Thesis

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# Introduction

## The need for TTE:

### The use of the underground medium

Using the underground medium as a valid part of the battlefield is not unique to the recent years. Tunnels have served the Vietnamese in the Vietnam War both as a shelter and a stealth base to launch attacks against the American military. In Korea, one of the most probable scenarios to which the South Koreans and their counterparts are preparing for is an invasion launched from tunnels dug beneath the border between the two hostile states. Yet, the most actual case is the Israel-Gaza border where the tunneling warfare occupies a major role on both sides; Hamas on the attacker side and Israel on the defending side. It has reached a point where an entire all out clash’s outcome depends mainly on the underground warfare. As a result, huge technical and financial efforts are put to outrank the rival.

On the Homeland Security area, the underground medium has a presence too. Emergency services, often need to penetrate into closed underground spaces where no communication infrastructure is present such as collapsed buildings. Also in that domain, is the problem of illegal infiltration through the Mexico-USA border, where tunnels are sometimes used.

Yet, probably the area where the underground medium is most present is the civilian. The mining industry has suffered for hundreds of years from a bad reputation for its high rate of accidents and fatalities. Very often the accident itself is the cause for a communication failure which is usually wired.

In all of these cases, we are facing the need for a reliable wireless ad-hoc communication ability.

### ULF-VLF approach and TTE devices

Despite the old and proven need for Surface to Underground TTE wireless communication, up until late 2010’s, no such commercial nor military communication system had been developed. The capability of low frequency (ULF-VLF band) Electromagnetic Fields to penetrate through the ground has been proposed as early as 1890 by Nikola Tesla [Carrol]. However, in the 1970’s a research conducted by the US Bureau of Mines suggested that the required transmitted power, namely on the underground side, should exceed the safety allowable levels, thus making it impractical. [NIOSH]

The advances in the communication technology from the 1990’s and on, namely the digital and coding techniques, offered enhanced receiver performance allowing reduction of the transmitted power. A sponsored study was initiated by the American National Institute for Occupational Safety and Health (NIOSH) on 2007, in which participated 5 contractors: Lockheed Martin, E-spectrum, Stolar and Alertek. Its aim was to examine the feasibility of TTE wireless communication in the mining industry. All but one (E-Spectrum) adopted the Magnetic field approach: large Loop antennas (Coils in fact) communicating through a Quasi-Static Magnetic Field

### ULF- VLF communication approach

## Electromagnetic analysis of VLF band

## Magnetic devices- Coils

## Channel model: Brazil figure 14

## The choice of OFDM

### Analog or FSK ( Brazil, p. 166)

### MSK (Brazil [2])

### impulsive noise (Brazil); frequency selective?

### No good model. (Brazil p.170 left)

### OFDM is flexible both on Tx and on Rx

Innovation: To our knowledge, none of the commercial manufacturers use OFDM. Enables frequency selective modulation and coding, what fits the still unknown TTE channel noise and shape. [NIOSH p.2 left up]

High sensitivity to mutual antennas orientation. We developed a 1x3 SIMO with 3-axis Rx antenna to prevent that, sensitivity (at least on the Rx side) namely for a moving object [NIOSH p.2 left middle

### CSIT is of advantage

# System, Magnetic and analog devices

## 

## 

## 

## 

## System requirements

### Throughput

### Range

### Antenna

### Frequency domain characteristics

### Direction sensitivity

## SIMO 1x3

### Ordinary use of SIMO: small scale fading

### Proposed use of SIMO: Large scale fading

## SDR concept

## Magnetic devices

### Tx

### Rx

## Analog devices

### D/A

### A/D

### Reconstruction & Anti-aliasing filters (Maxim)

## Link budget

### Calculation

### Simulation

# OFDM - General

## Need: Rx & Tx Selectivity

Along the years, communication systems have been challenged to provide higher data rates, to operate in increasingly difficult channel mediums and in increasingly densely occupied spectrum. The NLOS channels, in particular, confronted the communication system with highly frequency selective channels. All of the above created the need to provide waveforms with inherent frequency flexibility allowing both Tx and Rx chain to process the signal in frequency selective manner. The traditional single-carrier technology did come up with means of dealing with these impairments, with equalizers fora example, but this ability was limited to moderately selective channels and frequently did more harm than good

## Evolution of OFDM

OFDM and its ancestors are based on simultaneous transmission instead of serial transmission. A single carrier signal can be expressed as follows:



Where  is the pulse shaping function (usually belonging to the Raised cosine family),  is the n’th data symbol, and  is the symbol time. The separation between the consecutive symbols is in the time domain, and the pulse shaping function is such that enables the extraction of a given symbol form its predecessors and followers.

