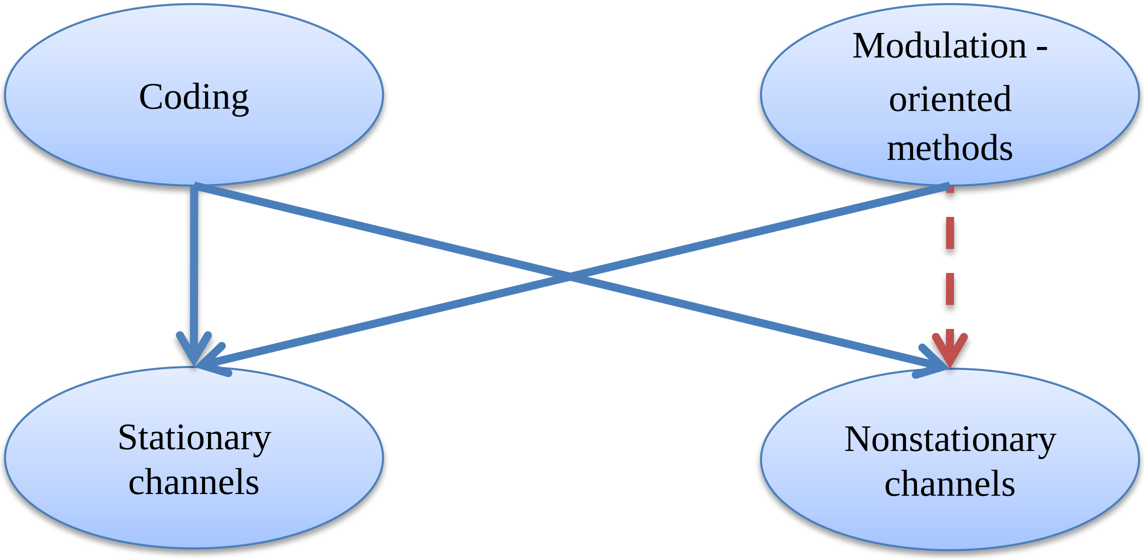
JACOBS UNIVERSITY

Lattice Signal Sets Combating Pulsed Interference from Aeronautical Signals

Khodr Saaifan and Werner Henkel

Motivation


Coding

Modulation - oriented methods

Stationary channels

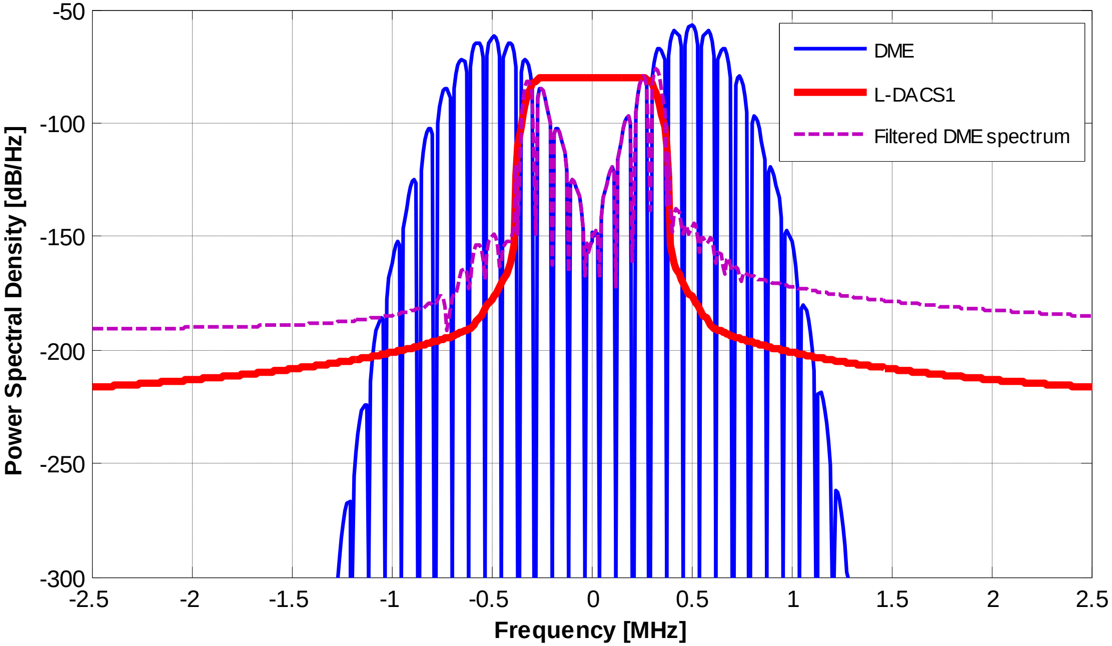
Nonstationary channels

Outline

- **System under consideration**
  - L-band Digital Aeronautical Communications System (**L-DACS**)
  - Distance Measuring Equipment (**DME**) Signal Structure
  - Current DME Signal Mitigation Techniques
- **Proposed DME Signal Mitigation Techniques**
  - Multidimensional Lattice Constellations
  - DME Signal Mitigation by Interleaved Lattice Code
  - Proposed DME Spectrum Clipping Techniques
  - Simulation Results
  - Future Works
- **Summary/Conclusion**

L-DACS

- L-DACS was proposed by DLR to replace the analog communication by a robust digital procedure
