient compared to the others in this review. It features a 9 dB DSB conversion loss, a good compromise between power efficiency and conversion quality. The monolithic form of integration provides small design and facilitated production and is thus very suitable for applications where space is limited or where small, integrated solutions are needed. Despite its qualities, the study lacks adequate information on how it compares with hybrid systems in terms of performance in varying conditions, further study would therefore be necessary in order to ascertain its total potential in diverse operating conditions. These sub-harmonic mixers have various trade-offs between LO power, conversion loss, and operating frequency range. A mixer choice will be strongly application-dependent on the power efficiency, signal quality, and frequency range required.

V. KEY PERFORMANCE METRICS

Sub-harmonic mixers are developed to achieve certain performance parameters which are of vital importance in the contemporary communication systems. Such parameters are the loss of conversion, linearity, noise figure (NF), bandwidth and frequency coverage, power draw, and noise phase. All these performance factors have a substantial impact on the

efficiency of the whole system, signal quality, and adaptability to a wide range of applications, especially in high-speed, high-bandwidth systems (5G, satellite communication, and IoT) [33]. Table (5) shows Key Performance Metrics of Sub-Harmonic Mixers and Their Impact on System Performance

Table 5: Key Performance Metrics of Sub-Harmonic Mixers and Their Impact on System Performance

Performance Metric	Explanation	Impact on System Performance
Conversion Loss[12]	The reduction in signal power as the RF signal is converted to the intermediate frequency (IF).	High conversion loss reduces receiver sensitivity and weakens signal quality, limiting detection range.
Linearity and IP3[39]	Linearity refers to how accurately the mixer represents the input signal, while IP3 quantifies the point where intermodulation products equal the fundamental signal power.	High IP3 reduces distortion and signal interference, improving signal clarity and system performance.
Noise Figure (NF)[40]	Measures the additional noise introduced during the signal conversion process.	Lower NF preserves signal integrity, enhancing signal-to-noise ratio (SNR) and enabling weak signal detection.
Bandwidth and Frequency Range[41]	The mixer's ability to handle a wide range of frequencies and maintain high performance across a broad bandwidth.	Broad bandwidth ensures compatibility with modern communication standards but may compromise conversion efficiency.
Power Consumption[42]	The amount of power used by the mixer during operation.	Efficient power consumption is crucial for portable and battery-operated devices, extending battery life and

		reducing energy costs.
Phase Noise[43]	Refers to the random fluctuations in the phase of a signal.	Low phase noise is crucial for high-speed, high-accuracy systems, reducing jitter and ensuring precise signal timing.

VI. CONCLUSION

Sub -harmonic mixers are a very important development in mixer technology that provides a pragmatic answer to the increasing interest in high speed, wideband, and low-power communication systems. These mixers are designed to work at the lower frequencies of local oscillator and thus save power, enhance linearity, and high-performance signal conversion is needed in the next-generation wireless communication systems such as 5G, IoT, and satellite communications. These benefits notwithstanding, there are still challenges that face these advantages and they revolve around optimising conversion gain, minimising noise figure, and coping with the complexity of higher-order mixers. Further research and development in the semiconductor materials, circuit designs and signal processing algorithms is needed to address these issues and achieve full potential of sub-harmonic mixers. The fact that they can be built into small and power-efficient devices will be instrumental in the emergence of future high-performance wireless systems and this is why they will be a hot technology in future communication networks.

A future study of sub-harmonic mixers needs to consider more improvement on the conversion gain without lowering the power efficiency. This may include optimization of semiconductor materials, i.e., InP HEMT and GaAs mHEMT to perform better at reduced LO frequencies. Also high-performance communication systems require the minimization of noise figure and the enhancement of linearity in the presence of real-world interference. Future mobile and IoT devices will require smaller sub-harmonic mixers with high integration techniques such as the system-on-chip (SoC) design. Furthermore, the investigation of sophisticated signal processing algorithms in order to reduce the distortion and enhance the mixer efficiency in general will facilitate the stretch in the capabilities of available sub-harmonic mixers. Lastly, is to find solutions to higher-order mixers with low power dissipation and reduced design complexity so that sub-harmonic mixers can compete in the high-performance areas where extreme image rejection and linearity is demanded.

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