A multicarrier waveform is expressed as follows:



Where  are called the “sub-carrier” functions and are the data symbols, and  is again the symbol time. Here, the separation is achieved in the frequency domain

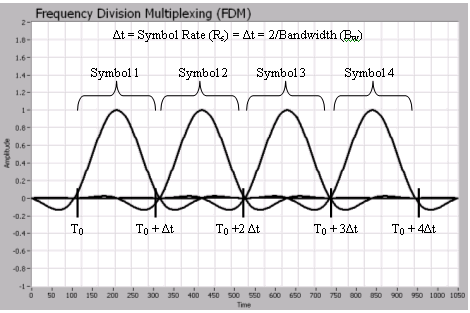
Naturally, in order to transmit the same amount of data symbols;



Hence, we can regard the multi carrier subcarriers as independent single-carrier waveforms, each spanning along a much longer duration in time that their corresponding true single carrier waveform. Longer duration means narrower bandwidth, which suggests why multi carrier waveforms deal better with frequency selective mediums.

### FDM

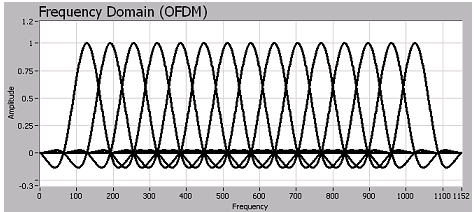
The basic waveform contains several sub carriers spectrally separated from each other. i.e; concatenated in such a way that a simple amplitude (e.g; brick wall, butterworth) filter bank can extract them with no significant loss of energy:



The implementation, however, is rather cumbersome and complex as it requires a bank of analog filters, frequency sources and mixers.

### Analog OFDM

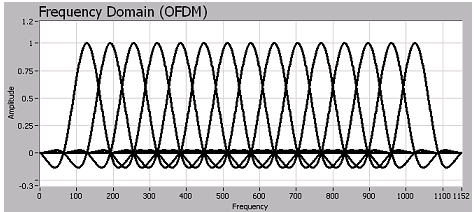
Orthogonal FDM uses the orthogonal Fourier basis for as the subcarrier family. That allows a denser arrangement, hence a better spectral efficiency



The analog implementation remains cumbersome

### Digital OFDM

The digital implementation of OFDM solves that problem of complexity of implementation as the simultaneous modulation/demodulation operations becomes IDFT/DFT operations. Those are naturally realized via the particularly efficient IFFT/FFT algorithms.



## Mathematical representation

### Tx

Additionally, it makes use of the DFT’s cyclic convolution property to easily estimate the channel and efficiently correct it.

## Mathematical representation

### Tx

the complex Fourier basis is:



i.e; a family of functions completing an integer number of cycles within the time span 



The transmitted signal, which is the linear combination of that basis with a QAM symbols stream as coefficients will be:



Will turn to:



The following figure demonstrates that procedure:

The symbol stream: multiplied by the above basis functions gives (real part)



Which look meaningless

### Rx: matched filtering as FFT

### Rx: matched filtering as FFT

## CP:

### General: Frequency domain equalization- Linear into cyclic convolution

### OFDM frequency domain equalization: flatness per subcarrier (channel=complex scalar)

### Preservation of orthogonality

### ISI (Guard time)

## Time synchronization problems: effect on signal (Prasad)

## Frequency synchronization problems: effect on signal (Prasad, NPTEL, my summary)

## Pilots

## Guard bands:

### The need to D/A

### the DC sc

## Preambles

### Long:

* + - 1. PN sequence

### Short:

* + - 1. Channel estimation
      2. SNR estimation

# OFDM –parameters calculations

## CP

## N FFT

## Length of preambles

# Transmitter

## Preambles enhancement

## PAPR reduction

## Analog HW compensation: inverse sinc, differentiator

# Receiver:

## Equalizer types (see findings document)

## Timing synchronization

## Frequency& phase synchronization

## MRC MIMO

# Data Converters integration:

## Setting the Fs, Frec

## Synchronization

## Frequency error effect on signal integrity. My analysis (summary) and results

# Results- Simulations

# Results- Field experiments

# References

[1] Through the Earth Communications for Underground Mines. Carreno, Silva et al

[2] NIOSH – sponsored Research in Through the Earth Communications for Mines: a status report

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Through the Earth Communications: Breathrough solution for Miner safety. Carrol Technology group