POLYPHASE UP CONVERTER CHANNELIZERS FOR FULLY DIGITAL FREQUENCY HOPPING MODULATOR

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ABSTRACT

Frequency hopping (FH) is a spread spectrum transmission technique that achieves frequency diversity gain over frequency selective fading channels and also has a low probability of interception. This technique has been widely used in military applications, for its recognized anti-jamming performance, and in some wireless standards such as GSM and Bluetooth, for its interference resistance. In this paper we present a fully digital architecture for performing frequency hopped modulation. The proposed structure is composed of a cascade of two polyphase up converter channelizers. The first one performs the M-FSK modulation of the baseband signals while the second one accomplishes the task of hopping the FSK modulated spectra under the control of a pseudorandom sequence generator. According to the authors' knowledge, a fully digital architecture for frequency hopped transmission has never been presented in the literature until now. In this paper, both theoretical aspects and simulation results, demonstrating the effectiveness of the proposed fully digital structure, are presented.

1. INTRODUCTION

Spread spectrum (SS) techniques were, at the beginning, investigated for military applications because of their characteristic of being highly jamming resistant. Today SS techniques are applied in many other important areas like communication, navigation, and test systems. Their name derives from the fact that the modulated signal is spread over a wider bandwidth before being transmitted. i.e. the bandwidth employed for transmission is much larger than the minimum bandwidth required to transmit the information. The spreading of the signal band provides a long list of benefits such as interference suppression, energy density reduction (low probability of detection) and fine time resolution. The signal spreading also allows sharing of a communication resource among numerous users in a coordinate way (multiple access transmission techniques).

Frequency hopping is one of the most common spread spectrum techniques in which the carrier frequency of the signal is periodically changed before transmission. In frequency hopping spread spectrum (FHSS) transmissions, a frequency band, called *hopping band*, that includes M channels, is accessed by a controlled pseudorandom sequence, called *frequency hopping pattern*, that shifts it to a different center frequency which is selected from N possible center frequencies. The number N is usually chosen to be very large because the bigger the number of possible hopping frequencies the better the FH system performs in terms of interference suppression, probability of interception and multiple access possibility [7]. The set, of dimensionality N, containing all the possible center frequencies is usually referred to as *hopset*. The large dimensionality of the hopset is one of the reasons for which the frequency hopping modulator is currently implemented in the analog way. Remember that the pseudorandom sequence is a deterministic, periodic signal that is known to both the transmitter and the receiver. It is named pseudorandom because it appears to have the statistical properties of sampled white noise.

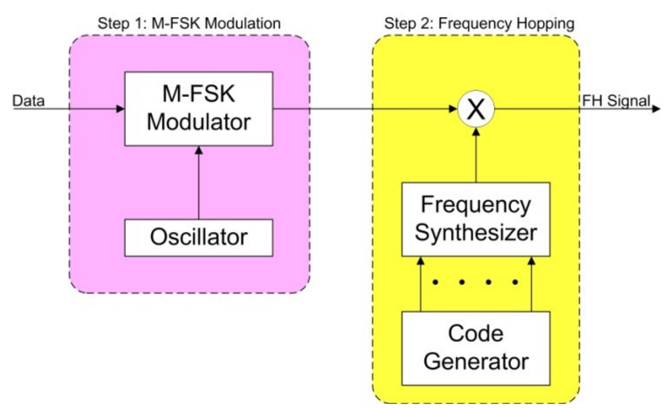

Figure 1: High Level Block Diagram of the Standard Frequency Hopping Modulator.

