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GMSK Modulator and Demodulator Techniques on Hardware and Software Platform with Research Gaps and Trends

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Abstract*: *The modulation system of Gaussian filtered Minimum Shift Keying (GMSK) is a narrow band and constant envelope format that is acceptable for bandwidth, power restricted environment of radio communication. The modulation technique encounters extensive approval from the cellular network market. Nonetheless, the present GMSK modulation scheme is majorly held back due to its two critical shortcomings, the necessity at the receiver section to shape the GMSK's symbol pulses for ISI and the absence of amended GMSK model including the bandwidth efficiency to improvise the link quality. At the moment, rare progressive research studies are being conducted in favor of hardware implementation of GMSK that can satisfactorily be applied to any GSM or AIS application. A standardized algorithm or framework that can guarantee high resiliency is yet to be introduced. Therefore, the paper gives a comprehensive outlook in the direction of understanding the drawbacks that are posed for the implementation of GMSK.

Keywords: Modulation, Minimum Shift Keying, Gaussian Minimum Shift, Keying, Gaussian Filter, FPGA

I. INTRODUCTION

The proliferation of computer systems in the present systems, have rapidly increased the necessity for data transmission on wireless links [1]. The binary data comprising of sharp edges,"zero to one" and "one to zero" state transitions, an outcome in harmonic information that is not likely to besuitable for the RF transmission [2]. Various factors are the reason for selecting a specific modulation scheme in the wireless communication. The cellular communication performing ability relies majorly on the modulation efficiency corresponding to the respective technique chosen for operation [3]. The commonly used constant envelope and linear modulation schemes used are GMSK-Gaussian Minimum Shift Keying, MSK-Minimum Shift Keying, BPSK- Binary Phase Shift Keying, QPSK-Quadrature Phase Shift Keying, etc. [4]. The prime aim of the modulation technique is to provide high-quality transmission in the transporting a message signal via a radio channel long with improvised energy efficiency and lesser bandwidth requirement [5].

Systems working on cellular radio communications permit the reuse of a higher density co-channel geographical path and are responsible for attaining efficient utilization of spectrum [6]. The digital technologies are efficiently implied in the successfully achieving the flexible control systems, providing high-grade mechanism apart from the reliable bit transmission property [7]. The variant properties of an environment depend upon the mobile-radio might possess adverse effect over the signal which propagates in the radio medium, and this would indeed show an impact on the service's quality [8]. The next generation looks forward at the upcoming technology of that is derived from the voice encoding technologies, digital signal processing techniques that till date have shown effectiveness in providing excellent processing speed. The digital modulation field had been flourishing since trending standards such as the Cellular Digital Packet Data (CDPD) mention the Gaussian Minimum Shift Keying (GMSK) to modulate the signal [8]. Moreover, GMSK is a fundamental yet instrumental approach addressed to incorporate digital modulation in the transmission of wireless data [9]. GMSK has been adopted by the European global system as a digital modulation scheme for cellular communications (GSM) standards because of the constant envelope, and spectral efficiency pertained to it[10]. The two attributes featured in GMSK impose superior performance when the non-linear amplifiers and Adjacent Channel Interference (ACI) is present [11]. As the basis for acquiring a GMSK signal is an MSK signal, including the operation of filtering the signal with a Gaussian filter providing a narrow-width output. It is likewise interpreted that a Continuous-Phase Frequency Shift Keying (CPFSK) is having a modulation index of the value 0.5 or being filtered to the Offset Quadrature Phase-Shift Keying (OQPSK) signal [12]. The paper contributes to active exploration of proposed work for implementing GMSK. Section 'A' focuses on the background part of prior review study following which the research problem is highlighted in Section 'B' with the proposed solution being elaborated in Section 'C'. Section 'D' and 'E' briefly discuss regarding the GMSK basics and the generation schemes respective to it. In the following Section II, the exiting research study in concern with GMSK execution over FPGA and MATLAB are discussed. Section III highlights the research gap observed in from the previously proposed manuscripts following which research trends are grounded in Section IV. The conclusion and future work are described in Section V.

