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Research Article

# FRFT based Method of Modulation Techniques for SDR

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## Abstract

*Software Defined Radio (SDR) works on a programmable hardware platform. Except for the antenna section, the conventional radio can be defined in a programmable hardware such as general purpose PC, special purpose digital signal processor or dedicated software defined radio kit. It represents a very flexible and generic radio platform which is capable of operating with various modulation types, waveform formats, and different bandwidths over a wide range of frequencies. SDR is evolving to be a promising solution for these challenges such as interoperability, global seamless connectivity encountered in wireless communication. In the case of digital modulation, sending bit stream with least bit error is the aim of every technique. Amplitude modulation, frequency modulation, phase modulation and also combination of these have been employed to distinguish ones and zeros or even combinations of ones and zeros. Factional Fourier Transform (FRFT) having its basis function as chirp signal, exhibits different orthogonal basis function with change in chirp rate. In this paper, possibility of employing basis functions of FRFT to distinguish various bit combination in digital signal transmission, is exploited. Results are presented for $M=2^b$-ary QAM signaling and is found to be a promising method of digital modulation.*

**Keywords:** *Software Defined Radio, FRFT etc.*

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## Introduction

Wireless communications, which stand at the forefront of the technological revolution, comprise a multiplicity of radio access technologies-GSM, GPRS, EDGE, WCDMA, HSDPA, LTE, GPS etc. The distinctive communication capabilities of these technologies present insurmountable barriers for interoperation and migration between one other's incumbent networking infrastructures inhibiting deployment of global roaming facilities and in rolling-out new services / features. Software Defined Radio technology promises to solve these problems by implementing the radio functionality running on a generic hardware platform and downloading software modules onto the handsets as and when required. The software modules that implement new services / features can be downloaded over-the-air onto the handsets. This kind of flexibility offered by SDR systems helps in dealing with problems due to differing standards and issues related to deployment of new services / features. The modulation identification and classification is one of the major tasks in the development of SDR.

The first generation of mobile cellular communications commenced in the1980s and used analog modulation techniques to transmit and receive only analog voice information between mobiles and base stations (Paul Burns, 2002). Second-generation (2G) systems of the early 1990s were known as digital because they encoded voice into digital streams and used digital modulation techniques for transmission. The digital nature of 2G allows limited fixed rate data services. The International Telecommunication Union (ITU) developed the IMT 2000 standard to define the requirements for 3G-compatible systems. All of the 3G systems are potential SDR applications. SDR offers the potential to solve many of the problems caused by the proliferation of new air interfaces. Base stations and terminals using SDR architectures can support multiple air interfaces during periods of transition and be easily software upgradeable. Intelligent SDR can detect the local air interface and adapt to suit the need.

Long Term Evolution (LTE) is widely accepted as the air interface of choice for 4G networks worldwide. The majority of Tier-1 mobile operators, including Vodafone, T-Mobile, Verizon Wireless and Orange have identified that LTE will be necessary to fulfill the growing demands of data-hungry end users in the years to come. However, LTE will require additional hardware expenditures both on the radio and core networks, meaning that mobile operators may be reluctant to experience another capital intensive upgrade cycle. Moreover, several mobile operators are currently experiencing capacity problems on their networks, meaning that they will have to upgrade current hardware to satisfy current demands. By using SDR today to satisfy short term capacity demands, mobile operators will be able to reuse this hardware to later rollout LTE, thus minimizing costs and removing the need for forklift upgrades when LTE enters the mass market.

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Thus, SDR is growing in popularity and the expression is becoming recognized in the wider technical community. The twentieth century radios are hardware defined with almost no software control. Their functionality are fixed and meant for broadcast reception. Since hardware components involved in such radios may change due to climate change and aging, they have a short life. SDR employs programmable digital devices to perform the signal processing necessary to transmit and receive baseband information at radio frequency. Devices such as digital signal processors (DSPs) and field programmable gate arrays (FPGAs) use software to provide them with the required signal processing functionality. Except for the antenna section, the rest of the radio unit is made as software based. This new technology offers greater flexibility and potentially longer product life, since the radio can be upgraded very cost effectively with software (Tsurumi, H., et.al., 1999, Markus Dillinger, et.al., 2003, Joseph Mitola, 2000). At the center of this new technology is the software architecture on which the radios must be built. Similarly, the channel coding and modulation functions are performed digitally at baseband by the same processing resources and communication protocols implemented.

