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Implementation of 8th Order Delta Sigma Modulation with Reconfigurable Multiple Bandwidth using Truncated Method on FPGA

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Abstract*:* In modern wireless communication technology, an energy and spectrum efficient reconfigurable transmitter design with a high data rate is required; and the conventional systems are wasteful during amplification. For high data rate transmission, LTE-A supports a reconfigurable transmitter design with carrier spacing and continuous carrier aggregation. This study shows how the carrier signal's wide bandwidth is fragmented into several smaller sub-carriers, thus 5G applications need multiband transmission. This work presents an 8th order reconfigurable multi-band delta sigma modulator (RMB - DSM) that enables the noise transfer function zero to be modified to fall at multiple carrier aggregation frequencies. When using several transmission bands, quantization noise between the bands becomes a major issue. Thus, we implement a multi-band additional noise shaping (ANS) function, which greatly reduces on noise over a range of pass-bands by creating notches around each carrier. Systematically designing a 4th order reconfigurable multi-band delta sigma modulator will increase logic size and energy consumption, and the logic's arithmetic operations will need a significant amount of logic in VLSI implementation. The 8th order reconfigurable multi-band delta sigma modulator given in the suggested study is an energy quality scalable truncated technology that would lower the quantity of logic size in arithmetic operations. With these truncated methods, the RMB-DSM architecture's internal and external logic are reduced, and the n x n multiplication yields just n-size output. The proposed approach has been proven by simulation and experiment for aggregating up to four and eight multiband long term evolution (LTE) signals, yielding a total bandwidth of and a sampling frequency of 1 GHz. The Xilinx Zynq 7000 FPGA will be used to implement both existing and proposed designs, and their logic size, latency, and power consumption will be compared.

Keywords: *Truncated Multiplier, Carrier Aggregation, Multi-Band Transmission, Base band signal generator.*

1. Introduction

In significant advancements in wireless communication, that has been a substantial increases in demand for energy and spectrum efficient, reconfigurable transmitter designs with a high data rate has increased significantly. For such high data rate transmission, the long term evolution advanced (LTE-A) standard suggests a carrier aggregation system in which a carrier with a wide bandwidth is divided into several sub-carriers with narrower bandwidths. Subsequently, these sub-carriers are sent on the spectrum's open bands. To simultaneously broadcast several subcarriers, a transmitter must support concurrent multi-band transmission. In addition, the availability of these free transmission bands may change rapidly based on the use of these frequencies by other service providers. Consequently, the transmitter must be equipped with a reconfiguration mechanism that allows the centre frequency and carrier spacing to be modified dependent on the availability of free bands. The delta sigma modulation (DSM) technique is used in such transmitters to attain high amplification efficiency. DSM converts envelope-changing signals with a high peak-to-average power ratio (PAPR) into signals with a constant envelope or a low PAPR, enabling the power amplifier (PA) to operate near the saturation zone for maximum efficiency. By adjusting the zero position of the noise transfer function, DSM's adaptable design offers the extra advantage of changing carrier positions (NTF).

In the proposed work, the wide bandwidth of the carrier signal is subdivided into several subcarriers with narrow bandwidth. Multiband transmission will be very beneficial for 5G applications. In this study, the noise transfer function zero may be adjusted to fall at various frequencies where the carriers are aggregated. The 8th order reconfigurable multi band delta sigma modulator (RMB-DSM) replaces the 4th order approach. In multi band transmission, quantization noise between transmission bands is the fundamental concern. Consequently, a multi band additional noise shaping (ANS) function is included, which generates notches around each carrier and reduces noise levels across several pass bands. Existing 4th order reconfigurable multi-band delta sigma modulator systematic design will increase logic size and energy consumptions, and logic arithmetic operations will need a high logic quality in VLSI implementation. Consequently, the proposed work would lower the quantity of logic size in arithmetic operations by using an energy quality scalable truncation approach that is present in a 4th order

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and 8th order reconfigurable multi band delta sigma modulator. This truncated technique that has been provided will result in an increase in the size of the output from n x n multiplication while simultaneously decreasing the amount of the logic that is both internal and external to the RMB-DSM architecture.