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A. *Background*

The section foregrounds the studies that exist for addressing the scarcity of GMSK implementation on the FPGA platform. In work done by Babu et al. [13], a cost-effective solution for implementing the GMSK over the FPGA platform was carried out. The proposed scheme holds well only for a project of GSM-Base Transceiver Station. Also, the solution could be utilized when less number of Inter-Symbol-Interferences (ISI) is operated at. Another approach of Bax and Copeland [14] introduced only transmitter architecture for the GMSK modulation. No proposal was addressed considering the same to design a receiver. With this, the transmitter architecture was applicable only to the GSM standard applications. Even when the addressed transmitter was made to operate with few specific applications, modifications were necessary to accomplish the GMSK modulation on FPGA. However, distinguishing from these, some manuscripts highlight the GMSK modulation implementation on Simulink.

B. *Research Problem*

Modern systems that work on the principles of digital communication make use of various kinds of modulation schemes to ensure the adequate spectrum performance in non-ideal surroundings. GMSK is one of the most popular types of static-envelope modulation, majorly involved in the operation of wireless systems limiting the spectral bandwidth range by Gaussian filtering the signal. GMSK is one of the most popular types of static-envelope modulation, majorly involved in the operation of wireless systems limiting the spectral bandwidth range by Gaussian filtering the signal. Since the GMSK modulation format at the demodulator section has to handle a massive volume signals in real time scenarios, the need of sampling equipment increases. The scheme suffers from the issue of high ISI-Inter Symbol Interference profound in case demodulation, requiring extremely complex algorithms for extracting the symbols. A wideband phase block for modulation has to be included in the polar transmitters of GMSK that will function by the input attained from bandwidth constrain Phase Locked Loop (PLL).

C. *Proposed Solution*

The study stresses over discussing the already recommended techniques that address the GMSK modulator, de-modulator implementation on FPGA and MATLAB. The most significant use of GMSK is in the field of Automatic Identification System (AIS) and Global System for Mobile Communication (GSM). Apart from the benefit of it being applied as a non-linear amplifier in communication domain, the modulation format also improvises the spectral efficiency and pertaining no manipulations in the value of amplitude. Presently there are manuscripts which are published in favor of GMSK modulation accomplished by Numerically Controlled Oscillator (NCO), to generate the sinusoidal and cosine values for modulation requirement. Defining modulation techniques when NCO is used in operation, is a highly challenging task as the necessity for explaining it in hardware is very complicated. This certainly affects the computational power and speed of the overall modulation mechanism. Few papers also focus on using Digital Frequency Synthesizer (DFS) to develop the values to have enhanced results in GMSK modulation. Following which, if pipeline architecture based on the principle of CORDIC processor is designed, improvised performance would be encountered. The proposed solution investigates the extent to which the hardware complexity of the previous works is explored. As a review is done for the existing techniques for FPGA and MATLAB implementation, the proposed system contributes to extract the research gap from existing work significantly.

D. *GMSK Fundamentals*

A scheme for continuous phase modulation called Minimum Shift Keying consists none of the phases discontinuously. Also, frequency variations would occur at the crossings of zero carriers. MSK is identical as there exists a relation between the logical one and zero, the main difference the frequency of logical one is zero is the half data rate. Likely, the modulation index at which MSK operates is 0.5, defined by the formula

$$m = \Delta f \times T$$
$$\text{Where, } \Delta f = |f_{logic1} - f_{logic0}|$$
$$T = 1/\text{bit rate}$$

For instance, a baseband MSK signal of 1200 bit per second could be consisting of 1200 and 1800 Hz frequency in case of logical one and logical zero accordingly.

