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Multi-Band Transmission of Reconfigurable and Truncated Baseband Carrier Aggregation on FPGA

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Abstract: The multiplier is a critical component in digital signal processing; for example the traditional array multiplier, MCM multiplier, DADDA Multiplier, its provides a fast and reliable technique, but it consumes a significant amount of area and power in all digital signal processing applications. This study of this work is a Multi-Band Transmitter digital signal processing application will have multiple baseband signal creation, FIR filter, multipliers. In Multi-Band Transmitter, the multiplier acquire huge importance to provide performance of area and power delay product, however the standard multiplier design takes up a lot of area and consumes a lot of power. Thus, this proposed work was introduced a Truncated Multipliers, rather than conventional multipliers, and its proposed for the design of the multi-band transmitter. A reconfigurable carrier aggregation transmitter with four and eight band bandwidths is also shown in this work, which employs several baseband signals shifted to a separate digital domain intermediate frequency (IF). 5G application of Carrier aggregation, for example, makes advantage of the reconfigurability of carrier spacing and the number of simultaneous carrier transmissions. Finally, this work has been created in Verilog HDL and synthesized on a Xilinx Vivado Zynq-7000 FPGA ZYNQ-7 ZC702, and all parameters in terms of area, delay and power have been compared.

Keywords: Carrier Aggregation, Multi band Transmission, Multiplier, Base band Signal generator.

1. INTRODUCTION

As a result of significant advancements in wireless communication, there has been a discernible rise in the need for a reconfigurable transmitter design that is both energy and spectrum efficient and has a high data rate. For the transmission of such vast amounts of data, the long term evolution advanced (LTE-A) standard recommends using a carrier aggregation system. In this system, a carrier that has a large bandwidth is divided up into numerous sub-carriers that have narrower bandwidths. After then, these sub-carriers are sent in the portion of the spectrum that is now open and accessible. Concurrent multi-band transmission must be enabled on a transmitter in order for it to be able to send out several sub-carriers all at once. In addition, the availability of these free transmission bands is subject to rapid shifts, which are based on the use of the bands by other service providers. As a consequence of this, the transmitter has to be equipped with a reconfiguration system that makes it possible to modify the centre frequency as well as the carrier spacing according to the availability of open bands. Carrier aggregation is gaining greater attention as a means of increasing signal bandwidth since there is less space available in the frequency spectrum band that can be used by the numerous wireless communication systems that are now in use. An example of this would be the LTE-Advanced standard [1]. The signal bandwidth together with its data rate may be enhanced when many RF channels are aggregated into one. In wireless communication, the carrier aggregation may be divided into two categories: intra-band and inter band carrier aggregations. The term "intra-band carrier aggregation" refers to the practice of using many distinct channels inside the same band. Baseband complex signal processing [2] or digital domain signal processing [3] may be used to partition the appropriate radio frequency (RF) channels for the purpose of realizing intra-band carrier aggregation while using a single frequency source. An inter-band carrier aggregation makes use of a number of distinct channels that are located on distinct frequency bands. However, the intra-band carrier aggregation may be accomplished with just many frequency source by using a method known as harmonic recombination.

This investigation into this work is a digital signal processing application that will be a Multi-Band Transmitter. It will feature multiple baseband signal, FIR filter, and multipliers. When it comes to the performance of a Multi-Band Transmitter's area and power delay product, the multiplier takes on a significant amount of significance; nevertheless, the usual multiplier design takes up a lot of area and uses a lot of power. As a result, the Truncated Multipliers were recommended for use in the design of the multi-band transmitter as part of this work that was being proposed. Conventional multipliers had previously been used. This study also presents a reconfigurable carrier aggregation transmitter that utilizes numerous baseband signals that have been moved to a distinct digital domain intermediate frequency [4]. This transmitter can support either four or eight band bandwidths (IF). For example, the Carrier Aggregation application of 5G takes use of the reconfigurability of carrier spacing as well as the number of simultaneous carrier transmissions. Section II describes Multi-Band Carrier Aggregation, and Section III describes Truncated Multiplier in base band carrier aggregation. Section IV describes the performance of results and implementation, and Section V provides a conclusion.