The goal of this research is to develop a digital signal processing application for use in a Multi-Band Transmitter with a programmable digital delta sigma modulator. Multiple baseband signals, DSM, FIR filter, and multipliers will be included. In terms of the performance of a Multi-Band Transmitter's area and power delay product, the multiplier comprises a significant portion of logic size; nevertheless, the conventional multiplier design occupies a large amount of area and consumes a great deal of power. As a consequence, it was proposed that the Truncated Multipliers be used in the design of the multi-band transmitter as part of this study. This work also proposes a reconfigurable carrier aggregation transmitter that employs several baseband signals shifted to a different intermediate frequency in the digital domain. This transmitter is capable of supporting both fourth order and eighth band bandwidths (IF). 5G's Carrier Aggregation application, for instance, makes advantage of the reconfigurability of carrier spacing and the number of simultaneous carrier transmissions. Multi-Band Transmission of reconfigurable 4th and 8th order digital delta sigma modulator is described in Section II, and proposed and modified multi-band transmission of reconfigurable 4th and 8th order digital delta sigma modulator is described in Section III. Section IV describes the FPGA results and implementation, Section V gives a hardware implementation and comparisons, and Sections VI and VII provide a literature review and conclusions, respectively.

2. Multi-band Transmission of Reconfigurable 4th and 8th Order Digital Delta Sigma Modulator

Multi-band transmission with a single delta-sigma modulator and radio frequency sequence is shown in Fig 1. A base band carrier aggregation unit and a delta sigma modulator conversion block start making up the design. The multiple bands are converted to the necessary carrier frequencies by the quadruple up converter, which gets the in phase (I) and quadrature (Q) components from the delta sigma modulator conversion block. Power amplification (PA) is used to boost the strength of the individual carriers, and a band pass filter is then used to rebuild the envelope for transmission. As can be seen in Fig. 1, in the digital domain, a new signal is generated in which the four carriers are located at their respective intermediate frequencies (IFs) F1, F2, F3, and F4. To convert this signal to a 4-level delta sigma modulator signal, the author proposes using a single 4th-order delta sigma modulator (DSM) function. Each I and Q component of aggregated carrier signals will pass via a 4th order delta signal modulator and then an enhanced noise shaping (ANS) function in a delta sigma modulator conversion block, as illustrated in Fig. 1. Four intermediate frequencies (IFs) accommodate the four baseband signals. In order to reduce inter-band quantization noise, the magnitude spectrum of a 4th order delta sigma modulator is reprogrammed to produce zeros at the required pass bands, and the enhanced noise shaping is reprogrammed to create multiple notches between these pass bands.

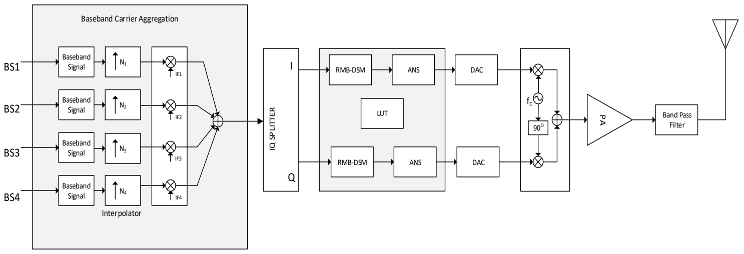

Fig 1 : Architecture of Reconfigurable transmitter architecture for concurrent multi-band transmission using 4th order RMB-DSM.