For 3G mobile and many other multiuser radio technologies, the ideal SDR is not yet a practical or cost-effective reality. Direct sampling of wideband (100s of KHz to 10s of MHz) RF frequencies (100s of MHz to 10s of GHz) at high signal to noise ratio, as required by the ideal multicarrier SDR, is not yet technically possible. Direct RF sampling for single carrier terminal/mobile devices is becoming feasible (Tsurumi, H., et.al., 1999). SDR thus, simultaneously provides flexibility, future enhancement and intelligence. While the mobile group seeks to promote the use of SDR technology in commercial and military applications under adverse terminal conditions where station mobility, dynamic networking, and operational flexibility are required using a variety of wireless and network interfaces.

Thus, next generation wireless communication systems demands technique of supporting multiple wireless communication standards with various different digital modulation schemes such as PSK, QPSK, QAM, GMSK. Modulation and detection of some of these are explored in recent literatures (Syed Salman, et.al., 2012). They should not be constrained to a single waveform. The bandwidth expected is wideband enough to be able to run several air interfaces in the same frequency band. Existing equipment must be upgradeable to future air interfaces, either by software or by adding a new baseband processing card to the installed hardware platform. The majority of infrastructure vendors now claim to support LTE through a card addition to their baseband units. They should have upgradeable processing capabilities for future air interfaces. This is especially applicable to LTE, which is expected to require additional processing at the base station due to its low latency, higher bandwidth requirements. Existing base stations need to be hardware upgradeable to more powerful processors. Power consumption is receiving increasing interest as operators aim to operate with low power networks. Mobile operators have traditionally relied on running several independent equipment racks for different air interfaces. However, a single hardware platform that can run all of these simultaneously can limit power costs greatly.

For example, M=2$^b$-ary QAM signaling employs waveforms with different amplitudes and phases depending on 0s and 1s that they are representing. Here, ‘b’ indicates the number of bits in a group that are assigned certain waveform as the symbol. With T as the bit period, the resulting waveforms may be written as (WonY. Yang, et.al., 2012)

$$s_m(t) = A_{mc}s_{uc}(t) - A_{ms}s_{us}(t)$$

$$= A_m\sqrt{\frac{2}{T}}\cos(\omega_c t + \theta_m)\,; \quad m = 0 \ldots M-1 \qquad (1)$$

With basis functions,

$$s_{uc}(t) = \sqrt{\frac{2}{T}}\cos(\omega_c t) \;\;,\;\; s_{us}(t) = -\sqrt{\frac{2}{T}}\sin(\omega_c t)$$

$$\& \quad A_m = \sqrt{A_{mc}^2 + A_{ms}^2} \;,\; \theta_m = \tan^{-1}(A_{ms}/A_{mc})$$

Orthogonal frequency-division multiplexing (OFDM) is yet another method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication and used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications. OFDM is essentially a frequency-division multiplexing scheme used as a digital multi-carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. These carriers are real / imaginary part of complex basis functions of Fourier Transform (FT). Each sub-carrier is modulated with a conventional modulation scheme such as quadrature amplitude modulation or phase-shift keying at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth (Massimiliano Martone, June 2001). Because subcarriers are orthogonal, sub-streams are free of inter-symbol interference. A base band signal in a generic N-channel multicarrier system may be expressed as (Massimiliano Martone, June 2001).

$$s(t) = \sum_{k=-\infty}^{\infty}\sum_{l=0}^{N-1} a_{k,l}\,g_{k,l}(t) \;=\; \sum_{k=-\infty}^{\infty}\sum_{l=0}^{N-1} a_{k,l}\,\Phi_l(t-kT) \qquad (2)$$

Where $a_{k,l}$ is the information bearing symbol and $\Phi_l(t-kT) = g(t-kT)e^{j2\pi lFt}$ are the N number of basis functions. Since Eigen modes of a frequency selective static channel can be approximated by Fourier basis functions, use of FT basis functions may be justified for static channels.