2. MULTI-BAND CARRIER AGGREGATION

Since of recent developments in wireless communication, there is a considerable rise in the need for an energy and spectrum efficient reconfigurable transmitter design that also has a high data rate. In order to facilitate the transmission of such a large amount of data at a high rate, a carrier aggregation scheme has been proposed as part of a long-term evolution advanced (LTE-A) standard. This scheme divides a carrier that has a large bandwidth into several sub-carriers that have narrower bandwidths. After then, transmission of these sub-carriers takes place in the free band that is accessible inside the spectrum. Because of this, a transmitter has to enable concurrent multi-band transmission so that it can send out all of these sub-carriers at the same time. In addition, the availability of these open transmission bands may be very variable and is often determined by how other service providers make use of these frequencies [5]. As a result, the transmitter has to include a reconfiguration scheme, which allows for the centre frequency and the spacing between carriers to be modified according to the availability of open bands. In order to obtain high efficiency at the amplification step in these types of transmitters, the delta-sigma modulation (DSM) approach is used. DSM takes signals with a changing envelope and a high peak-to-average power ratio (PAPR), and transforms them into signals with a constant envelope and a low PAPR. This enables the power amplifier (PA) to operate closer to the saturation area, where it can achieve the highest possible efficiency [6].

Recent times have seen the publication of a number of research articles that discuss simultaneous transmission across several bands. The multi-band concurrent transmission of several carriers in the case of an all-digital transmitter is a straightforward process. During this process, several DSM outputs generated by different DSM modulators operating in parallel mode are serialized into a single bit stream and unconverted by a multiplexer or serialized before being sent to a single PA for amplification. In the dual-band instance, this technique is suggested as an option. A strategy like this one makes use of high-speed serializes or multiplexers (MUX) with high sampling frequency, which is at least four times the needed carrier frequency. It is suggested that a highly effective concurrent dual-band DSM transmitter with digital outphasing be developed. This makes use of band-pass digital signal processing (DSM), radio frequency (RF) pulse width modulation (PWM), and outphasing in order to improve both the coding and the average power efficiency of the multiband transmitters. On the other hand, multi-band aggregated carriers may be made by utilizing an outphasing combiner to combine the outputs of many outphasing PAs. This results in a carrier with multiple bands. A complicated transmitter design is the consequence of having a significant number of modulation stages and PA units. In addition, a low combiner efficiency may be the cause of a decline in the overall performance of the transmitter [7]. In this study, an alternate method known as simultaneous transmission of multiple carriers is investigated. This method involves altering the DSM transfer function in order to show multiple pass bands. Because of this, it is possible to do signal up conversion and amplification with only a single RF chain and a single set of DSM, resulting in a minimal level of complexity. This strategy has been used in the beginning stages of development, although it has only been used to dual-band applications so far. This DSM transmitter can be tuned, but the frequency reconfigurability is restricted because of the integral connection between the baseband sampling frequency and the serialized sampling frequency. This is because the design of this transmitter is completely digital. Additionally, in order to achieve multi-band concurrent transmission, it is necessary to lessen the quantization noise that exists across the channels that are next to one another. Increasing the amount of DSM alone will not be sufficient to eliminate this altogether; an additional noise shaping function would be necessary instead. When using DSM with a single band, it is possible to eliminate out-of-band quantization noise by including an extra noise shaping function in the transmission process [8]. This strategy cannot be used in situations with contemporaneous multi-bands when the goal is to decrease noise, in particular between the numerous bands that are reconfigurable. Because of this, the extra noise shaping for the multi-band situation needs a filter that is capable of creating numerous stop-band notches and can be reconfigured so that it can adapt to the shifting frequencies of the transmission bands. In addition, this filter should not create a significant envelope fluctuation, since this would reduce the effectiveness of the PA. Therefore, a reconfigurable carrier aggregation transmitter with four and eight band bandwidths is also shown in this proposed approach. This transmitter uses several baseband signals that are shifted to a separate digital domain intermediate frequency (IF) of a 5G application using a digital domain intermediate frequency (DFIF). For instance, carrier aggregation takes use of the reconfigurability of carrier spacing as well as the number of simultaneous carrier transmissions in order to maximize efficiency. The architecture of baseband carrier aggregation shown in Fig. 1, it will have four base band, four interpolator and four carrier multiplication based IF Shifter, and finally added all the IF shifter output using Summations.