In the proposed digital domain work, eight base band signals have been produced at different intermediate frequencies (IFs), F1, F2, F3, F4, F5, F6, F7, F8 and then aggregated to form a new signal with eight carriers at independent IFs. This signal is then modulated by an 8th order delta sigma modulator (DSM) function that we propose. An 8th order delta sigma modulator is shown in Fig. 2 followed by an improved noise shaping (ANS) function in a delta sigma modulator conversion block for each I and Q component of signals with aggregated carriers. The eight baseband signals may be organized by means of these eight intermediate frequencies (IFs). Reprogramming the 8th order delta sigma modulator's magnitude spectrum to produce zeros at the desired pass band and the increased noise shaping to create numerous notches between these pass bands has reduced inter band quantization noise. Fig. 2 shows the baseband carrier aggregation block, which consists of an interpolator, an IF-Shifter, and a signal combiner. Each of the eight signals in the base band was associated with either four main carriers or eight sub-carriers of a wide-band signal. Sampling frequencies FB1, FB2, FB3, FB4, FB5, FB6, FB7, and FB8 are used to get the complex form (IB S + j * Q B S) of the input digital base band signals BS1, BS2, BS3, and BS4. To reach the same base band sampling frequency as RMB-DSM, i.e., FDSM, these base band signals are interpolated using a unique interpolation factor.

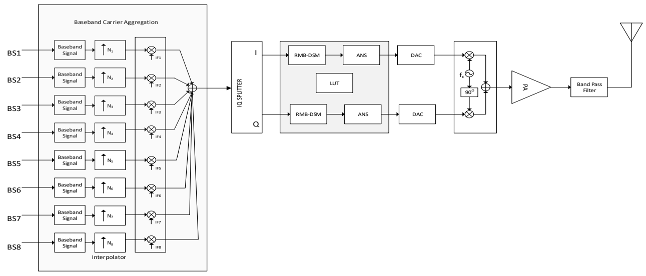

Fig 2 : Architecture of Reconfigurable transmitter architecture for concurrent multi-band transmission using 8th order RMB-DSM.

This solution included the modification of a digital transmitter that had changeable settings. This allowed for the simultaneous multi band broadcast of just four LTE carriers. An analytical derivation and the placement of pole zeros for the 4th order discrete-time stochastic model are thus carried out in order to make controllability possible in terms of NTF zeros. The zeros of an NTF may be reprogrammed to any frequency, creating notches in the magnitude spectrum in which carriers can be aggregated while experiencing the smallest amount of in-band noise. An ANS block is deployed in the space between the transmission bands in order to improve the out of band quantization noise. The recommended approach for ANS minimizes out of band quantization noise by inserting notches in the sidebands. This improves the CE of DSM when it is used in conjunction with a commercial AWG-based system. In the 15 MHz frequency region, the proposed approach may aggregate a maximum of four LTE carriers. The suggested technique incorporates both reconfigurability and concurrent multiband transmission with CE improvement. In addition, the system is flexible. When the correct off value is used, the ANS transfer function may optimize the shortest gap between transmission bands while still preserving acceptable in band flatness. This is done in order to compare the emitter's overall performance to that of classic transmitter designs. The sample frequency of the DSM is another factor that plays a role in determining the maximum frequency range that carriers may be programmed to operate within. As a consequence of this, the ANS transfer function, in conjunction with the highest possible frequency of DSM, is what establishes the scalability for managing a large number of carriers.

3. Proposed and Modified Multi-band Transmission of Truncated Reconfigurable 4th and 8th Order Digital Delta Sigma Modulator