In the frequency hopping transmitters, the modulation process occurs in two steps. At first the input signal is baseband modulated (generally by using an analog or a digital M-FSK modulator) and then, the complete hopping band is hopped over one of the N possible hopping frequencies by a second tier up converter. The two steps process is described in Figure 1 that depicts the general, high level form of the block diagram of a frequency hopping modulator. In such a modulator, the frequency synthesizer produces frequency hopping patterns determined by the time-varying multilevel sequence specified by the output bits of the code generator. At each hop time the pseudorandom code generator feeds a frequency synthesizer a frequency word which dictates one of the possible center frequencies from the hopset. The M-FSK data modulated signal is then mixed with the synthesizer output pattern to produce the frequency hopped signal. An example of this double processing (8-FSK modulation and up conversion) is provided in Figure 2. Here it is shown that the baseband spectrum, on the extreme left side of the figure, can be, at first, modulated over one of the eight possible channels and then it is hopped over different center frequencies from the hopset. In this example three different frequencies have been chosen for the hopping.

In spite of the efforts made in the direction of digitizing both the FH modulator and demodulator, today, frequency hopping systems are still implemented in the analog way. No computational efficient solution has been found until now for performing the hopping of the baseband modulated signal digitally. Some hybrid solutions are present in the literature [3]-[6], but no fully digital modulator exists for performing frequency hopped transmissions. In this paper we present a fully digital architecture for frequency hopping modulator. A dual fully digital frequency hopping demodulator has been presented by the authors in another paper [8].

The key element of the proposed architecture is the M-path polyphase up converter channelizer [1]. In its standard operating mode, an M-Path polyphase up converter channelizer, that is composed of an M-Point IFFT, an M-path partitioned filter and an output commutator, simultaneously performs three separate tasks [1], [2]. The first task is selection of the number of spectral Nyquist zones or channels. This is determined by M, the size of the IFFT. The second task is channel shaping with spectral characteristics, pass-band width, transition bandwidth, and in-band and out-of-band ripple. This is determined by the low-pass prototype filter from which the M-path polyphase partition is formed. The third task is the resampling operation which occurs in the output commutator. With all the input ports enabled, the M-path up converter channelizer shifts, by aliasing, the input base-band signals over M fixed, high order Nyquist zones. When only the input ports corresponding to the desired output channels are enabled, this engine shifts the input signal to the desired Nyquist zones, thus it represents a flexible fully digital, frequency selective up converter as well as an efficient FSK modulator and it can be used for building efficient (low workload), fully digital hopping structure.

This paper is organized in four main sections. In Section 2 we present the standard version of the polyphase up converter channelizer along with the proposed frequency hopping modulator. In Section 3 we provide simulation results in order to prove the effectiveness of the proposed design. The conclusions, along with suggestions for further developments, are given in Section 4.

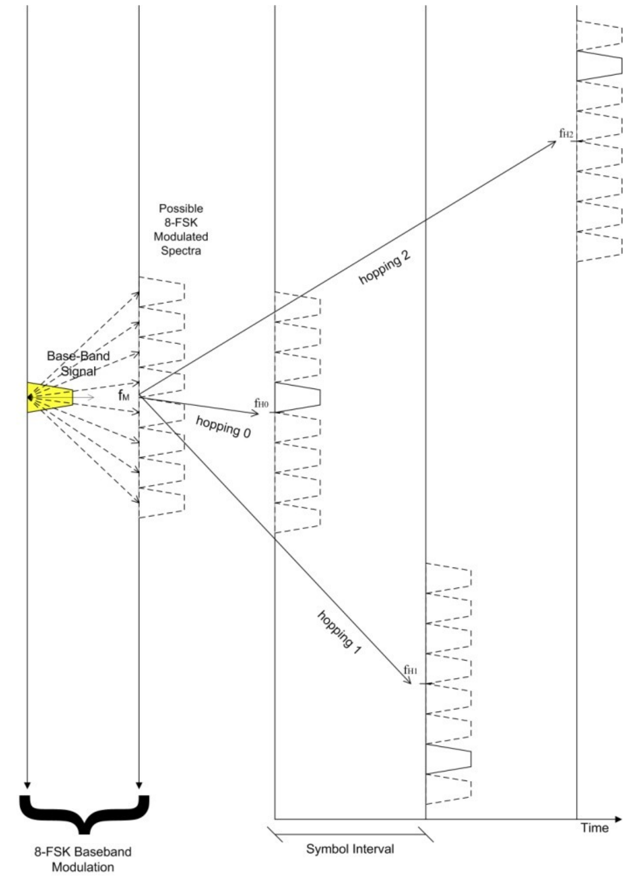

Figure 2: Frequency Hopping Example; The Baseband Spectrum (extremely left side) can be translated to 8 Possible FSK Channels and then it is hopped to Different Center Frequencies.