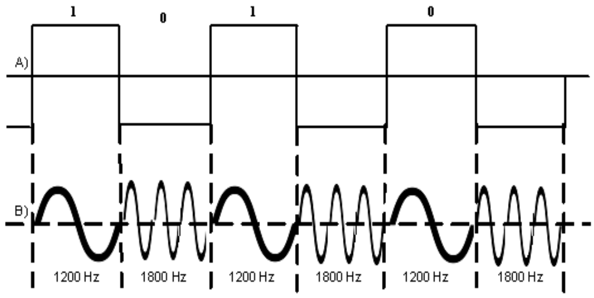

Fig.1. MSK data Signal A) NRZ data B) MSK signal

The baseband MSK signal is illustrated in Figure 1, happens to be a means of robustly forwarding information in wireless systems, as the data range here is comparatively y less when compared to that of the bandwidth of the channel. The alternative way such as generation of MSK modulated signal can be accomplished by injecting NRZ bits having the modulation index set to value 0.5 for a frequency modulator. The approach behaves in the manner that can be equalized to the baseband MSK. Henceforth, the Voltage Controlled Oscillator (VCO) is an approach that directly enables the selection of RF/IF signals, wherein the baseband is the section for converting the MSK baseband voltage to frequency.

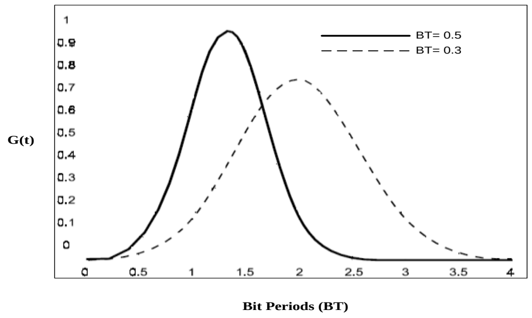

Fig.2. Filter responses for Gaussian Filter

The preliminary issue with the baseband MSK signal is that spectrum is not concise for the data rate realization that approaches towards the bandwidth of RF channel. The MSK spectrum has the side lobes that extend above the bit rate. Systems that need effective utilization of RF channel bandwidth, it is mandatory to minimize the poor consumption in case of upper side lobes for MSK. The filter accommodated during the operation of pre-modulation must have narrow bandwidth persisting a sharp cutoff frequency and a less value of overshoot for the impulse response respectively. Here, the necessity to include a Gaussian filter arises. Its impulse response is characterized via Gaussian distribution as illustrated in Figure 2. Figure 2 depicted the Gaussian filter impulse response with bit period of 0.3, 0.5 for a 3dB bandwidth data rate given by,

$$\text{Bit period} = f_{-3dB} / \text{Bitrate}$$

Therefore, for a bit data rate of 9.6kbps, bit period being equal to 0.3, the filters cutoff frequency is obtained to be 2880Hz. In relevance to the Figure 2, a bit spread can be observed almost for 3bit periods for bit period of 0.3 and remain two-bit periods of 0.5 values. A phenomenon named as the Inter-Symbol Interference arises here (ISI). Higher is the extent at which ISI is found; spectrum would be permissible for the enormous amount of compactness enabling issues in performing demodulation.

E. GMSK Generation

There are mainly two methods in which the GMSK modulation can be achieved. The most usual technique is by using a Gaussian filter. Here, the modulated signal is filtered, and therefore this is applied further to the frequency modulator, setting the modulation index to 0.5. This technique happens to be operating requiring underlying fundamentals with the limitation that modulation index should always be set to 0.5 as seen in Figure 3.

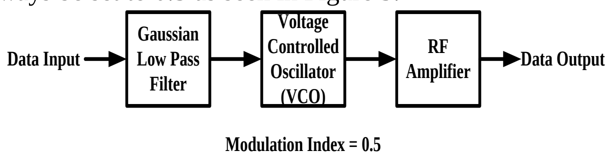

Fig.3. Illustration of GMSK modulations through VCO and Gaussian filter

The most widely incorporated second method is the quadrature modulator. The terminology quadrature implies that the signal's phases are 90 degrees to each other. The modulator is named as the I-Q modulator. The modulation can be adjusted to 0.5 automatically without the necessity for any manipulations. This enables the utilization of the modulator to be simple, meeting the performance need for variations. To perform demodulation, the same technique can be implied reversely from Figure 4.