The design of the RMB-DSM, a 4th order reconfigurable delta sigma modulator, is shown in Fig. 3. This modulator may be utilized for both multi-band and single-band transmission. In this case, a one-order circuit includes a multiplier, adder, delayed element, and feedback element. Using the RMB-DSM architecture, the parameters a, a1, a2, a3, a4, b, b1, c, c1, c2, c3, c4, d, g1, and g2 define the RMB DSM's operating configuration. These parameters are revised in light of the number of transmission bands and the necessary notch frequencies. For the purpose of computing these coefficients, let us assume that, in the case of quad band transmission, the relevant notch frequencies are fn1, fn2, fn3, and fn4. Coefficients of the Radial Basis Function in the DSM are as follows: A1, A2, A3, A4, A5, B1, P1, P2, P3, P4, and P5. In the appendix, we provide a detailed explanation of how to get these coefficients from known zero values. Fig. 4 depicts the RMB-DSM design, which is a systematic implementation of an 8th order reconfigurable delta sigma modulator that may be used for multiband and single band transmission. In a single order, a multiplier, an adder, a delayed element, and a element feedback are provided. The working configuration of RMB DSM is determined by the parameters a, a1, a2, a3, a4, a5, a6, a7, a8, b, b1, c, c1, c2, c3, c4, c5, c6, c7, c8, d, e, f, g, h, g1, g2, g3, g4 in the RMB-DSM architecture. This order number is modified according to the number of transmitting bands and the required notch frequencies. For the calculation of these coefficients in the case of octa band transmission, consider that the relevant notch frequencies and RMB DSM coefficients are fn1, fn2, fn3, fn4, fn5, fn6, fn7, and fn8; A1, A2, A3, A4,.... A8; B1, P1, P2, P3,.... P9; and P1, P2, P3,.... P9. The procedure for determining these coefficients using the zero value that has been established is outlined in the appendix. The Schematic of DSM Conversion block with RMB-DSM and ANS Block shown in Fig.5.