However in reality, communication channel is not static. To model the nonstationary characteristic of the real channel, time frequency representation (TFR) methods have to be exploited which may be with or without any extra computational complexity. Short time Fourier transform (STFT), wavelet transform (WT), fractional

Fourier transform (FRFT) are some of the examples of TFR oriented transforms (L. Cohen, 1989, H M Ozaktas, et.al., 2000). While STFT is the fundamental TFR, helps in understanding the basics of TFR, it has fixed analysis window. It does not catch the rhythm of the signal. WT overcomes the drawback of STFT, in that it has variety of scaled and time shifting basis function. The uniqueness of WT is that there is no unique basis function. Basis function can be selected based on the characteristics of the signal to be analyzed. Hence it exhibits better time-frequency resolution. FRFT is a special case of WT, with chirp as the basis function. In the proposed work, FRFT is employed in $M=2^b$-ary QAM signaling.

Commonly used FT can be interpreted as a rotation of time domain signal by an angle $\pi/2$ in the time-frequency plane and represented as an orthogonal signal representation for sinusoidal signal. A rotation by integer multiple of $\pi/2$ can thus be defined through repeated application of FT. A rotation angle $\alpha = a\pi/2$, with *a* being a real number, leads to a domain that represents the signal both with respect to time and frequency. Signal representation along this intermediate axis making an angle $\alpha$ with time axis, in time-frequency plane has nonzero time and frequency resolutions. As the angle of rotation is fraction *a* of $\pi/2$, the transform is known as fractional Fourier transform (FRFT) with an order parameter *a*. FRFT serves as an orthonormal signal representation for the chirp signal, a signal whose frequency varies linearly with time. Computational complexity of FRFT is same as that of FT. It is a powerful tool in solving many signal processing tasks such as differential equations, optical signal processing, time variant filtering, signal compression (Vijaya C. et.al., 2006, 2008), pattern recognition, digital watermarking, time-frequency signal analysis, Fourier optics and optical information processing etc.

The pulse g(t) is modulated by $f_{\alpha,n}(t)$ given in equation (4). It is derived in such a way that (Massimiliano Martone, 2001) in Fractional Fourier domain it corresponds to an impulse. In this respect, it is similar to a sinusoid being an impulse in Fourier domain. Thus,

$$\Phi_l(t-kT) = g(t-kT)\, f_{-\alpha,n}(t-kT) \qquad (3)$$

with $$f_{\alpha,n}(t) = \sqrt{(\sin\alpha + j\cos\alpha)/T}\, e^{\left(-j\frac{t^2+(2n\pi\sin\alpha/T)^2}{2}\cot\alpha + j2n\pi t/T\right)} \qquad (4)$$

for $-T/2 \le t \le T/2$

The frequency of n^th^ basis function is given by $\omega_{\alpha,n} = 2n\pi/T - t\cot\alpha$. This clearly shows that either by changing n or changing in rotation angle, the function in equation (4) may be changed, by maintaining the orthogonality among the basis function.

## Proposed work

FRFT Rotation Angle based Modulation (FRAM) of digital data is presented. The real part of the function in (4) is used to represent M = 16 different bit combinations in $M=16=2^4$-ary QAM signaling. That is, each 4 bit group is represented by real part of the function in (4) with different rotation angle. Minimum difference between the rotation angles of these signals is 0.01pi. It can be even less than 0.01pi. The plot of two orthogonal functions with rotation angle differing by only 0.01pi is shown in figure 1. The functions are strongly correlated among themselves. But they are uncorrelated with each other. This property is depicted in figure 2 taking examples of rotation angle 0.01pi and 0.02pi. The peak in the correlation in the first plot in figure 2 is more than 20 when the function in (4) is correlated with itself, whereas there is no clear peak in the second plot in figure 2 when two functions with different rotation angle (difference being 0.01pi) are compared. This property of correlation has been taken into account in detection of the FRAM. Signal corresponding to a particular 4 bit combination is transmitted to the receiving side. It is correlated against signals of all combinations at the receiving side. Maximum correlation with one of the combination detects the bit combination that is actually represented by the received signal.

