Journal of Electronics and Electrical Engineering
https://ojs.wiserpub.com/index.php/JEEE/

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Review

Advanced Phased Array Transceivers for Enabling Next-Generation 5G Communication Networks

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Received: 3 August 2023; **Revised:** 21 August 2023; **Accepted:** 29 August 2023

Abstract: This article presents advancements and key considerations in the design implementation of phased array transceivers for the fifth-generation (5G) communication networks. It emphasizes the significance of careful consideration and system-level optimization to realize the full potential of phased array transceivers. The focus is on antenna elements and beamforming techniques with a detailed discussion on different types of beamforming techniques used in wireless communication systems. These include analog, digital, and hybrid beamforming. The article starts by introducing the concept of a phase shifter, which is a crucial component in controlling the phase of the transmitted signal. It then proceeds to discuss the role of a variable gain amplifier in amplifying the signal received by each antenna element of the array, followed by emphasizing the importance of a Low-Noise Amplifier (LNA) in transceiver design to amplify weak signals with minimal noise. In addition, this article provides a detailed discussion on the mixer, which is used to downconvert or upconvert the frequency of the received signal to a more appropriate frequency for further processing or transmission. Finally, the power amplifier (PA), which is used to boost signal power in 5G networks, is also discussed in detail.

Keywords: phased array transceivers, 5G communication networks, beamforming, phase shifter, VGA, LNA, mixer, PA

1. Introduction

As the demand for high-speed and reliable wireless communication grows, 5G wireless communication networks have emerged as the latest standard. These networks require advancement in technologies to achieve high data rates, low latency, and high capacity. Phased array transceivers have been identified as one such technologies, which can significantly improve the performance of 5G communication networks.

The capability of 5G to provide fast data transfer rates of up to 10 Gbps, very short delay times of 1 millisecond, and accommodate a significant number of devices of up to 1 million per square kilometer makes it a versatile option for various fields of application [1]. Three primary categories of applications have been identified for 5G technology, namely enhanced mobile broadband (eMBB), ultra-reliable and low latency communication (URLLC), and massive machine-type communication (mMTC).

The 3rd Generation Partnership Project (3GPP) has established the frequency range for 5G new radio (5G NR) bands, which includes millimeter-wave (mm-wave) frequencies from 24.25 to 52.6 GHz. This range is considered an expansion of the existing sub-6-GHz Frequency Range (FR1). One of the unique characteristics of 5G NR is the use of phased-array beamforming directional communication, which improves the signal strength and spatial efficiency [1–3].

The selection of mm-wave bands for 5G networks was primarily motivated by the need to significantly increase capacity. To achieve the necessary link budget at these high-frequency bands, Phased Array Antenna

DOI: https://doi.org/10.37256/jeee.2220233485

(PAA) methods have been employed. The transmitter utilizes phased array technology to reduce the power requirements of the power amplifier. In addition, incorporating an N-element phased array receiver enhances the Signal-to-Noise Ratio (SNR) at the receiver's end, resulting in a substantial increase in communication capacity. These factors have resulted in the widespread application of phased array designs that utilize mm-wave frequencies in 5G networks [4]. The remainder of this paper is organized as follows. Section 2 reviews millimeter-wave transmitter beamforming architectures. Phased-array transceiver design is reviewed in section 3. In section 4, a performance comparison is outlined. Finally, section 5 presents the conclusion of this study.

2. Millimeter-Wave Transmitter Beamforming Architectures

Beamforming is a signal processing technique used for wireless communication systems. In wireless communication systems, beamforming is used to improve the quality of the signal and increase the data transfer rate. By directing the transmission and reception of signals towards a specific user or location, beamforming can reduce interference and improve the signal-to-noise ratio. This is particularly useful in environments with a high degree of interference, such as urban areas.

Beamforming architectures can be divided into various classifications depending on various characteristics and design elements such as the architecture of hardware (circuit) implementation, feeding system, geometrical arrangement, and specific requirements of the wireless communication system. Study [5] discusses how Beamforming can be classified based on the physical hardware implementation of their beamforming structure. As illustrated in Figure 1, Beamforming can be divided into three main groups with further subgroups [5].

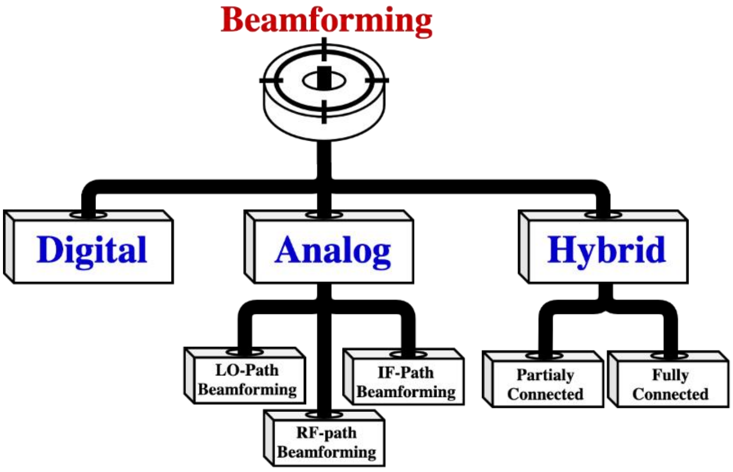

Figure 1. Classification of beamforming techniques [5].

2.1 *Digital Beamforming*

In digital beamforming, transceiver dedicates an RF chain per antenna as shown in Figure 2. Every antenna element is equipped with its own dedicated RF chain, as well as individual DACs and ADCs. Each spatial sample's gain and phase are individually adjusted during baseband processing, either before upconversion at the transmitter or after downconversion at the receiver [6].