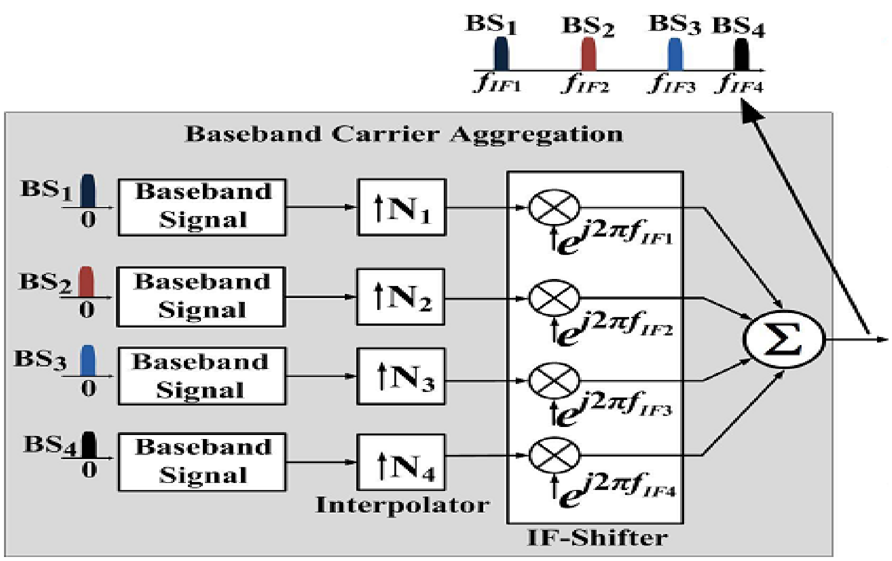


Figure 1 : Architecture of Baseband Carrier Aggregation

3. PRESENCE OF TRUNCATED MULTIPLIER IN BASE-BAND CARRIER AGGREGATION.

In this Digital signal processing application, the multiplier has the highest priority to reduce signal noise and fluctuation in all types of devices, and it's using applications on signal processing, image processing, and cryptography, as these methods have the highest priority in contemporary technologies such as 3G, LTE, Tele-Communication, audio and video processing, etc. In current mathematical processes, multipliers with more precision, speed, area, and power will be required. The multiplication process has three primary steps: partial product production, reduction, and addition.

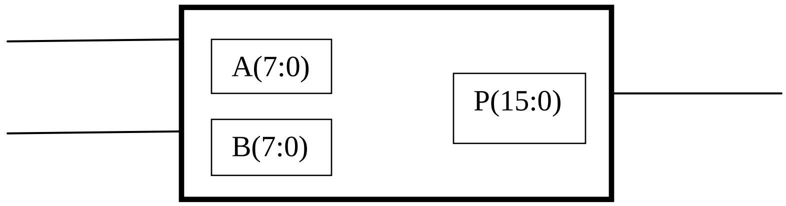


Figure 2 : Block Diagram of Standard 8x8 Multiplier

In this approach of multiplier types, an unique truncation multiplier is presented. The objective of this multiplier is to reduce the large area in the architecture of inner and outer architecture by employing the truncated rounded base technique, which compares the summing output of 2n-bit partial products, this operation of 2n-bits, and the MSB of rows and columns by means of truncation, deletion, and rounding to correction in an uneven method.