2. PROPOSED STRUCTURE

In its most common incarnation, an M-path polyphase up sampling channelizer simultaneously up samples and up converts M equally spaced, fixed bandwidth channels [1]. Figure 3 shows its complete structure formed by an M-point inverse discrete Fourier transform (IDFT), an M-path partitioned low-pass prototype filter and an M-port output commutator. For computational efficiency the IDFT is implemented with the IFFT algorithm.

In this engine, M-point IFFT performs two simultaneous tasks; an initial up sampling of 1-to-M which forms an M-length vector for each input sample x(n,k) and further imparts a complex phase rotation of k cycles in M-samples on the up sampled output vector. The IFFT generates a weighted sum of complex vectors containing integer number of cycles per M-length vector while the polyphase filter forms a sequence of column coefficient weighted, MATLAB's dot-multiply, versions of these complex spinning vectors. The sum of these columns, formed by the set of inner products in the polyphase partitioned filter, is the shaped version of the up-converted M-length vector output from the IFFT. The M-port commutator, at the end of these processes, delivers M consecutive samples from the output ports of the M-path filter to deliver the 1-to-M interpolated, up converted and shaped time series formed by the channelizer.

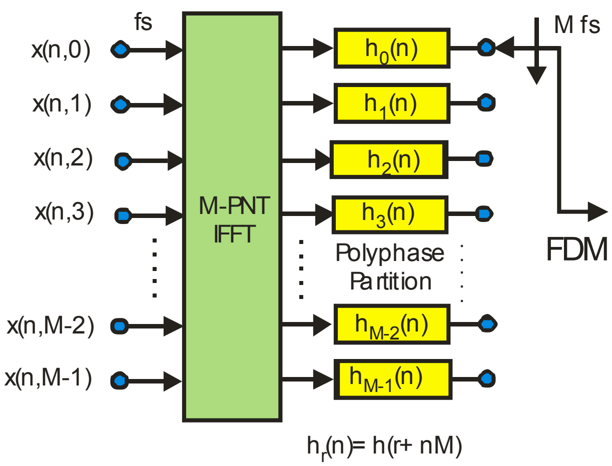

Figure 3: Standard M-path Polyphase Modulator; M-PNT IFFT, Polyphase Partitioned Filter and Output Commutator.

Summarizing, we can describe the three basic operations performed by a standard polyphase up converter channelizer as: digital up conversion to higher Nyquist zones by the IFFT, spectral shaping and filtering due to the M-path partitioned filter weights, sample rate change due to the M-port output commutator. These three operations are completely independent of each other and they can be modified to achieve different goals based on different channelizer applications.

For the purpose of designing a frequency hopping modulator we cascade two standard forms of the up converter channelizer that have channel spacing, channel bandwidth and output sampling frequency all equal to each other. In Figure 4 the high level block diagram of the proposed architecture is shown. Like its analog antecedent, it is composed of two stages, each one formed of a polyphase up converter channelizer. The first tier channelizer is an M-path polyphase engine which performs the M-FSK modulation of the input signal digitally. This channelizer, whose channel center frequencies are selected for matching the center frequencies of the FSK modulated signal, aliases the input signal to the selected center frequency among the M possible center frequencies. This task is accomplished by enabling the corresponding channelizer input port.