On the receiver side, digital beamforming involves converting received RF signals to a lower frequency. The signals are then digitized and processed by a digital signal processor (DSP) to determine the optimal phase shift for each antenna element. The signals or multiple beams are generated using the digital phase shifter. In this architecture, the phase shift values are applied to the signals before they are transmitted to achieve the desired beam direction. Depending on where the phase shifters are located in the RF chain, the analog beamformer topology is divided into three subcategories RF path beamforming, LO path beamforming, and IF path beamformer [5].

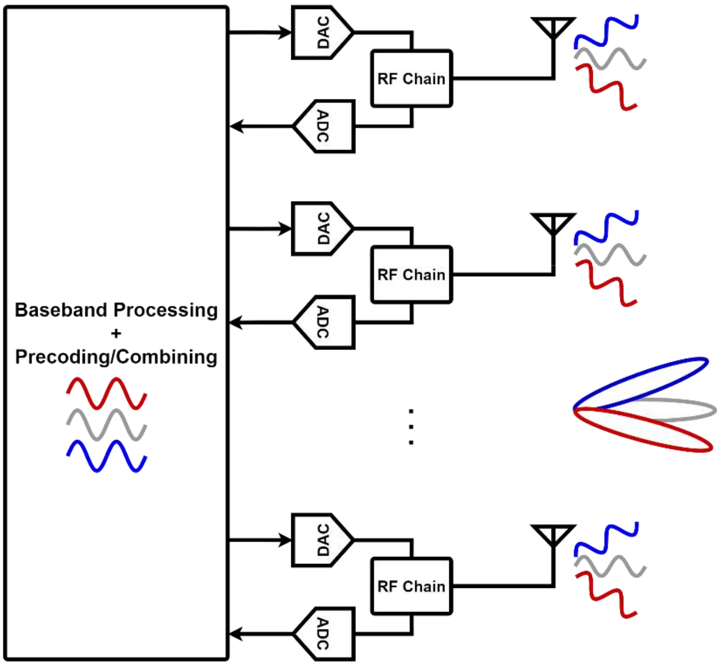

Figure 2. Digital architecture [6].

2.2 *Analog Beamforming*

A basic form of analog beamforming employs a single pair of ADC and DAC, along with a lone RF chain. The process involves channeling a singular input data stream through a series of feedlines, connected to adjustable phase shifters. These phase shifters are incorporated at each antenna element, as illustrated in Figure 3. This configuration enables the formation of versatile and adaptable beams, with the ability to direct signals in any desired direction [6].

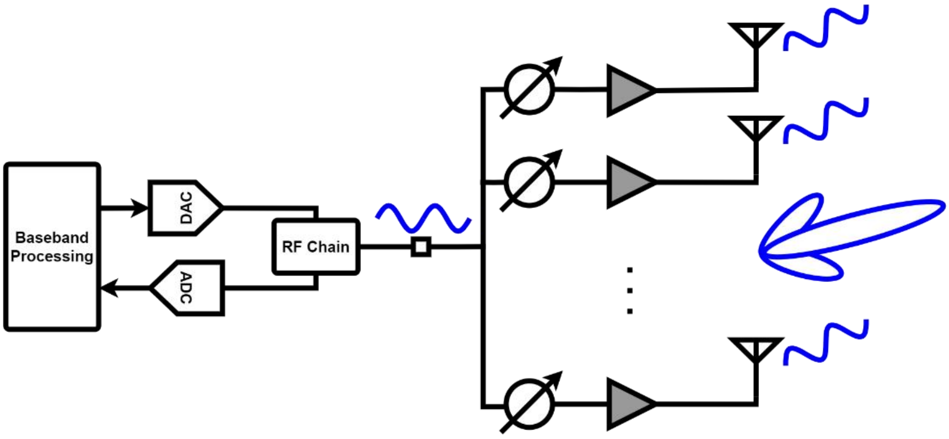

Figure 3. Analog Beamforming [6].

The topology of the analog beamformer can be further categorized into three distinct subtopologies, based on the location of the phase shifters within the RF chain as shown in Figure 4.

1) *RF path beamformer*: RF design is a popular technique for its efficiency in minimizing component requirements. It involves phase shifting at high frequencies, resulting in smaller components and a more compact beamformer. The key advantage of RF beamforming is in the spatial filtering of undesired signals by selectively reducing interference in received signals through multiple antenna elements. These elements analyze signals from different directions and combine them to enhance desired signals while suppressing undesired ones, thus improving wireless communication quality. However, there are drawbacks, notably the gain degradation and increased Noise Figure (NF) caused by phase shifters positioned in the signal path before combination as illustrated in Figure 4a. This makes phase shifter performance critical to overall system effectiveness [5,7].

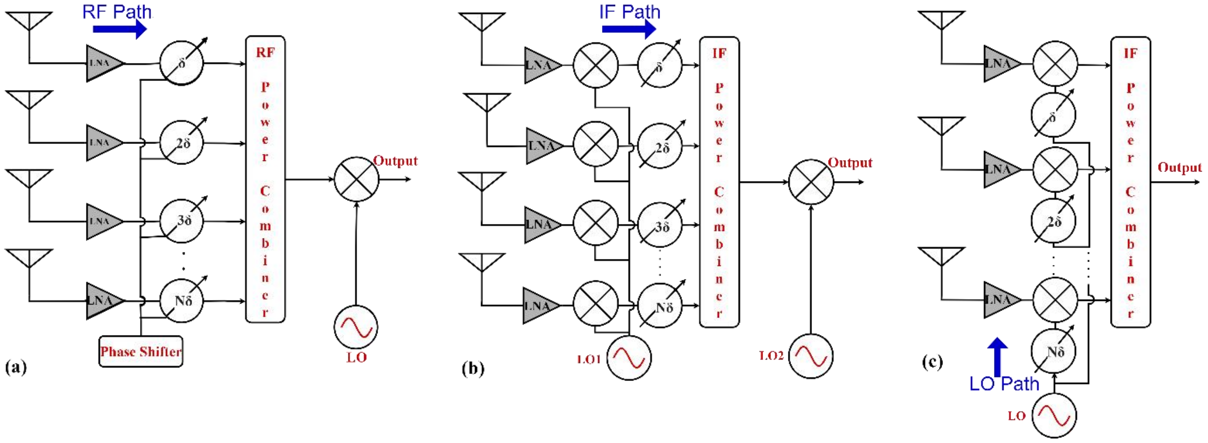

Figure 4. Block diagram of (a) RF-Path beamformer, (b) IF-Path beamformer, (c) LO-Path beamformer [4].