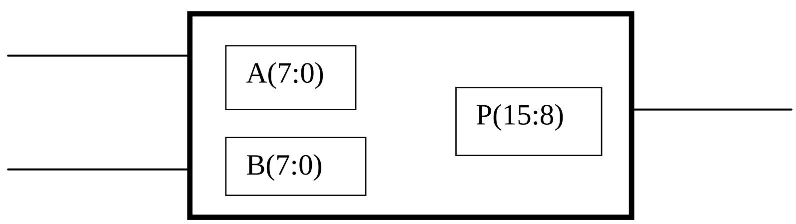


Figure3: Block Diagram of Truncated 8x8 Multiplier

A traditional multiplier of n x n bits computes and outputs the sum of 2n bits, as seen in Fig. 2, while a truncated multiplier computes and outputs the total of n bits, as depicted in Fig. 3. A truncated multiplier is a logic size and area efficient multiplier that is useful for increasing the substitution accuracy and reducing the hardware cost. This is because the truncated multiplier helps to produce the output of n-bits from n x n bits of multiplication in a shorter amount of time. In the partial product generation of the conventional method, a greater number of columns are required, which are eliminated in terms of area and power consumption, and the delay is also reduced in comparison to the conventional operation. However, this truncated multiplication has some drawbacks, as this multiplier is not focused on carry operations, such as addition and carry skip operations, and a number of full adders are used for addition, but the simple and efficient adder is not implemented. In this technique, truncated multipliers are wholly based on conventional full adders, as seen in Fig. 4. These multipliers have the potential to replace conventional multipliers in the Baseband carrier aggregation method. The proposed architecture of Truncated Multiplier using Baseband Carrier Aggregation architecture will shown in Fig. 5 [9].