After the baseband modulation has been performed we still need to hop the signal according to the hopping pattern. The hopping process is nothing different but another up conversion process, so, by inputting the FSK modulated

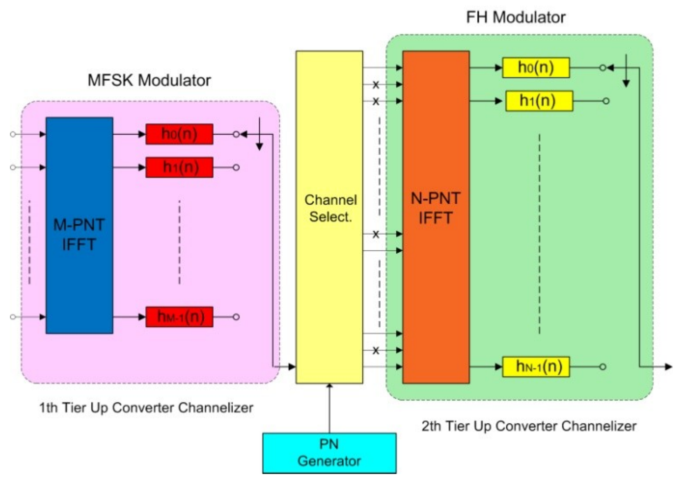

Figure 4: High Level Block Diagram of Proposed Frequency Hopping Modulator.

signals to the proper ports of the second tier up converter channelizer, we acquire the capability to hop the modulated signal over the N possible hopping center frequencies. The number of arms of the second tier channelizer, N, is selected according to the desired dimensionality of the hopset while the channelizer channels' center frequencies are designed to match the frequencies composing the hopset. The dimensions (number of paths and IFFT block) of the two tier channelizers composing the proposed architecture are of course different. The number of paths, M, in the first one is selected according to the desired baseband modulation level while the number of paths of the second one is selected according to the dimensionality of the hopset. The modulation level we select here is 8, consequently the first tier channelizer is composed of 8 paths while, just for simulation purposes, we selected the number of paths, N, of the second channelizer, to be equal to ten. Note that increasing the number of paths of the second channelizer only slightly affects the total workload of the proposed modulator. This is a clear consequence of the fact that the IFFT block embedded in the polyphase channelizer provides its best performance with higher dimensionality.

A channel selector, controlled by a pseudo noise sequence generator, and placed between the two engines, delivers the input signals to the proper input port of the second up converter channelizer for performing the desired hops.

3. SIMULATION RESULTS

In the following we present some simulation results that show the effectiveness of the proposed FH modulator. In particular, Figure 5 shows, in the upper and lower subplot, the impulse response and the frequency response respectively of the low-pass prototype filter belonging to the first tier channelizer which is an 8-path polyphase up converter performing 8-FSK modulation of the input signal.

In the same fashion, in the upper subplot and in the lower subplot of Figure 6 the impulse response and the frequency response of the low-pass prototype filter belonging to the second channelizer are shown. For simulation purposes the number of paths here has been selected to be equal to ten. In reality the number of the possible hopping center frequencies is much bigger. It is not an issue to change the number of paths of the up converter channelizer. The IDFT which is embedded in this engine, in fact, preserves its computational efficiency when the number of paths is greatly increased.

In the simulation results presented here we used the most standard configuration of the polyphase up converter channelizer with the channel spacing, the channel bandwidth and the output sampling frequency equal to each other. This choice prevents us from using the external channels of the hopping band for transmission because the channelizer results critically sampled and that implies spectral folding. Further developments in this research area could go in the direction of implementing up conversion processes by using different up converter channelizer implementations which are not critically sampled.

Figure 7 shows, in the normalized frequency domain, the output spectra of the first tier channelizer at ten different symbol times. The input signal is a complex sine wave. According to the goals of simplifying the understanding process for the reader, each of the 8-FSK modulated spectrum is depicted on a different subplot.

In Figure 8 the outputs of the second tier channelizer are shown. These are the hopped versions of the bandwidths shown in Figure 7; on each subplot is shown the corresponding 8-FSK spectrum (on the same subplot) of Figure 7 hopped (aliased) on a different center frequency dictated by the pseudorandom sequence generator that, in the proposed structure, communicates with the channel selector block which delivers the signal to the proper input ports of the second channelizer in order to achieve the desired center frequency location.

In Figure 9, in order to give a more compact view of the overall FH modulation process, we show a contour plot of the transmitted spectra.

