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On the design and realization of novel Intermediate Frequency Hopping Spread Spectrum (IFH-SS) for wireless communications

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ABSTRACT

Designing of Very Large Scale Integrated Circuits (VLSI) operates at Megahertz and Gigahertz satisfying the design constraints for desired applications is a challenging job due to various reasons like transient time effect, high power requirement and consumption etc. Phase Locked Loop (PLL) is an important integrated circuit used in various areas of communications. Frequency synthesizers when used in Frequency Hopping Spread Spectrum (FH-SS) requires strict timing synchronization between transmitting and receiving system for successfully despreading and the power consumption is also high due to high frequency operation. In this contribution a new scheme has been proposed, in which frequency hopping transmitter and receiver has been operated at intermediate frequency and the same hopping rate was obtained as can be achieved by fast hopping spread spectrum operated at high frequency and therefore requires low speed frequency synthesizers and offers many advantages like more user capability, Low cost and simple amplifiers, filters, ADC and DAC converters requirement. The IFH-SS transmitter and receiver based on proposed intermediate frequency hopping spread spectrum has been experimentally verified. The results of experimental investigation have been presented in the paper. The waveforms obtained at various check nodes have also been presented.

Introduction

Wireless personal communication systems enable geographically dispersed users to exchange information using a portable terminal, such as a handheld transceiver. Often, the system engineer's design objective is to maximize the transmission rate and number of simultaneous users (capacity) under the constraints of robustness, power consumption and hardware complexity. The tradeoffs among capacity, reliability, signal power, and cost of equipment can be complex.

Future generations of wireless personal communication systems will be based on digital transmission technology. Digital technology has important advantages over traditional analog technology. With digital technology, radio communication systems can be designed to meet more stringent transmission reliability requirements. Furthermore, digital technology enables more efficient sharing of channel resources when multiple users need to access the system through a common channel simultaneously. The use of radio telephones has evolved rapidly and grown explosively in the last few decades. This evolution of wireless systems can be viewed to have occurred in different stages. The main force driving the evolution is an increasing public demand for wireless services. To meet this ever increasing demand, better communication technologies are required to increase network capacity, to improve quality of service (QOS), and to introduce new service features.

As the public appetite for wireless services gets bigger, the capacity of first generation systems, even with improvements, soon became insufficient to satisfy the demand in some areas. This led to the development of the second generation digital wireless systems, built in the 1980's and the 1990's. In this period, digital technology is implemented to improve the system capacity several times over traditional analog systems. At this stage, vehicular cellular radio and cordless telephone are developed and optimized separately to provide service to users with different mobility patterns and communication needs. The typical vehicular radio systems include Global System for Mobile Communications (GSM) in Europe and Digital AMPS (IS-54) in the United States; the typical cordless telephone systems include CT-2 in Europe and some spread spectrum products in the United States.

Among second generation systems, one of the new technologies used to boost system capacity is Code Division Multiple Access (CDMA). CDMA, based on spread spectrum technology, is developed to utilize the available spectrum more efficiently in multi-cell networks. The history of spread spectrum (SS) communications can be traced all the way back to its military origin during early phases of World War II [1]. In military applications, spread spectrum technology is used to combat intentional jamming by an enemy transmitter. The approach to defeat jamming is to transmit over many signal coordinates with large-bandwidth signals, such that the jammer cannot achieve large jammer-to-signal power ratio in all the coordinates. The anti-jamming properties of SS signals are well investigated and documented [4].

Since spread-spectrum uses large-bandwidth signals that result in the apparent inefficient use of the radio spectrum, people had assumed that commercial applications of SS radios were impractical [1][4]. Cooper and Nettleton, in 1978, were the first ones to recognize that digital spread-spectrum radio had a potentially higher capacity for mobile radio applications than the

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analog narrowband radios used at that time. More research on digital SS mobile radio soon followed in 1980. By the late 1980's and early 1990's, advances in Very-Large-Scale Integrated (VLSI) circuit technologies has made low-cost implementation of spread-spectrum radio possible while the popularity of mobile radio has spurred the market demand for high-capacity systems. These factors contributed to a renewed interest in the application of spread-spectrum technology for mobile radio. The widespread commercial development of SS wireless systems today is sparked by two key events. One of the events is the 1985 FCC ruling which allows the unlicensed use of spread spectrum radio in ISM bands, which include the 902 to 928 MHz band. Another key event is the well-publicized Qualcomm Direct Sequence Spread Spectrum (DS/SS) and frequency Hopping Spread Spectrum (FH/SS) CDMA system which has led to the adoption of a second U.S. digital cellular standard, IS-95 [8]. Commercial spread-spectrum radios are now being used in indoor office applications, such as wireless local area networks (WLANs), and wireless cordless phone (PBX) systems. Among the interesting outdoor applications is the Federal Emergency Management Agency's (FEMA) experimental use of spread-spectrum radios to transmit digital video. In some situations, unlicensed spread spectrum radio is used as an emergency backup to wired lines and in many cases; they are used as a more economical substitute for digital leased lines.