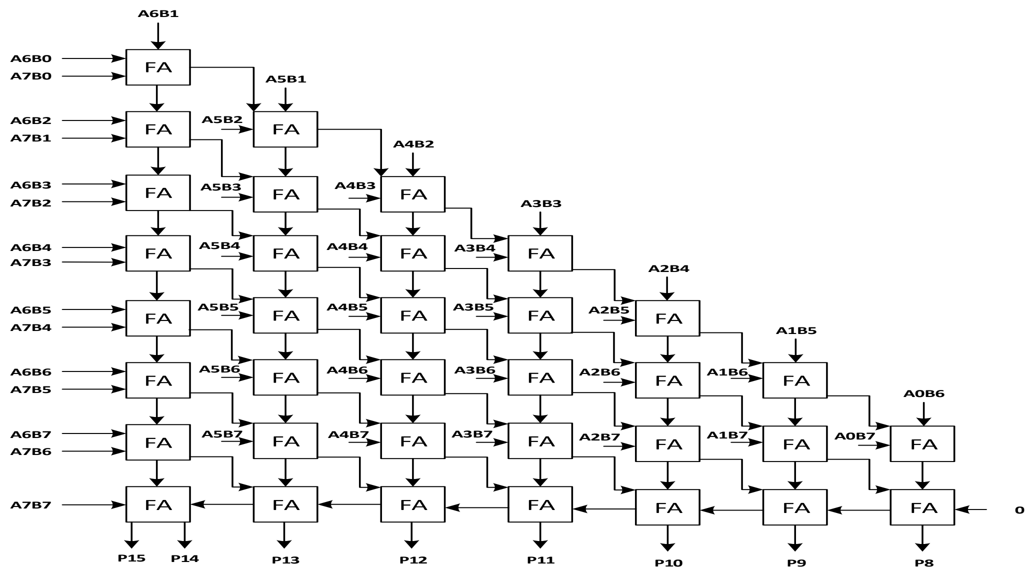


Figure 2 : Architecture of Truncated 8x8 Multiplier

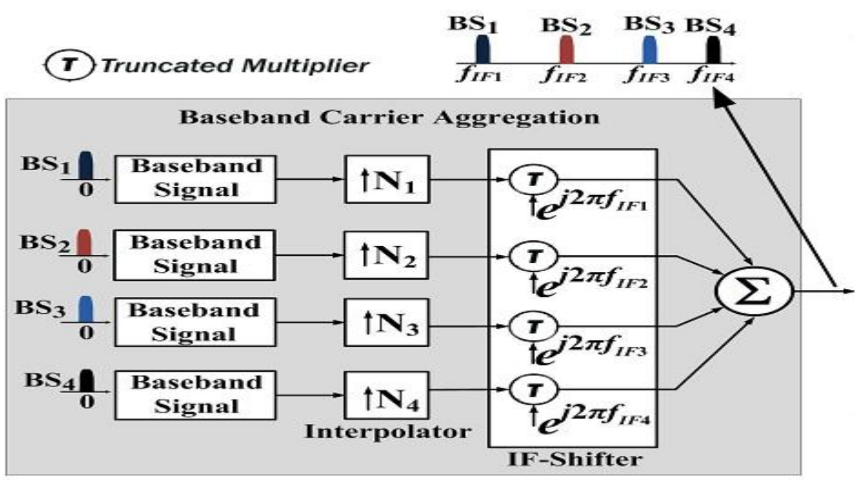


Figure 3 : Truncated Multiplier using Baseband Carrier Aggregation

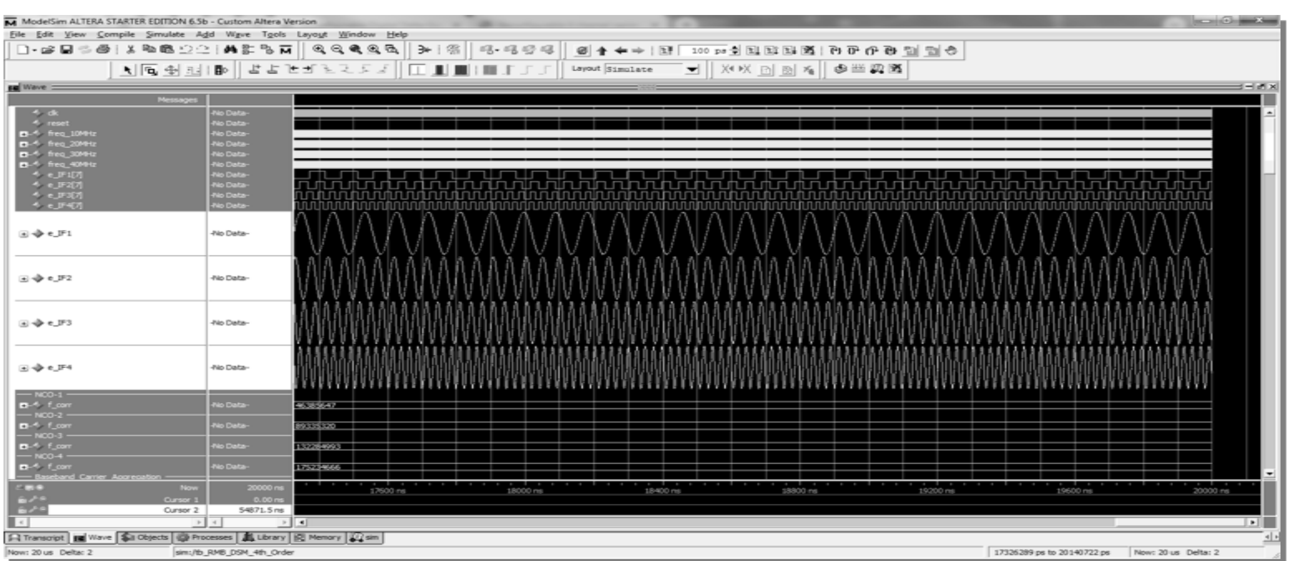


Figure 4 : Simulation results of Base band Carrier Aggregation using Truncated Multiplier.

4. RESULTS AND IMPLEMENTATION

A digital transmitter with reconfigurable configurations for simultaneous multi band broadcast of four and eight LTE carriers was updated in this method. Hence to allow controllability in terms of NTF zeros, an analytical derivation and pole zeros placement for the 4th order and 8th order baseband carried out. NTF's zeros may be reprogrammed to any frequency, presenting notches in the magnitude spectrum where carriers can be aggregated with the least amount of in band noise. This work has been developed in Verilog HDL and synthesized on a Vivado Zynq-7000 FPGA, and all parameters in terms of area, delay and power have been compared, the comparisons of 4th order and 8th order baseband carrier aggregation shown in Table.1 and the comparisons analysis chart shown in Fig.7. The simulation results of truncated baseband carrier aggregation will shown in Fig.6 and the 4th order RTL Schematic shown in Fig.8, and 8th order RTL Schematic shown in Fig. 9.