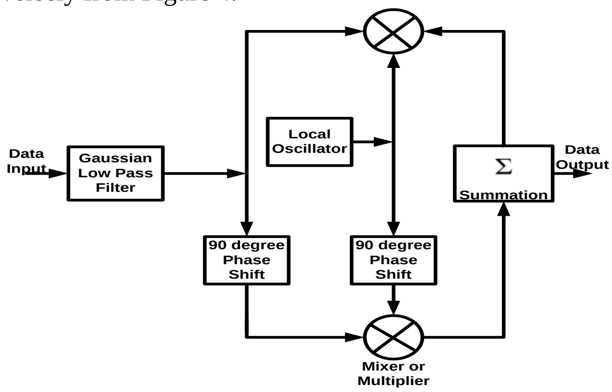

Fig.4 Illustration of GMSK modulations via I-Q modulator

II. EXISTING IMPLEMENTATIONS IN GMSK MODULATION ON FPGA AND MATLAB

This section discusses the current implementations of GMSK modulation proposed previously over the hardware of FPGA and Simulink. A clock circuit for recovering GMSK demodulated signal mapped with Altera MAX9400 was studied by Abdollahi et al. [15].The method of serially coding and interleaving the continuous phase modulation was investigated by Dai et al. [16]. The work of executing GMSK demodulation over the Graphic processing unit using CUDA was studied by Xiaopeng and Deping [17]. Gao and Liu [18] introduced the bi-channel receiver for Automatic Identification System, operating on FPGA basis.Gupta et al. [19] proposed the GMSK transceiver FPGA implementation that utilized the scheme of non-coherent detection. The low-energy design of a GMSK demodulator scheme was discussed by Kumar et al.[20] that used the baseband quadrature signals.Lee et al.[21] studied the system design and implementation of an entire GMSK modulation communication model. Liu and Liu [22] presented a mechanism digitally operating at the linear approximation principle derived from the characteristics of ISI and the partial response of signals. A Generalized Parametrizable Modulator (GPM) is developed by Shah and Somani [23] that performs the GMSK modulation.Sun et al.[24] investigated an equalizer architecture and algorithm for cost-effective implementation on FPGA. A coherent detection scheme with carrier recovery circuit for the system of GMSK was introduced by Gao and Feher [25].

Bagazhov[26] describes the generation GMSk modulated signals by defining them on MATLAB.Dalwadi et al.[27] carried the Rician channel mechanism simulations with MATLAB. A description of state space model for the continuous phase modulated signal was carried out Gal et al.[28].Satheesh et al.[29] designed a technique of spectrum sensing which was cyclo-stationary based on GMSK channels. The study of Ghnimi et al.[30] focused on the BER performance analysis for GMSK modulation in various environments of the mobile radio network.