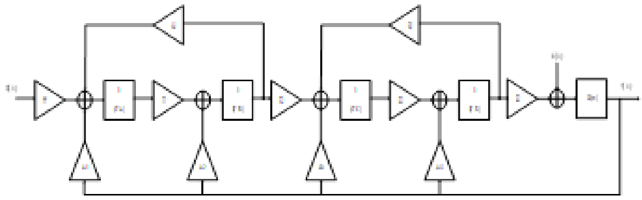

Fig. 3 Reconfigurable 4th Order RMB-DSM Architecture

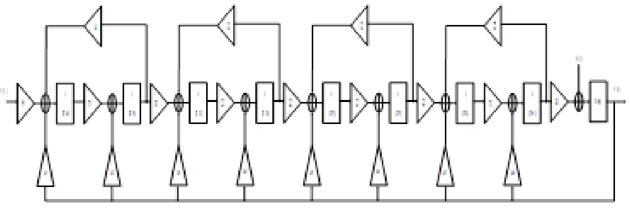

Fig 4 : Reconfigurable 8th Order RMB-DSM Architecture

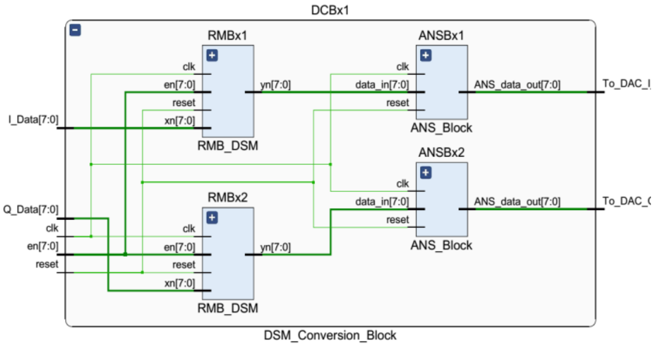

Fig. 5 RTL Schematic of DSM Conversion Block

In despite the reality that the carrier aggregation technique was successfully put into action, the degree of quantization noise that exists in the spaces in between the transmission bands is still rather high. Since the primary purpose of the NTF zeros of RMB-DSM is to cut down on the in-band noise that occurs inside transmission bands, the ANS may be used to cut down on the noise that occurs between these various transmission bands. If this is not avoided, a significant portion of the DC power that is used in the PA would be squandered in the process of amplifying the quantization noise, which in turn reduces the overall efficiency of the transmitter. Following the RMB-DSM, an ANS block is added in order to enhance the CE by lowering the amount of out-of-band quantization noise that is present around each transmission band. Despite the fact that this will cause a very little envelope change in the output of the DSM, it will result in an increase in the overall efficiency of the transmitter. Since it leads to a noticeably better CE in contrast to the modest deterioration at the amplification stage that is predicted with the rise in PAPR of the DSM signal, and because this improvement comes about as a consequence of the former. The architecture of the ANS is seen in Figure 8; it is made up of two magnitude scaling blocks and two delay units, each of which has a distinct delay. One such formulation for the ANS transfer function is as follows:

$$H(w) = \alpha_1 e^{-jw\mu_1}[1 + \frac{\alpha_2}{\alpha_1} e^{-jw(\mu_2-\mu_1)}]$$

where µ1 and µ2 represent the delay factors, and µ1 and µ2 represent the magnitude scaling factors, as seen in Fig. 6. Both the µ1 and µ2 delay factors may take on any integer value, and they are chosen in such a manner that the maximum value of the signal is unaffected by the ANS. Therefore, one is always equal to the sum of minus one and minus two. Adding envelope variation to the ANS output may be accomplished by modifying the values of α1 and α2. Doing so will result in a reduction in the amount of out-of-band quantization noise, which will ultimately lead to an improvement in the CE. Because the suggested ANS method also results in some envelope fluctuation when applied to 3-level DSM, it is compared not only with standard 4-level DSM but also with 4-level DSM in which no ANS is used. The architecture of ANS Block using Array Multiplier and Truncated multiplier shown in Fig. 7 and Fig. 8.

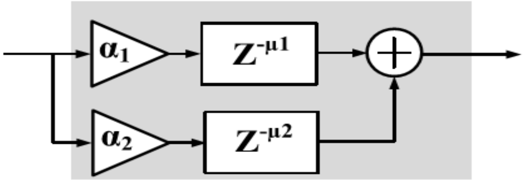

Fig 6 : The architecture of ANS Block

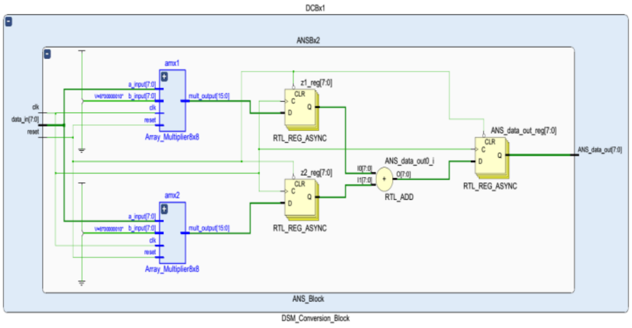

Fig 7 : The Architecture of ANS Block using Array Multiplier

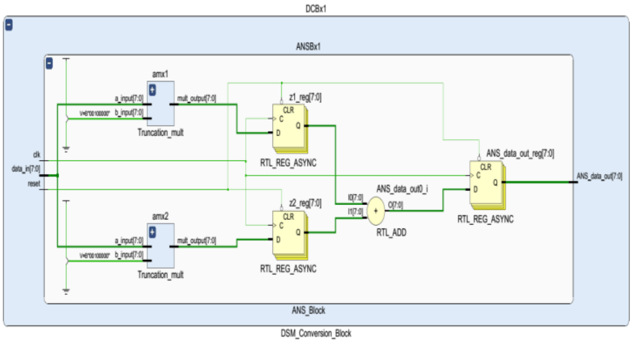

Fig 8 : The Architecture of ANS Block using Truncated Multiplier

4. FPGA Results & Implementation

For the purpose of aggregating up to four and eight multiband long term evolution (LTE) signals, the proposed method of this RMB-DSM Conversion has been proven by simulation and synthesized in the Xilinx Vivado Software. This has resulted in a total bandwidth of and a sampling frequency of 1 GHz in simulation. The Xilinx Zynq 7000 FPGA will be utilized in the implementation of both existing and proposed designs. The logic size, latency, and power consumption of these designs will be compared, and the results of these comparisons will be updated in Table 1 and the top module RTL Schematic that is depicted in Fig. 9 and comparison analysis chart shown in Fig. 10, and Fig. 11 shows the Simulation Results.