Table 1 : Comparisons of 4th and 8th Order Baseband Carrier Aggregation

	Comparisons of 4th and 8th Order Baseband Carrier Aggregation, Synthesized on Vivado Zynq-7000 FPGA			
	4th Order		8th Order	
	Conventional	Truncated	Conventional	Truncated
Aggregated Band	4	4	8	8
Sampling Frequency	1 GHz	1 GHz	1 GHz	1 GHz
Transmit Signal	LTE	LTE	LTE	LTE
Bandwidth (MHz)	10/20/30/40	10/20/30/40	10/20/30/40/50/60/70/80	10/20/30/40/50/60/70/80
Number of LUT	238	120	490	255
Number of FF	46	5	91	9
IOB	46	46	82	82
BUFG	1	1	1	1
Dynamic Power (W)	12.089	10.349	19.537	16.252

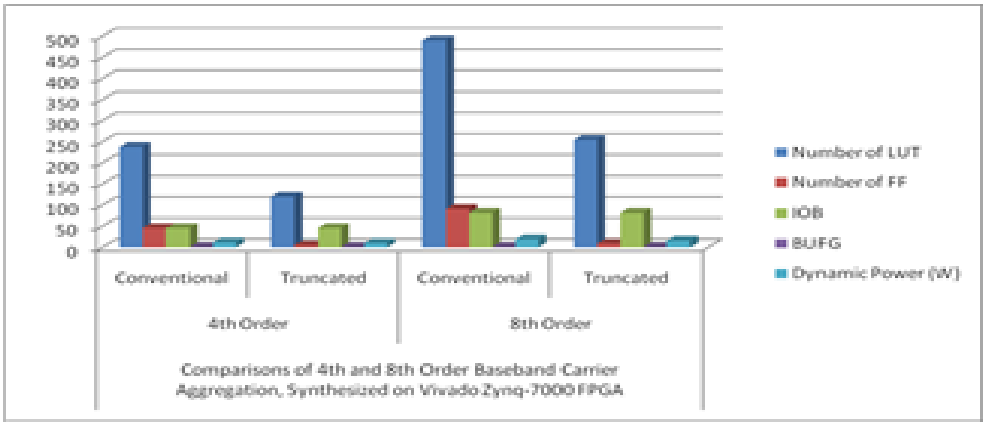
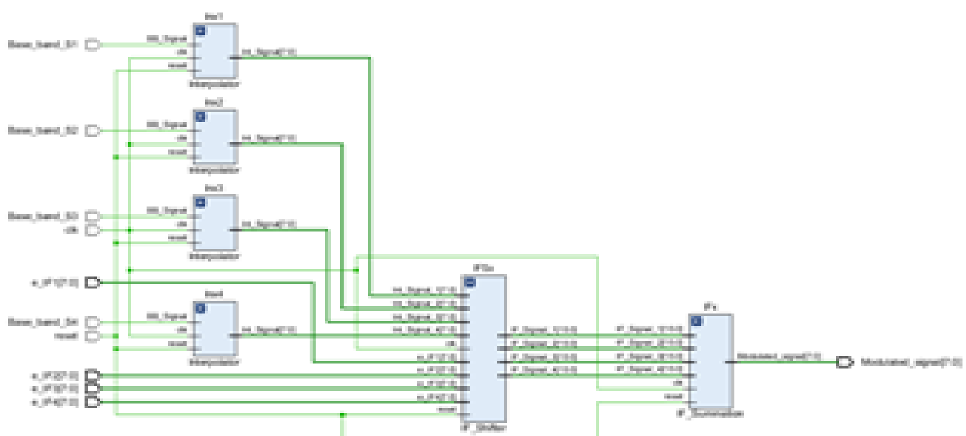
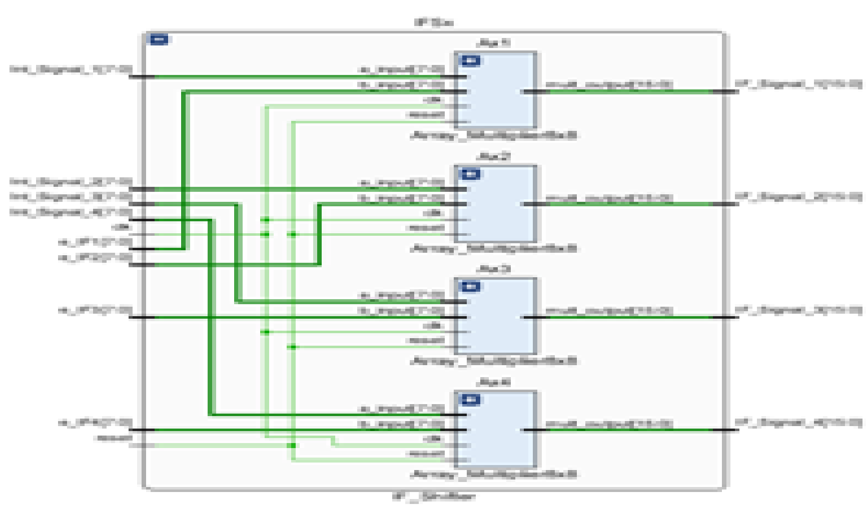