Table.1. Existing Approaches Summary

Authors	Problem	Technique	Performance Parameter
Abdollahi et al. [15]	Bandwidth and synchronization complexity	Programmable Digital Controlled Oscillator	Frequency tuning
Dai et al. [16]	Spectrum Inefficiency	Serial coding and interleaving	BER
Xiaopeng and Deping [17]	Hardware platform complexity	GMSK modification on GPU	Computational speed
Gao and Liu [18]	Scarcity to identify ships	Dual-channel AIS	Carrier frequencies
Gupta et al. [19]	Hardware complexity	Non-coherent detection	BER, symbol rate
Kumar et al. [20]	Modifying quadrature and in-phase signals	Low-Power design of GMSK	BER, Eb/ No, Power usage
Lee et al. [21]	Lack of effective GMSK communication system	Communication system design using GMSK	Signal value, timing recovery
Liu and Liu [22]	Combining GMSK with linear modulation	Digital scheme of Linear approximation	Relative power,frequency
Shah and Somani [23]	Higher hardware complexity	GPM	None
Sun.et al. [24]	GMSK modulation at instantaneous transmission	Low-cost FPGA algorithm and architecture	Error Transmission rate.
Gao and Feher [25]	High power utilization	An efficient system for cross-co-related FQPSK	BER, Eb/No
Bagazhov [26]	Communicationrequirements for navigational service	AIS Testing	Data transmission, reception rate
Dalwadi et al. [27]	Presence of large propagation path in system	Rician channel model	BER, SNR
Gal et al. [28]	Demodulation of CPM `	CPM State-space model	SNR, BER
Satheesh et al. [29]	White space trigger in robust spectrum techniques	Cyclo-stationary GMSK, spectrum sensing	SNR
Ghnimi et al. [30]	Speaker identification in GSM environment	BER performance comparison among GMSK systems	BER, Eb/No

III. RESEARCH GAP

Below mentioned is the notable research gap recognized as the existing study is reviewed for the GMSK application on FPGA and MATLAB

- The hardware implementation of GMSK modulation techniques has been observed to be comparatively less as per the existing work that could work for all possible GSM and AIS applications.
- It can be noticed from the exiting study that not an entire system of GMSK transceiver is employed on the platform of FPGA or MATLAB individually presenting effective results.
- Using the conventional method of NCO that generates the signal is more complex pertaining higher hardware needs.
- The realization of Forward Error Correction (FEC) is lacking from most of the literature presented.

IV. RESEARCH TRENDS

The research work carried out in addressing the GMSK implementation on various platforms is very rare in number. The years we explored were from the range starting from 2000-2018, showing that there were only 13 Conferences and 1 Journal published for GMSK FPGA prototyping whereas that in the case of MATLAB were seven conferences. For the CORDIC processor execution precisely in GMSK was only two conferences. Until now, it is noticed that most of the research is conducted considering FPGA; with this not all the specifications for a given application are satisfied.

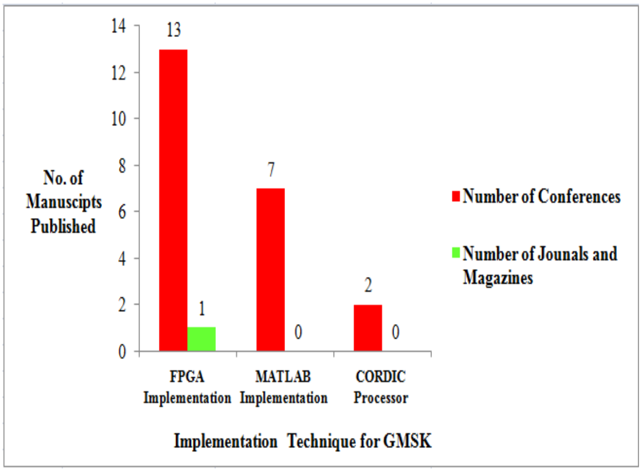

Fig.5. Graph of Research Trends from the year 2000-2018

V. CONCLUSION AND FUTURE WORK

As the existing work is reviewed based for addressing the various approaches that support the hardware implementation of GMSK modulation, we can conclude that there is the greater extent of problems being witnessed for prototyping both the transmitter and receiver section on the either FPGA or MATLAB individually. This hardware complexity can be minimized if an efficient implementation of pipelined CORDIC architecture is used, with the significant involvement of Digital Frequency Synthesizer (DFS) to generate the in- and quadrature phase components in the modulation arrangement.

Further, the same architecture can be implied in the Forward Error Correction (FEC) realization that makes it more efficient serving for most of the prime GSM and AIS applications. Incorporation of differential encoder and decoder would enable the operation of modulation and demodulation in GMSK. In the following manuscripts, we aim to design the same to achieve an efficient implementation of GMSK. This would give a solution to transmit data both at the modulator and demodulator section.

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