In this paper a novel scheme based on Intermediate Frequency Hopping Spread Spectrum (IFH-SS) has been used. The fast hopping spread spectrum is presently the most widely used technique for both commercial and military applications. However, the implementation of this scheme demands high speed frequency synthesizers and moreover code synchronization between transmitter and receiver at high frequency is very difficult to achieve. further most of the frequency synthesizers are available in integrated circuit form and implemented using CMOS technology. However, at high frequency the power consumption of CMOS based circuit's increases.

In this paper a new scheme has been used in which both FH transmitter and receiver are operated at an intermediate (lower) frequency. The Frequency Modulated (FM) signal available at the transmitter and receiver has been demodulated using CXA1619BS module to generate similar low frequency voice signals at the transmitter and receiver ends. The voice signals so generated are used for IF-SS signal at the transmitter side and for IFSS demodulation at the receiver.

Code Division Multiple Access (CDMA)

Random access protocols require less centralized coordination than fixed assignment protocols. CDMA is a sophisticated random access protocol that uses spread spectrum techniques. Each user is assigned a unique code sequence which modulates the data signal before transmission. With this modulation, the signal is spread over a much wider bandwidth than that required to support the source data rate. At the receiver, a matching code sequence is used to de-spread the received signal to recover the original data. With this spread and de-spread procedure, all the other simultaneous transmissions in the channel will act as additive noise to the desired signal [7]. If the codes are orthogonal, the interference can be removed completely. Based on the spread spectrum technique, CDMA can be divided into Direct Sequence CDMA (DS/CDMA), Frequency Hopping CDMA (FH/CDMA). In DS/ CDMA systems, each user occupies whole of the bandwidth at the same time with a unique signature code. In FH/CDMA, each user is assigned a unique FH pattern. Users hop around in frequency. FH/CDMA can be further divided according to the hop rate. In Fast FH/CDMA (FFH/CDMA), there are multiple hops per information symbol, and in Slow FH/CDMA (SFH/CDMA), there are multiple information symbols per hop. With well-designed channel coding and interleaving, FH/CDMA can also obtain interferer diversity and multipath diversity characteristics as DS/CDMA. The main difference in the performance between DS and FH is due to the different forms the intra-cell interference takes in the two methods. While in DS, intra-cell interference is typically dominant, for FH there is little or no intra-cell interference since FH can be made approximately orthogonal within a cell.

The performance of DS/CDMA (e.g. IS-95) has been studied extensively. Key advantages of CDMA are well documented in literature [9]. This includes the following prominent ones:

1: In CDMA, since the whole bandwidth is used in each cell (universal one-cell frequency reuse) the need for complex frequency planning can be eliminated.

2: CDMA allows for the system to be designed based on the average interference, which provides more capacity than the worst case design.

3: Voice activity utilization can easily improve system capacity. Multiple access interference (MAI) in CDMA is the dominant factor in the limitation of capacity. A way to reduce MAI is to generate no packets whenever the voice source is silent. By employing voice activity detection, the capacity can be increased.

4: CDMA is interference limited, any interference suppression technique can be directly translated into an increase in system capacity.

5: CDMA systems have soft capacity and soft handoff features.

FH/CDMA fares better than DS/CDMA in this respect because FH/CDMA uses power control only to reduce intercell interference and as such, power control can be less accurate. FH/CDMA has other advantages over DS/CDMA for personal wireless applications, in which a low power implementation of the handheld transceiver is an important goal. For an FH system, the signal processing is performed at the hop rate, which is much lower than the chip rate encountered in a DS/CDMA system. Slower signal processing components in a FH/CDMA system result in less power consumption. Another advantage of FH technique is frequency agility, which means the spectrum does not have to be contiguous. With frequency agility, the effect of narrow band external jammers can be nullified. The potential problems with FH/CDMA are the need for complex frequency synthesizer and strict time synchronization requirements to ensure the orthogonality of FH patterns. This paper presents a novel method to mitigate the need for strict synchronization requirement in conventional FH/CDMA. Further, by employing Intermediate Frequency Hopping Spread Spectrum modulation, the design of the frequency synthesizer becomes simpler.