2) *LO path beamformer*: LO path beamforming incorporates phase shifters in the LO path before mixing, directing the primary signal beam to a specific location, as depicted in Figure 4b. Gain variations in LO phase shifters during tuning won't impact the RF path's Signal-to-Noise-and-Distortion Ratio (SNDR), preserving output signal quality—a significant advantage that enhances the system's gain performance. However, this approach increases component count, elevating power consumption. Consequently, more power is needed for system operation, potentially raising costs and diminishing battery life. Moreover, the layout of the LO distribution network becomes crucial at high frequencies [4,8].

3) *IF path beamformer*: IF phase shifting architectures involve phase shifting before up-conversion or after down-conversion stages, depicted in Figure 4c. These methods operate at lower frequencies, imposing fewer demands. Nevertheless, the overall circuit topology becomes more complicated. Each antenna in the array necessitates a frequency conversion stage, adding to the complexity of IF phase shifting architectures [9].

The selection among RF, IF, hybrid, and analog beamforming topologies depends on factors including application, system complexity, cost, and desired performance.

2.3 *Hybrid Beamforming*

Hybrid beamforming employs a dual-stage architecture that combines the advantages of both analog and digital beamforming techniques, aiming to attain the utmost achievable data rate [10]. Within this framework, the initial precoding occurs within the analog domain, followed by further processing in the digital domain. Consequently, the hybrid beamforming architecture strikes a balance between complexity and flexibility, offering precise beams with phase shifters in the analog domain while retaining the flexibility of the digital domain. In this advance topology, the number of RF chains and ADC/DAC is fewer than the number of antenna elements, while the antenna elements are still driven by analog phase shifters, as depicted in Figure 5. This reduction in the number of data converters and corresponding chains leads to reduced complexity of hardware implementation, reduced costs, lowered computational load, and reduced power consumption [6].

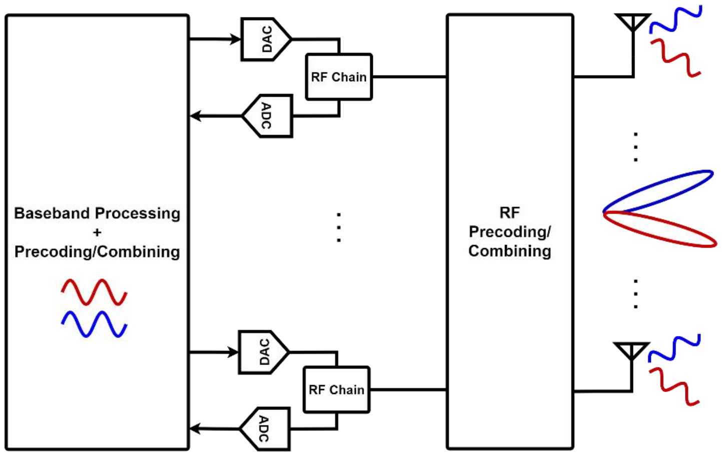

Figure 5. Hybrid Beamforming [6].

3. Phased-Array Transceiver Design

Phased array is a type of antenna array that consists of multiple antennas arranged in a regular pattern, typically in a straight line or a grid. They are typically used in radar and communication systems to scan a wide area and detect or transmit signals in a specific direction. Each antenna element is fed with a slightly different phase shift to create a beam pattern that can be steered electronically in a specific direction. Both beamforming and phased array techniques are used to improve the performance of various types of communication and radar systems. By providing greater control over the directionality of the antenna array, these techniques can improve signal quality, reduce interference, and increase data transfer rates.

The phased-array transceiver (TRX) design is an important area of research in the field of wireless communications. A phased-array TRX is designed with an array of antennas and electronic circuitry to transmit and receive signals in a precise and controlled manner. In wireless communication, using phased-array TRX can effectively increase wireless network's signal strength and range while minimizing interference. Phased array transceiver architectures are used in antenna arrays that require beamforming to direct the signals in a specific direction. There are several types of phased array transceiver architectures, including analog, digital, hybrid and active.

To illustrate the fundamental components required for the design of a TRX, we can examine the block diagram of a conventional phased-array TRX, as shown in Figure 6. The TRX switch shares the antenna, while the transmitter and receiver chains are separate. This example provides a valuable demonstration of the essential building blocks needed for a transceiver design. The following sections will discuss the primary components required for designing a transceiver.