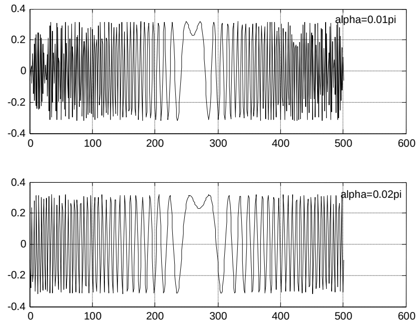

Fig.: 1Plot of orthogonal functions for two clsely spaced alpha

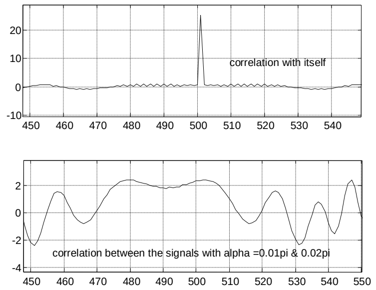

fig.2: Plot of Correlation between two orthogonal functions

## Results

The results are presented considering noise free channel and noisy channel. Bit error in detecting the 4 bit combination in a steam of 0s and 1s is computed by comparing bit combination planned to be sent at the transmitting side and the detected bit combination. To verify the robustness of the scheme proposed, a total of 400 bits are transmitted to the receiving side. The bits are grouped into 4 bits each and a predetermined function in (4) is sent to the receiver in the place of 4 bits to be transmitted. When there is no noise, the bit combination is detected correctly irrespective of number of bits transmitted. In figure 3 a typical signal transmitted to receiving side for a particular bit combination with and without noise is shown. SNR after adding noise is about 6.0896 dB. In spite of poor quality of signal received, as indicated in terms of poor SNR, the bit combination is detected without much error. The plot of typical noise added, resulting SNR and total number of bits found to be in error are plotted in figure 4. The noise added is randomly selected one of the signals in (4) but with low amplitude.

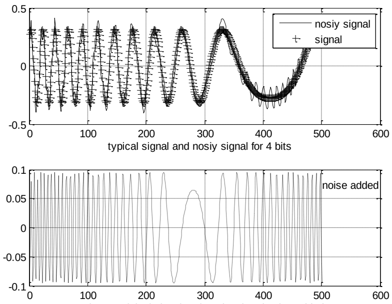

Fig. 3: Original signal, noisy signal and noise added

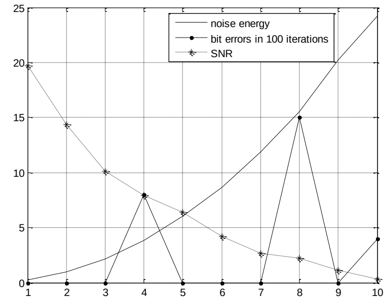

Fig. 4: For 10 noise energy levels, bits in errors out of 400 bits & SNR

## Conclusion

A method of digital modulation and its detection using FRFT is explained. While modulation selects one of the orthogonal functions with certain rotation angle for transmitting 4 bits, the detection is based on correlation property. The proposed method is tested in noise free and noisy channel situations. Even with poor SNR, the method exhibits good performance which is noted in terms of number of bits which are in error after detection. The method proposed, will add on to the solutions to provide the capability of assimilating different communication technologies on the base stations of network service providers. Since there is high decorrelation among the signals with slight different rotation angle, it is easy to extend the method to any $2^b$-ary QAM signaling. Fast method of correlation needs to be evolved to speed up the detection. Or a method to determine rotation angle may have to be developed to improve the speed of detection.

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