4. CLOSING COMMENTS AND FURTHER DEVELOPMENTS

In this paper we proposed a fully digital frequency hopping modulator architecture. Two polyphase up converter channelizers, in cascade, compose its core. The first channelizer performs the M-FSK modulation of the baseband spectrum while the second one hops the modulated spectra over N possible center frequencies. The novel architecture inherits the flexibility of these engines that allows us to select the levels of the M-FSK modulation, as well as the dimensionality of the hopset and the hopping bandwidth while, due to the efficiency of the IFFT algorithm, the total workload of the structure is kept low which makes feasible the realization of the proposed fully digital frequency hopping modulator.

The idea of using polyphase channelizers for performing fully digital FH transmissions can be easily applied to the receiver side of the transmitter chain; in fact, a dual structure, which presents a fully digital FH demodulator, is presented by the authors in [8]. On the receiver side, the advantages of having a fully digital architecture are even more visible because the synchronization issues have to be considered.

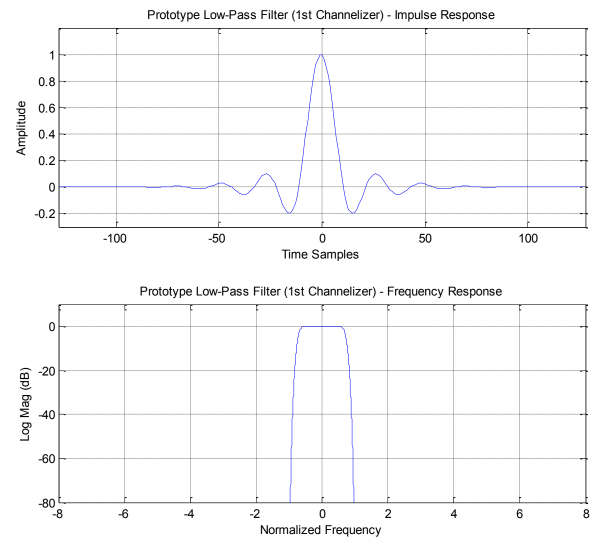

Figure 5: Impulse Response and Frequency Response of the Low-Pass Prototype Filter belonging to the First Tier Channelizer.

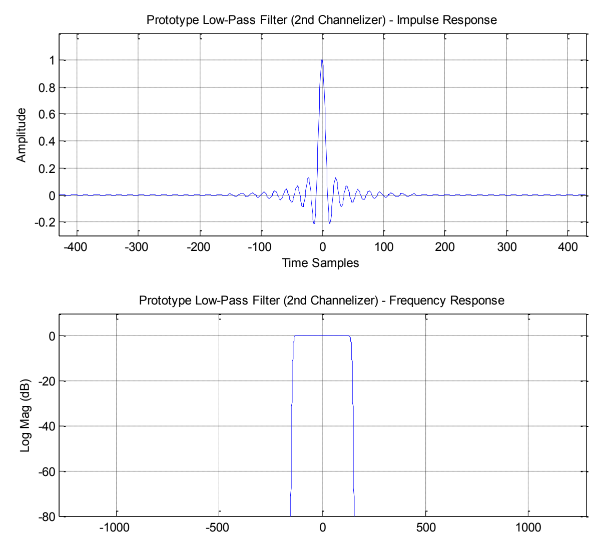

Figure 6: Impulse Response and Frequency Response of the Low-Pass Prototype Filter belonging to the Second Tier Channelizer.

Note that among the many benefits that may accrue for the polyphase channelizer based hopping modulator there is the possibility of easily implementing fast and slow hopping as well as the option to transmit multiple simultaneous hopping sequences for multiple accesses and for channel diversity transmissions.