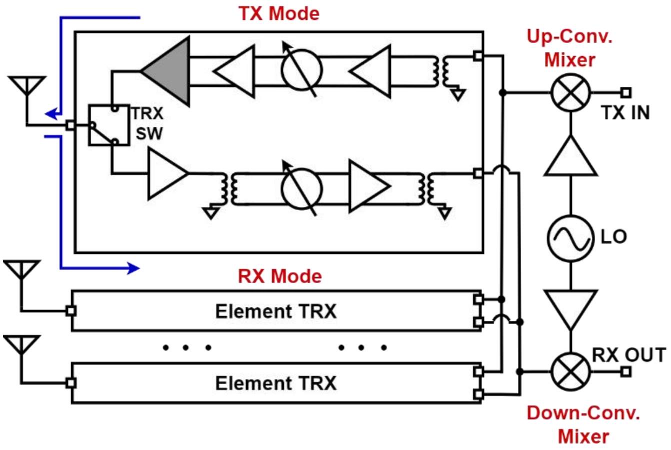

Figure 6. A conventional phased-array transceiver utilizing a transmit/receive module, phase shifters, power amplifiers, and control circuits [11,12].

A phased array transceiver design typically involves several fundamental blocks such as, Antenna array, Digital-to-Analog Converter (DAC), Analog-to-Digital Converter (ADC), Digital Signal Processor (DSP), Phase Shifters, and RF Front-End includes low-noise amplifiers, mixers, filters, and power amplifiers. Here we review several important blocks.

3.1 *Antenna Array*

An antenna array is a set of multiple connected antennas that can be steered to create a directional beamforming. By coordinating the phases of the signals that are fed to each antenna element, the array can steer the radiation pattern and focus the transmitted or received signals in a specific direction. This technology, known as phased array antennas, proves highly effective for applications such as mm-Wave 5G and other high-frequency uses.

3.2 *Phase Shifter*

The phase shifter is a vital component of the system, controlling the relative phase shift between the antenna elements to adjust the incoming signal's phase. The precision and accuracy of the phase shifters play a crucial role in the accuracy of beamforming, making them essential components of the system. The correct adjustment of the phase shift enables constructive interference of the received signals from the different antenna elements, resulting in a stronger signal at the receiver. Besides, to achieve the necessary rejection of side lobes in phased-array receivers, it is essential to adjust both the phase shift and gain of each signal individually [13]. Therefore, independent control over both gain and phase is desirable in these systems. Phased-array receiver design offers increased signal strength and directionality, making it a popular choice for communication and radar systems. References [14,15] presents a low-power 26–28 GHz phased-array receive channel in 45nm CMOS SOI. They use a Switched-LC Phase Shifter (SWPS) illustrated in Figure 7. The SWPS works by using a bank of capacitors and inductors (L-C circuit) that are selectively switched in and out of the circuit to adjust the phase of the signal.

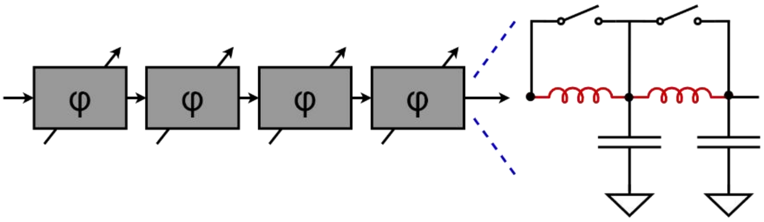

Figure 7. Switched-LC Phase Shifter circuit consisting of an LC network and a set of switches that can connect or disconnect the LC network to the input and output of the circuit [14,16].

Also, Switch-Type Phase Shifter (STPS) and Reflective-Type Phase Shifter (RTPS) are two types of passive phase shifters that are commonly used in phased array transceiver designs operating at mm-Wave frequencies. In general, passive phase shifters are critical for phased-array systems because they can provide accurate phase control without requiring a significant amount of power. By adjusting the tuning of the reflective loads, the RTPS can introduce a variable amount of phase shift to the incoming signal, which allows for precise control of the direction of the beam in phased array transceiver designs as shown in Figure 8.

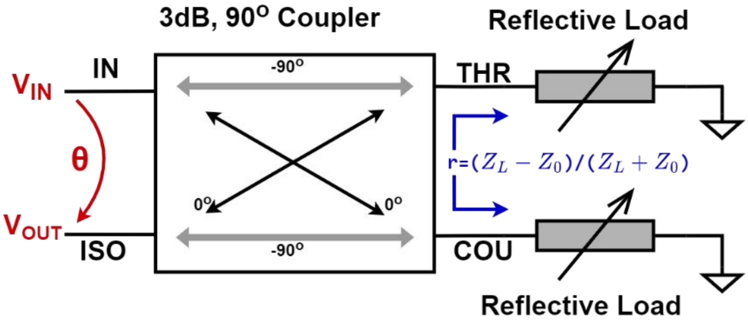

Figure 8. Reflective-Type Phase Shifter (RTPS) composed of 3 dB coupler and reflective loads [16].

Reference [17] implemented Vector-Modulated Phase Shifter (VMPS) to design a high phase resolution and low gain variation.

The reference [18] describes a phase shifter which is made up of several individual units, that when combined, create an artificial transmission line. The Cascaded Unit Cell Phase Shifter comprises multiple unit cells, each of which is a small component, as depicted in Figure 9. The unit cells are connected in a series to form the complete phase shifter. It utilizes an artificial transmission line to introduce a variable phase shift into the signal passing through it. Every unit cell has side-shields and a Metal-Insulator-Metal Capacitive Array (MIMCA) that can be interchanged to switch between two different phase-shifting modes. The first mode is characterized by high inductance and high capacitance, leading to a high delay, while the second mode has low inductance and capacitance, resulting in low delay. The delay introduced by each unit cell is determined by the product of its inductance and capacitance, which controls the two different delay modes. By changing the inductance and capacitance values in the MIMCA, the delay can be varied, resulting in a variable phase shift across the artificial transmission line.