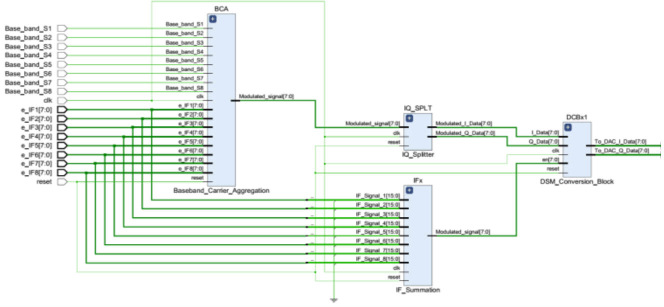

Fig 9 : Top Module architecture of RMB-DSM Conversion RTL Schematic

Table 1: Comparisons of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter

	Comparisons of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter			
	4th Order		**8th Order**	
	Conventional Method	**Truncated Method**	**Conventional Method**	**Truncated Method**
Aggregated Bands	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
Aggregated Bandwidth (MHz)	100	100	360	360
DSM Order	4	4	8	8
DSM Levels	3	3	7	7
PA Used	Yes	Yes	Yes	Yes
Number of LUT	591	295	914	395
Number of FF	274	122	392	169
IOB	54	54	90	90
BUFG	1	1	1	1
Dynamic Power (W)	28.254	22.068	35.417	23.059
Static Power (W)	1.039	1.039	1.039	1.039

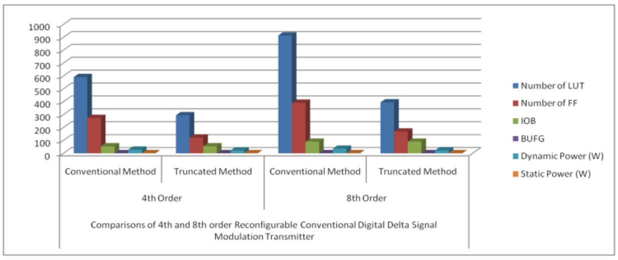

Fig 10 : Comparisons analysis of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter

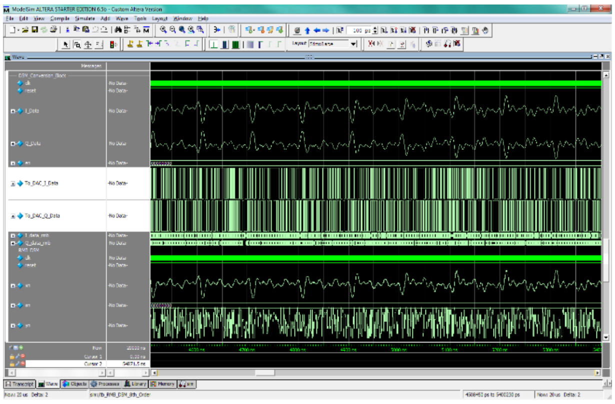

Fig 11 : Simulation Results of 8th order DSM Conversion Block

5. Hardware Implementation

In this Work, specifics the measurement setup and the experimental validation of the proposed technique are discussed in depth. The baseband signals are created and aggregated to the IF frequencies before being transformed to a 3-level DSM signal in-house using a voltage control oscillator at a frequency range of 10 to 40 KHz. The I and Q output of the proposed DSM are played back using AWG, which the output immediately goes through. After that, the AWG makes use of its internal DACs and the digital quadrature up conversion capability in order to convert the aggregated LTE carriers to the carrier frequency of about 1 MHz while the system clock is operating at 50 MHz. The results of the comparisons of logic size with LUT, FF, and Power are going to be updated in the table. II. The Comparisons analysis Chart is shown in Fig. 12, and the Hardware Implementations are displayed in Fig. 13.