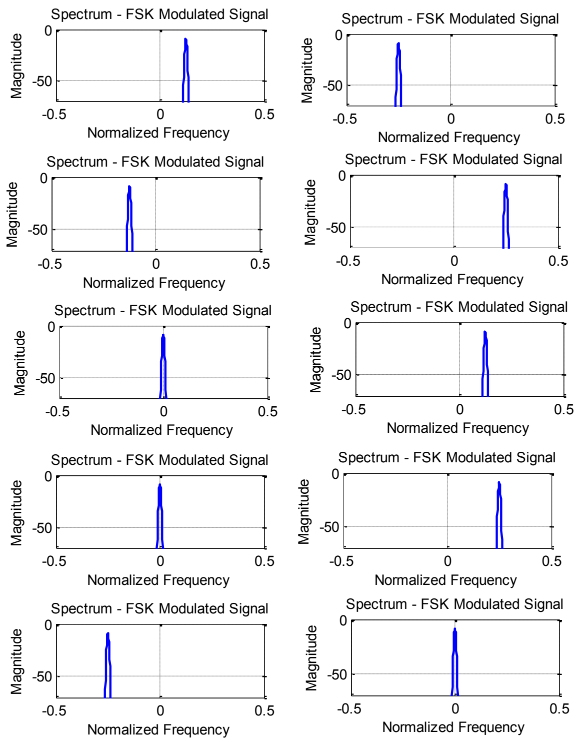

Figure 7: First Tier Channelizer Outputs; 8-FSK Modulated Spectra.

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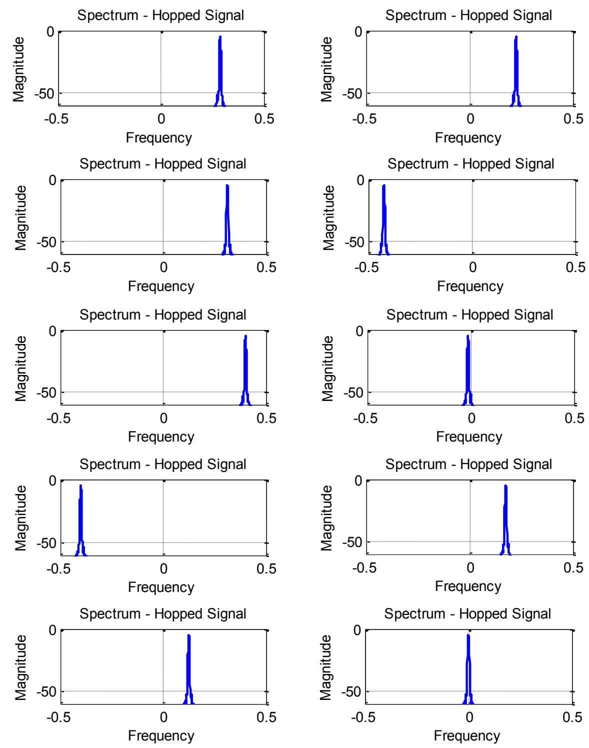

Figure 8: Second Tier Channelizer Outputs; Hopped Spectra (Number of Hops: 10).

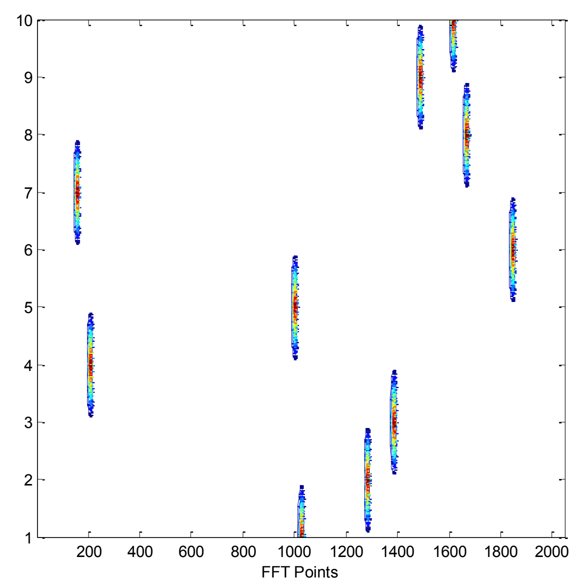

Figure 9: Contour Plot of the Hopped Spectra of Figure 8.