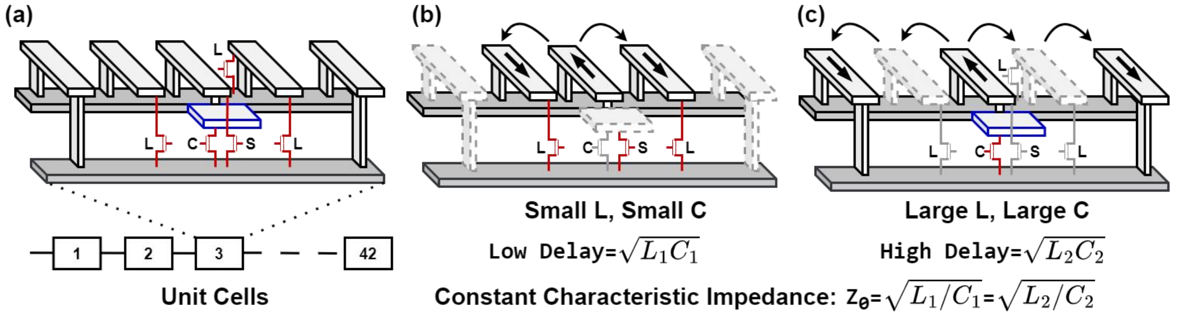

Figure 9. A phase shifter utilizing cascaded unit cells. (a) a detailed view of a single rotated unit cell, (b) a depiction of the approach used to achieve low delay and high delay modes within each unit cell [18].

A hybrid phase shifter is another instance of a phase shifter that utilizes both passive and active techniques. Phase shifters are commonly categorized into two main types: passive and active. Passive phase shifters can operate in both directions and maintain high linearity, but their loss increases as the phase shift range grows. In contrast, active phase shifters minimize loss and offer precise phase-shift resolution throughout the full 360° range, but they consume more power and can only operate in one direction. To balance the tradeoffs between linearity, phase-shift range, and phase-shifter loss, a hybrid active-passive approach can be used. In this approach, the passive stage provides fine-resolution while the active stage provides coarse 180° steps. Research [19] discusses a hybrid approach that involves two stages connected in series: a discrete phase-inverting stage and a bidirectional Reflection-Type Phase Shifter (RTPS), as shown in Figure 10. These stages are connected in series and consist of a discrete phase-inverting stage and a bidirectional Reflection-Type Phase Shifter (RTPS). The RTPS is capable of achieving a continuous phase variation up to 180° and helps to achieve the desired phase shift range and linearity [19].

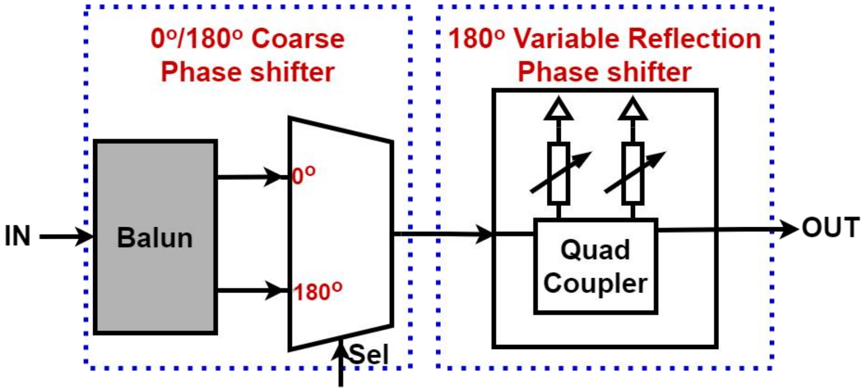

Figure 10. A 94-GHz phase shifter employing a cascaded active-passive phaseshift method, with a variable phase shift of 360° with a 5-bit phase resolution [19].

3.3 *Variable Gain Amplifier*

A variable gain amplifier (VGA) is a type of electronic amplifier that allows for the amplification of a signal with adjustable gain. In the context of a phase array transceiver, a VGA is often used to amplify the signal received by each antenna element of the array. In a phase array transceiver, the received signal from each antenna element is first amplified by a Low-Noise Amplifier (LNA). The amplified signals are then combined in a phase shift network and a power combiner to form the final output signal. A VGA is placed between the LNA and the phase shift network to adjust the signal gain from each antenna element. This adjustment helps compensate for differences in the received signal strength from each antenna element and ensures that the output signal from the transceiver has uniform power and phase across the entire array. The gain of the VGA is typically controlled by a voltage or current applied to a control input. This control input can be adjusted dynamically to compensate for changes in the received signal strength or to adjust the overall gain of the system.

3.4 *Low-Noise Amplifier*

Another crucial component in transceiver design is the LNA. The purpose of the LNA is to amplify the received signal with minimal noise, typically located close to the antenna element. The LNA is designed to have a high gain and a low noise figure, amplifying the weak signal without introducing additional noise into the system. In a study described in Reference [20], a 140 GHz IF beamforming phased-array receive channel with low noise performance in a 45 nm RFSOI process. The LNA used in this study is illustrated in Figure 11 and consists of three fully-differential stages of amplification, each coupled with a transformer. This design utilizes cross-coupled pairs of transistors and neutralization capacitors to increase the maximum available gain and enhance overall performance. This results in a high-gain, low-noise LNA suitable for applications requiring sensitive signal detection.