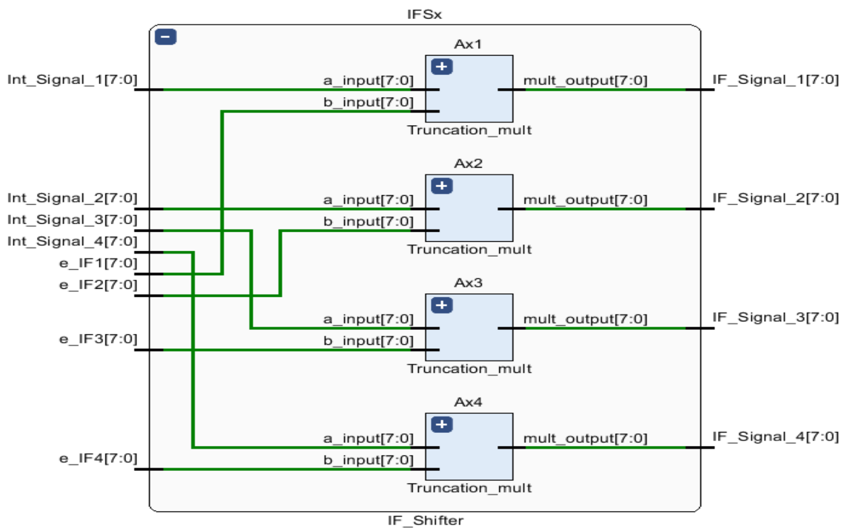
Figure 5 : Comparisons Analysis Chart of Base band Carrier Aggregation



(a)

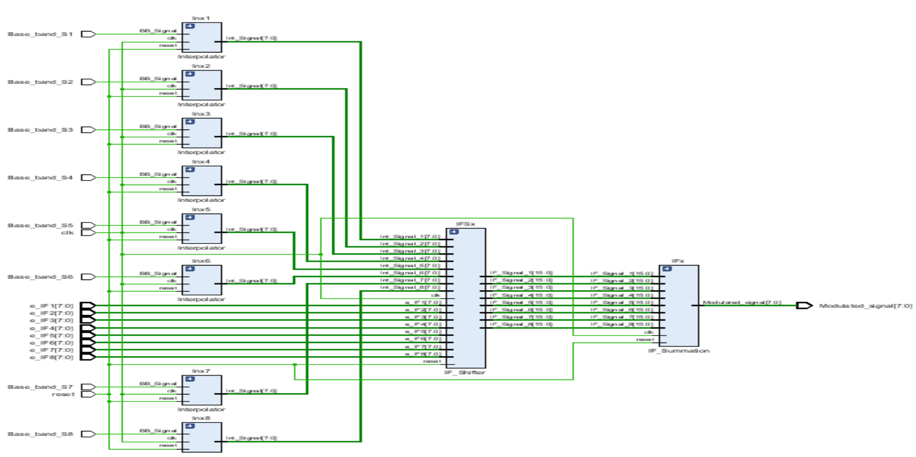


(b)

