1. Introduction
   1. The need for TTE:
      1. NIOSH
      2. Robot, rescue, first responders…
      3. Manufacturers: Ultra (Rock Phone), Lockheed- Martin (),,…
      4. Approaches:
         1. E-field: https://www.cdc.gov/niosh/mining/researchprogram/contracts/contract\_200-2008-26818.html
         2. B-field
         3. Alertek, Lockheed, Stolar, E-spectrum, Ultra
   2. Electromagnetic analysis of VLF band
   3. Magnetic devices- Coils
   4. Channel model: Brazil figure 14
   5. The choice of OFDM
      1. Analog or FSK ( Brazil, p. 166)
      2. MSK (Brazil [2])
      3. impulsive noise (Brazil); frequency selective?
      4. No good model. (Brazil p.170 left)
      5. OFDM is flexible both on Tx and on Rx
      6. CSIT is of advantage
2. System, Magnetic and Analog Devices
   1. System requirements
      1. Throughput
      2. Range
      3. Antenna
      4. Frequency domain characteristics
      5. Direction sensitivity
   2. SIMO 1x3
      1. Ordinary use of SIMO: small scale fading
      2. Proposed use of SIMO: Large scale fading
   3. SDR concept
   4. Magnetic devices
      1. Tx
      2. Rx
   5. Analog devices
      1. D/A
      2. A/D
      3. Reconstruction & Anti-aliasing filters (Maxim)
   6. Link budget
      1. Calculation
      2. Simulation
3. OFDM- general
   1. Need: Rx & Tx Selectivity
   2. Evolution
   3. Mathematical representation
      1. Tx
      2. Rx: matched filtering as FFT
   4. CP:
      1. General: Frequency domain equalization- Linear into cyclic convolution
      2. OFDM frequency domain equalization: flatness per subcarrier (channel=complex scalar)
      3. Preservation of orthogonality
      4. ISI (Guard time)
   5. Time synchronization problems: effect on signal (Prasad)
   6. Frequency synchronization problems: effect on signal (Prasad, NPTEL, my summary)
   7. Pilots
   8. Guard bands:
      1. The need to D/A
      2. the DC sc
   9. Preambles
      1. Long:
         1. PN sequence
      2. Short:
         1. Channel estimation
         2. SNR estimation
4. OFDM- parameters calculations
   1. CP
   2. N FFT
   3. Length of preambles
5. Transmitter:
   1. Preambles enhancement
   2. PAPR reduction
   3. Analog HW compensation: inverse sinc, differentiator
6. Receiver:
   1. Equalizer types
   2. Timing synchronization
   3. Frequency& phase synchronization
   4. MRC MIMO
7. Data Converters integration:
   1. Setting the Fs, Frec
   2. Synchronization
   3. Frequency error effect on signal integrity. My analysis (summary) and results
8. Results- Simulations
9. Results- Field experiments

Introduction

Recent years have introduced an ever-growing need for wireless, high-rate and reliable Through-The-Earth (TTE) communication: two-way link between ground surface and underground devices. That necessity has emerged both in the Homeland security sector (e.g: USA-Mexico border) as well as in the military (e.g: Gaza border) sector as asymmetric warfare is slowly migrating to the underground medium, bypassing the surface artificial obstacles.

In fact, that need had been met years before that in the mining industry, where wireless communication was a necessity in various applications, from emergency communication in case of collapse to monitoring underground sensors and robots. The first choice would be radio frequency communication, which obeys the far field propagation regime on the relevant ranges ( ~10's meters), due to availability of bandwidth. However, that kind of propagation is highly sensitive to electric conductivity, namely to that of a medium composed of soil and rocks That sensitivity results in substantial attenuation of the signal making them useless above few meters for a practical system. Apart from that, radio frequency channel suffers from the known issue of multipath due to its non-homogenous ingredients.

The sensitivity of RF signals to electric conductivity led to the concept of near-field quasi-static communication