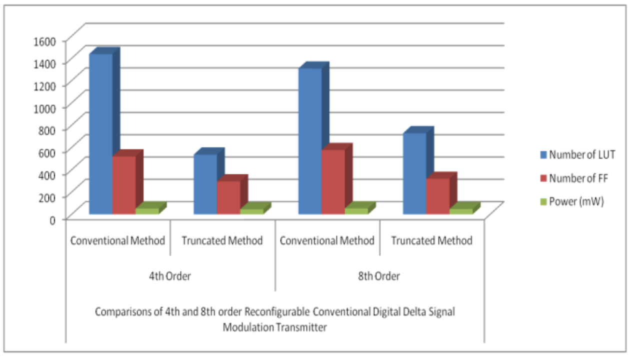

Fig 12 : Comparisons analysis of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter

Table 1: Comparisons of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter

	Comparisons of 4th and 8th order Reconfigurable Conventional Digital Delta Signal Modulation Transmitter			
	4th Order		**8th Order**	
	Conventional Method	**Truncated Method**	**Conventional Method**	**Truncated Method**
Aggregated Bands	4	4	8	8
System Clock	50 MHz	50 MHz	50 MHz	50 MHz
DAC Interface Clock	1 MHz	1 MHz	1 MHz	1 MHz
Sampling Frequency	10 ~ 40 KHz	10 ~ 40 KHz	10 ~ 80 KHz	10 ~ 80 KHz
Number of LUT	1438	536	1308	727
Number of FF	519	295	576	318
Power (mW)	51	45	53	47

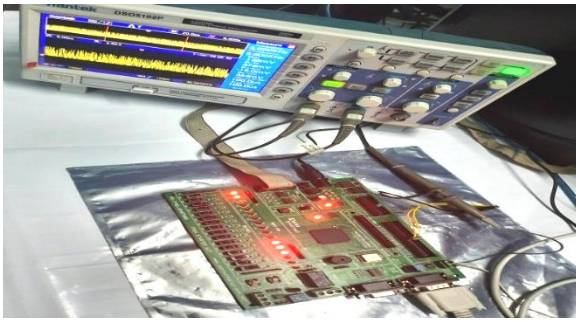

Fig 13 : Hardware Implementation setup and tested DSM Conversion Block DAC Output in Oscilloscope

Fig 14 : Hardware Implementation setup and tested Noise Shaping ANS DAC Output in Oscilloscope

6. Conclusion

Modern wireless communication technology requires an energy- and spectrum-efficient reconfigurable transmitter with a high data rate. LTE-A uses a reconfigurable transmitter with carrier spacing and continuous carrier aggregation for high-data-rate transmission. This research illustrates how 5G applications require multiband transmission since the carrier signal's vast bandwidth is fragmented. This study provides an 8th order reconfigurable multi-band delta sigma modulator that allows the noise transfer function zero to fall at numerous carrier aggregation frequencies. Quantization noise between transmission bands is a problem. Thus, we design a multi-band additional noise shaping (ANS) function, which decreases noise across pass-bands by notching each carrier. The 8th order reconfigurable multi-band delta sigma modulator in the recommended research reduces logic size using Truncated Multiplier in arithmetic operations. With these abridged approaches, RMB-internal DSM's and external logic are decreased, and n x n multiplication provides n-size output. This method aggregates up to four and eight multiband LTE signals, producing a 1 GHz overall bandwidth and sampling frequency. The amount of processing power required by the Base band carrier aggregation Digital Delta Sigma Modulation architecture will be reduced by using this truncated method.

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