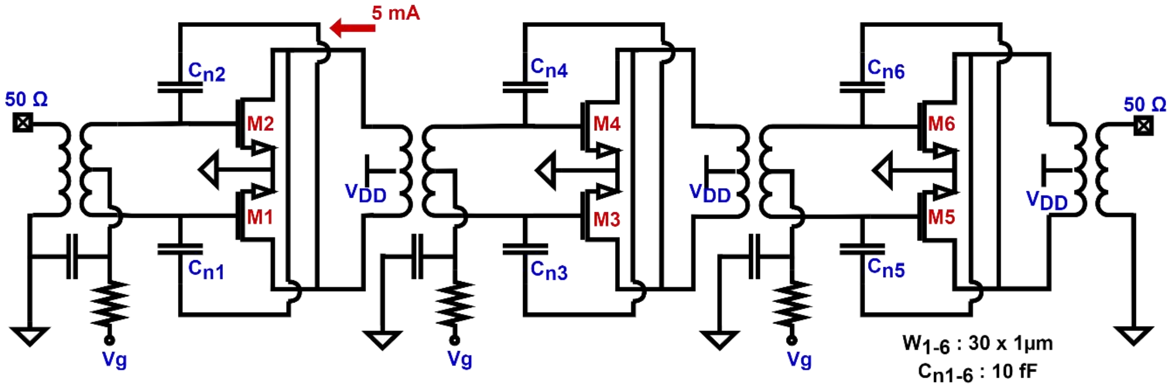

Figure 11. Block diagram of the 140 GHz LNA breakout circuit [20].

3.5 *Mixer*

A mixer is an essential component in a phase array transceiver as it is used to downconvert or upconvert the frequency of the received signal to a more appropriate frequency for further processing or transmission. This is necessary because the signal received by the antenna may not be at a suitable frequency. To achieve this, the mixer is used to translate the signal to a more appropriate frequency. A study presented in reference [21] reports on the design of a mixer that is specifically designed for wideband IF operation. The mixer design reduces the number of capacitors, which in turn reduces the conversion loss, as reported in reference [21].

3.6 *Power Amplifier*

In 5G communication, reliable and high-speed data transmission is achieved through the use of Power Amplifiers (PAs) that boost signal power. However, the development of PAs for 5G networks has been challenging due to the HF bands used in 5G communication. To overcome these challenges, researchers have proposed various PA architectures with different trade-offs in terms of efficiency, linearity, bandwidth, and complexity such as class AB cascode PA and PA-LNA, among others. For instance, reference [12] outlines the authors' proposal for a scalable 28-GHz phased-array architecture intended for 5G communication. This section provides a detailed discussion of PA architectures.

The class AB cascode PA, illustrated in Figure 12, is a type of PA architecture commonly used for RF applications. The PA is equipped with a 1:1 transformer balun that serves a dual purpose by providing loading and protection against electrostatic discharge (ESD) at the antenna ports. The transformer balun is constructed using a single turn in the top two metal layers. For a PA operating under modulation, the AM-PM distortion is a critical metric to consider as it can significantly affect the quality of the transmitted signal. If the distortion level is excessive, errors or interference can occur, leading to poor signal quality or signal loss. Therefore, for 5G data links that rely on complex modulated waveforms with high PAPR, minimizing AM-PM distortion is crucial to ensure reliable and efficient communication. According to reference [12], measurements were taken at 28 GHz to determine the levels of AM-AM and AM-PM distortion. The research findings show that at P1dB and with a total bias current of 24 mA, the level of AM-PM distortion is less than 8° [12].

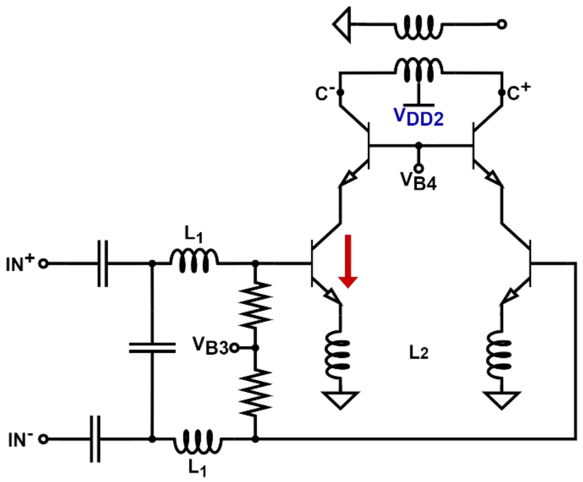

Figure 12. A Class AB cascode power amplifier utilizing two transistors in a cascode configuration to achieve high gain and wide bandwidth [12].

A different type of PA known as the PA-LNA was also investigate. PA-LNA, illustrated in Figure 13, integrates both a power amplifier and a low noise amplifier on a single chip, as discussed in reference [11]. This research describes a low-cost and area-efficient 28-GHz CMOS chip for 5G mm-wave DP-MIMO systems. It adopts a neutralized bi-directional technique to reduce chip area and share the same circuit chain between transmitter and receiver. The transistors in PA and LNA circuits have different size requirements. PA circuits utilize larger transistors to increase power delivery, while LNA circuits utilize smaller transistors conserve power. The proposed adaptive antenna-sharing network is optimized by switching the transistor to achieve the necessary impedance for maximum output power in PA mode and minimum noise figure in LNA mode.