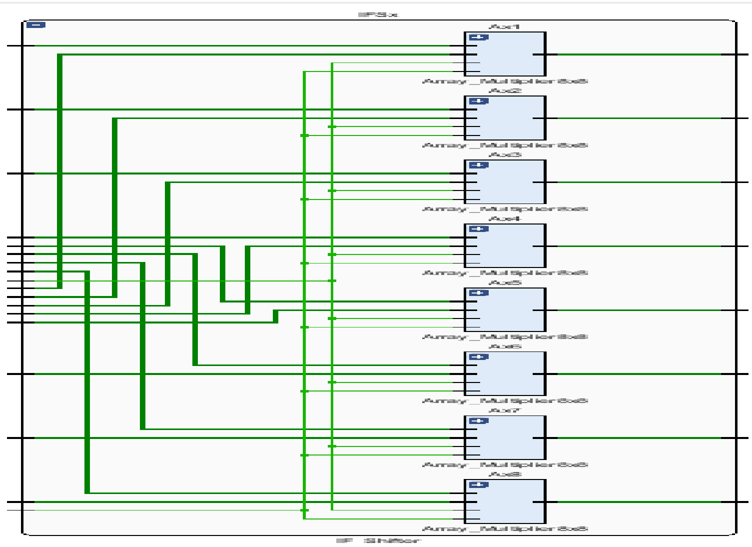


(c)

Figure 6 : RTL Schematic of 4th order Baseband Carrier Aggregations:
(a) Top module architecture, (b) IF Shifter using Array Multiplier, (c) IF Shifter using Truncated Multiplier



(a)



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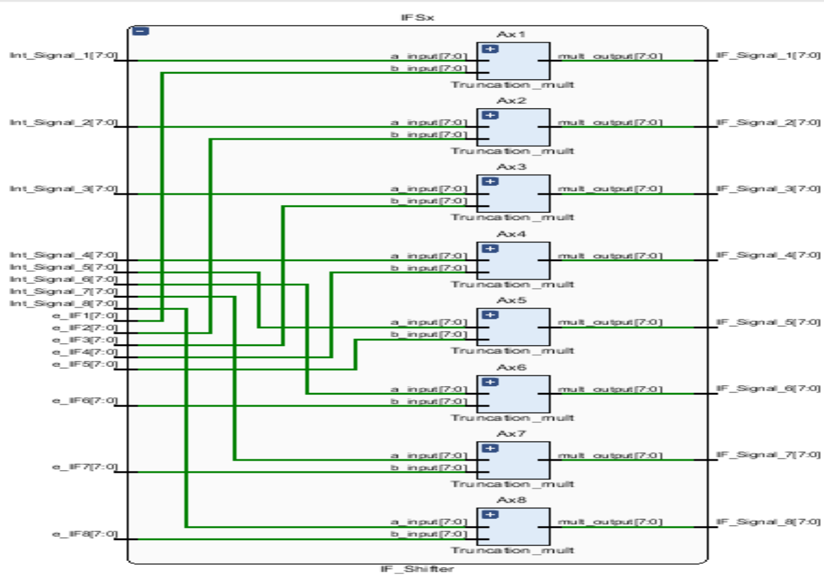

(c)

Figure 7 : RTL Schematic of 8th order Baseband Carrier Aggregations:
(a) Top module architecture, (b) IF Shifter using Array Multiplier, (c) IF Shifter using Truncated Multiplier

5. CONCLUSION

This Work describes a reconfigurable multiband carrier aggregation transmitter that can broadcast up to eight LTE carriers simultaneously, supporting several standards and multiple streams. It is possible to minimize the amount of LUT and Slice register as well as latency and power consumption in Carrier Aggregation by using a truncated multiplier. For 5G, a separate digital domain intermediate frequency will be generated by multiplying the carrier signal and the base band message signal. For the proposed work on aggregating up to eight baseband LTE signals with an overall aggregated bandwidth of 160 MHz and a sampling frequency of 1GHz, modeling and experimentation have confirmed the results. With an 8th order reconfigurable multiband delta sigma modulator, the proposed work would reduce the size of the logic used in mathematical operations by using an energy quality scalable truncated technique. This truncated technique will reduce the amount of internal and external logic in the Base band carrier aggregation architecture.

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