Proposed Novel Intermediate Frequency Hopping Spread (IFH-SS) Spectrum

The block diagram of the proposed novel Intermediate Frequency Hopping Spectrum (IFH-SS) is outlined in Fig's. 1 and 2 respectively. The design has been implemented efficiently using modular approach. The FM signal has been received by CXA1619BS receiver. The voice signal (Random in nature) obtained after demodulating the received FM signal has been used as a reference signal to spread the data. The voice signal is converted into a digital code for spreading the message signal. The same voice signal has been used as the base-band message signal for transmission. The spreading code has been used to select a particular carrier frequency which is a function of modulating signal to be transmitted. The hopping rate of the carrier frequency is approximately equal to the bit rate i.e., each bit is transmitted over a single frequency.

Since this information signal is truly unpredictable for any unauthorized receiver, The pattern of the N- frequencies of this message as a code or a key for a purpose of randomly selecting frequency chosen for implementing the FH-SS modulation system is significantly unpredictable for an un-authorized user. The signal spreading using the proposed IFH-SS system is based upon the digital code generated from the voice signal obtained from the local FM broadcast station. However, the FM signal more importantly the scheme of generating the spreading code from the demodulated FM signal can be made available to the authorized receiver to facilitate for signal demodulation

At the transmitting end the FM signal has been received by using CXA1619BS FM receiver and is given to the amplifier and clamper circuitry. The Output of the clamper is given to the ADC. The binary message bit stream obtained from serial message source (FM Receiver) is applied to 8-bit SIPO shift register. This 8-bit output of the shift register has been given to one of the inputs of the 8 AND gates. Another input of the AND gates is actually a random signal obtained from LFSR (Code Conveter) which adds more security to the proposed scheme. The output of AND gate has been given to 8x3 encoder circuitry implemented by using conventional ICs. This 3-bit output of 8x3 encoder is applied to a digital frequency synthesizer which generates N frequencies at its output. The output of the frequency synthesizer is applied to one input of X-OR gate and another input of the X-OR gate is driven by the binary message signal obtained from FM demodulated signal. The X-OR gate combines the base band data signal with the given frequency available at the output of the frequency synthesizer by simply performing modulo- 2 addition. Finally, the output of X-OR gate is transmitted as IFH-S signal.

At the receiving end the same FM signal has been received with the help of another FM receiver, after performing same steps as followed at transmitting end. The de-spreading code has been obtained using the same procedure as that of generating the spreading code. The proposed scheme has been implemented using synchronous mode of operation. The code generated at the receiving end and incoming IFH-SS signal are given to modulo – 2 adder so as to recover the original message. The Waveforms obtained at various check points are included in the present paper. Besides above mentioned advantages the user capacity of the proposed technique can be considerably increased by increasing the signal to noise ratio as at low frequency the noise power would be low.

The signal to noise ratio in case of CDMA is given as

$$SNR = \frac{1}{N-1} \quad \text{...(a)}$$

In CDMA *SNR* can also be replaced by $\frac{Eb}{N0}$ so

$\frac{Eb}{N0}$ = *W/R/N-1* Where *W* is chip rate , *R* is data rate. If consider the background thermal noise in spread bandwidth, then

Eb/ No= W/R/(N-1)+ (η/S). Thus users served in a single cell are

N= 1+W/R/Eb/No - (η/S). If voice activity is also being considered in CDMA so

N= 1+ 1/α W/R/α Eb/No. The load factor is defined as

η= ∑ 1/ 1+ 1/α W/R/Eb/ No……………………..(b)

The load factor comes near 1, the interference margin is getting quite fast. Typically the load target should be maintained between 50% and 75% because at these points the system is stable and can serve users effectively and efficiently. From the above discussion it is clear that number of users served by a particular cell depends on the signal to noise ratio, in the proposed technique the signal to noise ratio is quite high as it has been operated at intermediate frequency. Moreover jamming margin is also high because of high load factor as clear from equation (b).