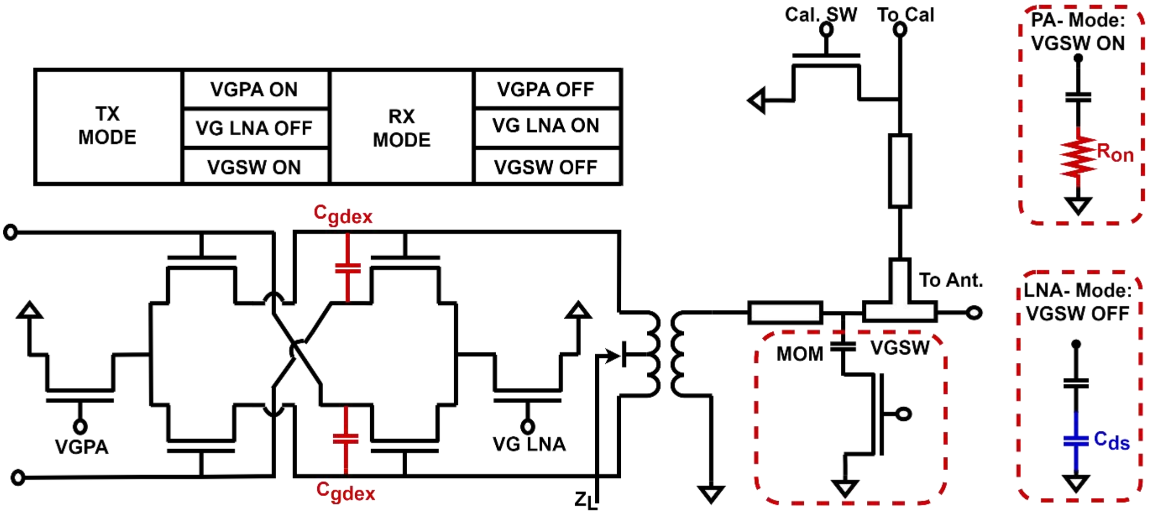

Figure 13. PA-LNA based on unbalanced neutralized bi-directional technique [11].

There are various factors to consider when choosing the best PA design for a phased array transceiver. One of the key considerations is the chip area, as a large PA design may occupy valuable space on the chip and potentially increase costs. One possible approach is to focus on bi-directional designs that can help reducing the chip area. Additionally, designers should consider whether a linear or switching PA designs to be implemented depending on the required output specification. Linear PAs are typically preferred for applications that require high linearity, while switching PAs are better suited for applications that require high efficiency. Optimizing the PA design requires a careful balance of these considerations, based on the specific requirements of the phased array transceiver. Other key factors to consider include the frequency band and power output, all of which can impact the performance of the transceiver.

The Doherty Power Amplifier (DPA) is another commonly employed employed in transceivers and is a popular choice for phase array transceivers due to its various advantages. These include improved power efficiency and reduced distortion, which make it a popular choice in RF applications. The DPA improves power efficiency by utilizing two amplifiers to handle different portions of the input signal power, namely a main amplifier and an auxiliary amplifier as depicted in Figure 14. The main amplifier is responsible for handling the majority of the signal power, while the auxiliary amplifier handles the remaining power [22].

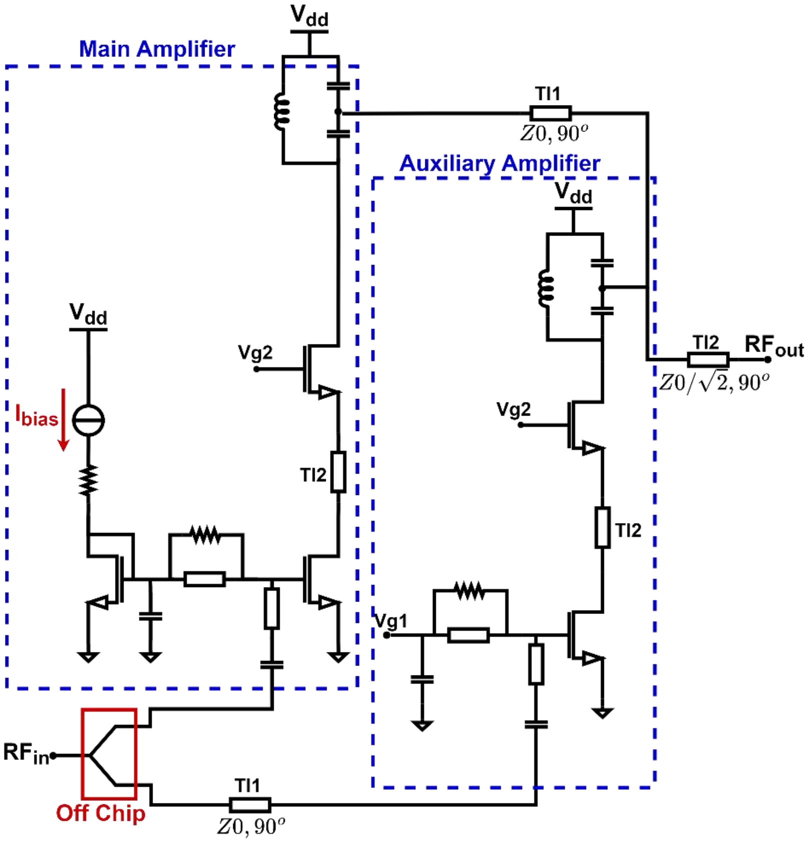

Figure 14. Schematic diagram of Doherty Amplifier utilizing a main amplifier and an auxiliary amplifier [23].

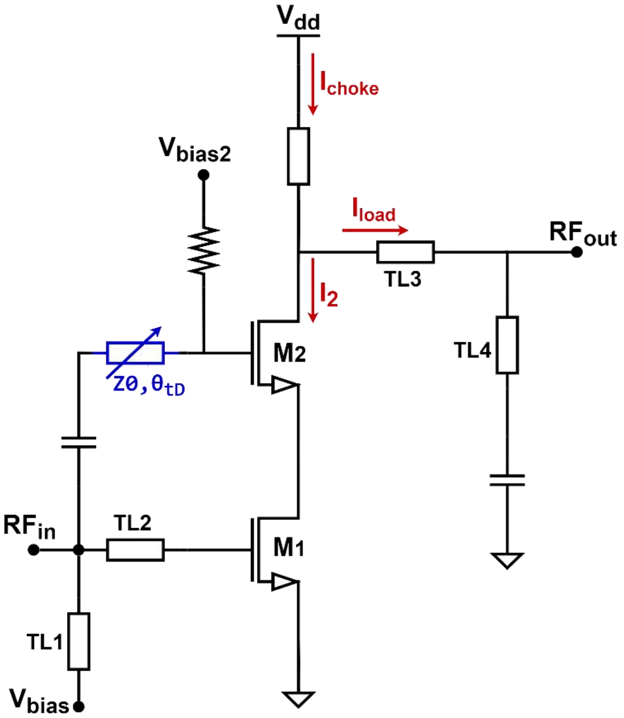

Figure 15. A switched cascode Class-E PA, wherein the cascode transistor features a switching input exhibiting a duty cycle of 50. The phase of the input is modulated through a tunable transmission line with a delay of θ_{tD} [23].