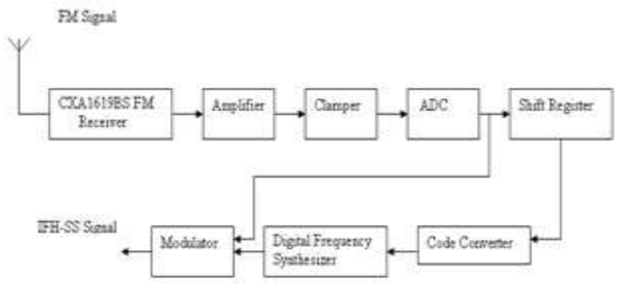

Fig 1. Block Diagram of the Transmitter

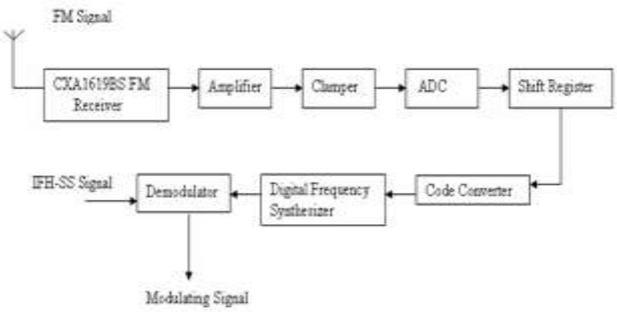

Fig 2. Block Diagram of the Receiver

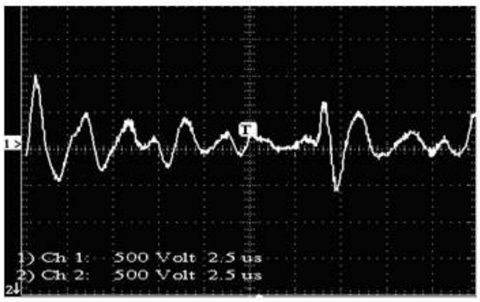

Fig.3. Waveform of un Voiced part of voice Signal at transmitting end

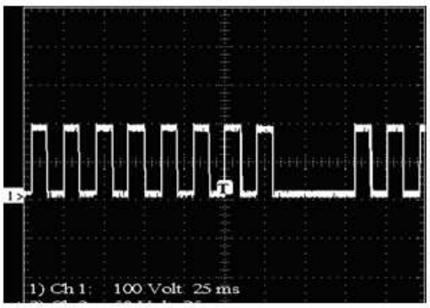

Fig.4. Output of Analog to Digital Converter

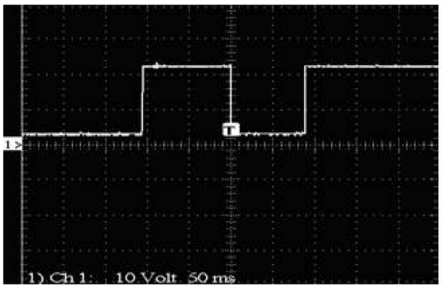

Fig.5. Waveform of Frequency Synthesizer at transmitting end

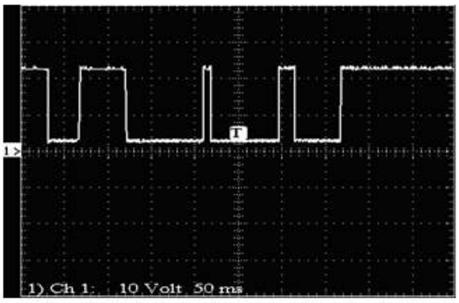

Fig.6.Waveform of IF-FH signal (Transmitter Output)

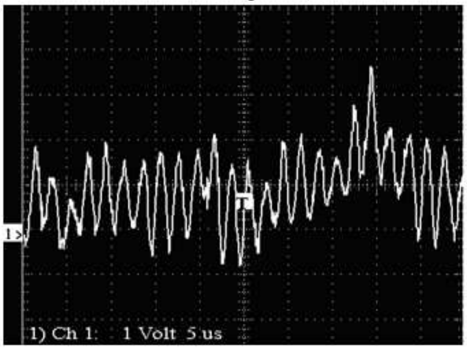

Fig.7. Waveform of un voiced part of voice signal at receiving end

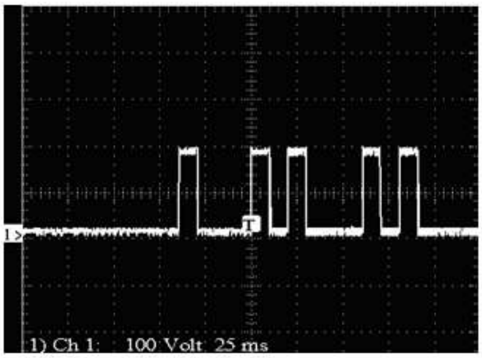

Fig.8. ADC output at receiving end

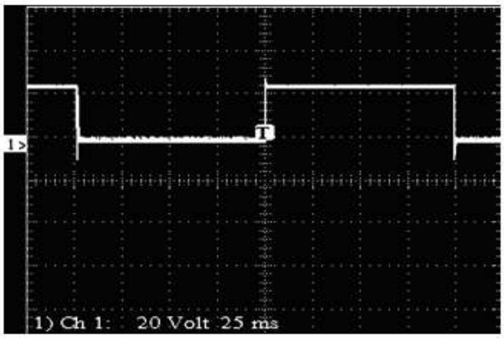

Fig.9. Waveform of Frequency Synthesizer at receiving end

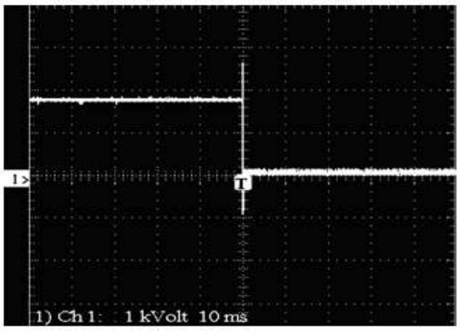

Fig.10. Waveform of IFH-SS demodulator

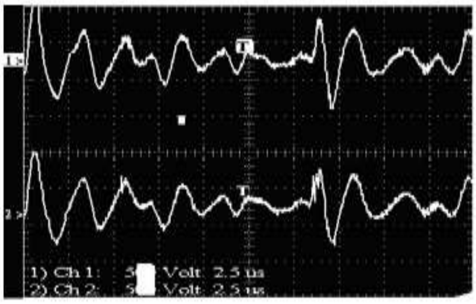

Fig.11. Waveforms of Transmitted and received voice signal.
Ch 1: Transmitted Signal
Ch 2: Received Signal

Experimental Verification and Results

The proposed Intermediate Frequency Hopping Spread Spectrum signal (IFH-SS) has been experimentally tested for its performance by transmitting and receiving voice signal. The voice signal obtained after demodulating an FM broadcast signal has been made to generate a spreading code at the transmitter and the de-spreading code at the receiver. The proposed scheme minimizes the disadvantage of fast hopping spread spectrum of the requirement of high speed frequency synthesizers and strict code synchronization and proposes a new concept of Intermediate frequency hopping spread spectrum with inherent advantages of need of low speed frequency synthesizers, less synchronization problem, requirement of low cost and simple amplifiers and filters. The proposed scheme has been tested experimentally using hardware modules and the resultant waveforms have been put in the paper. Various waveforms obtained while transmitting and receiving the voice signal has been recorded for technical observation. The waveforms obtained at various check points have been found satisfactorily and are in conformity with the technical observation. The waveforms obtained at various check points are shown in Fig's 3 to 11 respectively.

Conclusion

The use of Spread Spectrum modulation techniques in Code Division Multiple Access (CDMA) Systems and Secure Message Communication have increased over the past few years. However to be able to implement spread spectrum systems both Direct Sequence (DS-SS) and Frequency Hopping (FH-SS) spread spectrum requires very complex circuitry and more power. The FH-SS has numerous advantages over the DS-SS. The potential problems with FH/CDMA are the need for complex frequency synthesizer and strict time synchronization requirements to ensure the orthogonality of FH patterns. Two variants of FH-SS reported so for in the literature are Fast Frequency Hopping (FFH-SS) and Slow Frequency Hopping Spread Spectrum (SFH-SS). Fast Frequency Hopping (FFH-SS) has many advantages over Slow Frequency Hopping Spread Spectrum (SFH-SS). However FFH-SS suffer by need of high speed frequency synthesizers particularly in CDMA applications which operates at high frequency in megahertz range, strict time synchronization and consequently power consumption is more which poses a problem in VLSI implementation. The work presented in the paper proposes a new variant of FFH-SS Modulation called a Intermediate Frequency Hopping Spread Spectrum (IFH-SS) with better performance in terms of low power requirement, no need of strict time and code synchronization, requirement of low cost and simple filters and amplifiers both at transmitting and receiving end compared to other variants of FH-SS and also has user capacity. The paper presents a novel method to mitigate the need for strict synchronization requirement in FH/CDMA. Further, by employing intermediate frequency hopping spread spectrum modulation, the design of the frequency synthesizers becomes simpler. The new variant of FH-SS can be simulated using simulation software for comparing its performance with conventional one, and is open for further research in terms of calculation of bit error rate, auto correlation and cross correlation properties using Monte- Carlo simulation approach.

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