The authors of reference [23] utilized Class-A and Class-C amplifiers, along with a cascoding technique and a tapped capacitor output matching network, as illustrated in Figure 14, to enhance power efficiency. Additionally, reference [23] presented a cascode Class-E PA with a tunable transmission line, as illustrated in Figure 15. By varying the delay, the degree of overlap between the output voltage and current waveforms can be adjusted, leading to an increase in efficiency. This delay element in the amplifier is implemented through a tunable transmission line [23].

3.7 *Analog-to-Digital and Digital-to-Analog Converters*

Analog-to-Digital Converters (ADCs) convert the analog RF signal to digital data for digital processing and manipulation. Digital-to-Analog Converters (DACs) convert digital signals back to analog for transmission.

4. Digital Signal Processing

Digital signal processing (DSP) refers to various signal processing tasks, including multiple mathematical operations such as modulation/demodulation, error correction, filtering and more.

5. Performance Comparison

Advanced phased array transceivers are a vital component in the development of next-generation 5G communication networks. Their capabilities in beamforming, mmWave communication, energy efficiency, and network integration contribute to delivering higher data rates, improved coverage, and enhanced user experiences in the 5G era. Digital beamforming to be much better than analog beamforming as offering adaptability to a wide range of frequency bands, beam steering for accurate user targeting, and support for spatial multiplexing and massive MIMO. Its effectiveness in interference mitigation and it well-suited for the dynamic and diverse 5G environment. On the other hand, analog beamforming provides a simpler and cost-effective hardware implementation. However, lacks the beam steering precision and spatial multiplexing capabilities. Hybrid beamforming combines the benefits of both techniques as mentioned in Table 1.

The utilization of phased-array systems in 5G millimeter-wave communication has been extensive due to the beamforming abilities enabled by the antenna array’s multiple elements. To evaluate phased array transceiver usually use some performances such as, RX NF (Noise Figure), TX 1dB (compression point), array size, power generation/ consumption and chip area. For a meaningful comparison, we have compiled a list of works that use CMOS technology at approximately 28GHz frequency.

Table 1. Comparison Of Beamforming Classification

Characteristic	**Digital Beamforming**	**Analog Beamforming**	**Hybrid Beamforming**
Beam Steering Precision	Precise and adaptive beam steering, allowing for accurate targeting of users.	Limited steering capabilities compared to digital.	Offers both adaptability and hardware simplicity, achieving reasonable beam steering precision.
Spatial Multiplexing	Enables spatial multiplexing and massive MIMO for higher network capacity	Limited ability for spatial multiplexing and MIMO.	Provides spatial multiplexing benefits while balancing hardware complexity and power consumption.
Interference	Effective interference mitigation due to narrow and adaptive beamforming.	Relatively lower interference rejection capabilities.	It improves the channel gain and minimize the interference.
Implementation Complexity	Typically requires more complex signal processing and hardware.	Simpler hardware implementation.	Balances signal processing complexity with hardware simplicity.
Support Multiple Streams	Multiple spatial streams can be simultaneously created for spatial multiplexing	It is difficult to support multiple streams for multiuser MIMO.	Support multiple data streams.
Cost	Generally higher implementation cost due to digital signal processing.	Lower implementation cost due to simpler hardware.	Offers a compromise between cost and performance by leveraging benefits from both techniques.

To analyzing the receiver performance, the receiver Noise Figure (RX NF) is crucial. The Table 2 shows that the reference [24] offers the best RX NF (3.2–4.4 dB) compared to the other two references. On the other hand, TX 1dB (OP) is essential for evaluating the linearity of the transmitter. While reference [25] provides the highest TX 1dB value, suggesting better linearity. In terms of physical size, all references occupy a relatively small area per channel, ranging from approximately 0.99 mm^2 to 1.16 mm^2.

Table 2. Performance Comparison of MM-Wave Phased Array Transceivers For 5G

Ref	[24]	[25]	[26]
Technology	Bulk CMOS	40nm CMOS	65nm CMOS
Frequency (GHz)	28	27–30	24–27
Phase Shifter Resolution	3 bit	3 bit	6 bit
RX NF (dB)	3.2–4.4	5.5–6	5.2
TX 1dB (OP)	>12	14.6	14.5
RX/TX Power (per channel (mW))	42/90	32/137	160/250
Area mm^2	1.16 (Die size per channel)	0.99 (one channel core area)	1 (one channel core area)

6. Conclusion

This article provides insights into the key considerations in phased array transceivers for 5G communication networks. The selection of mm-wave bands for 5G networks was primarily motivated by the need to significantly increase capacity, which has been achieved through the use of phased array antenna methods. The implementation of these methods is crucial to achieving the necessary link budget at HF- bands. The article focuses on beamforming techniques, including analog, digital, and hybrid methods. Additionally, the article describes the essential components required for designing a transceiver. It starts by introducing the concept of a phase shifter, which is a crucial component in controlling the phase of the transmitted signal. It then proceeds to discuss the role of a VGA, LNA, mixer, and PA in the design and implementation of transceivers for 5G communication networks.

Conflict of Interest

There is no conflict of interest for this study.

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