- To make as much bandwidth as possible in L-band, L-DACS developed as an Inlay system
- L-DACS physical layer is based on OFDM modulation and designed for operation in the aeronautical L-band (960-1164 MHZ)



L-DACS 1 – A concept for future digital air communications that exploits spectral gaps

DME Signal Structure

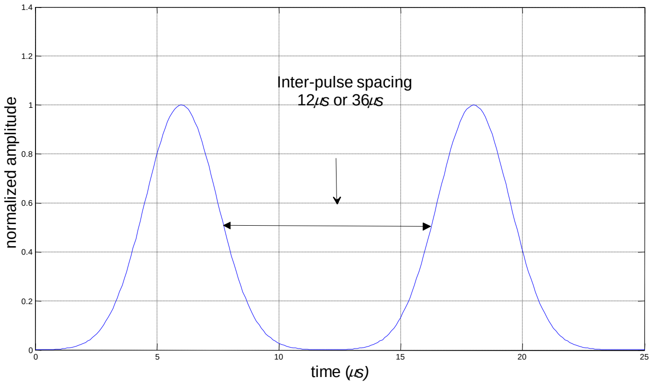
- The DME signal consists of pairs of Gaussian-shaped pulses with spacing Δ*t*

$$b^{DME}(t) = \exp\left(-\frac{\varepsilon}{2}t^2\right) + \exp\left(-\frac{\varepsilon}{2}(t-\Delta t)^2\right)$$

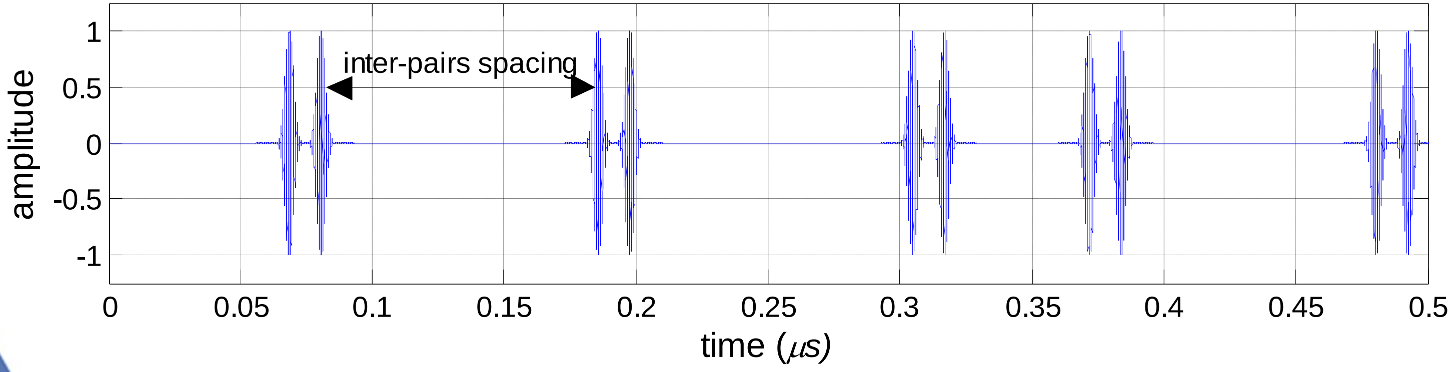
where $\varepsilon = 4.5 \times 10^{11} s^{-2}$

$\Delta t = 12\mu s \text{ or } 36\mu s$

The constant ε determines the pulse width, while Δ*t* is the inter-pulse spacing



- The ground beacon transmits 2700 pulse pairs per second (ppps) for DME and 3600 ppps for TACAN ground stations

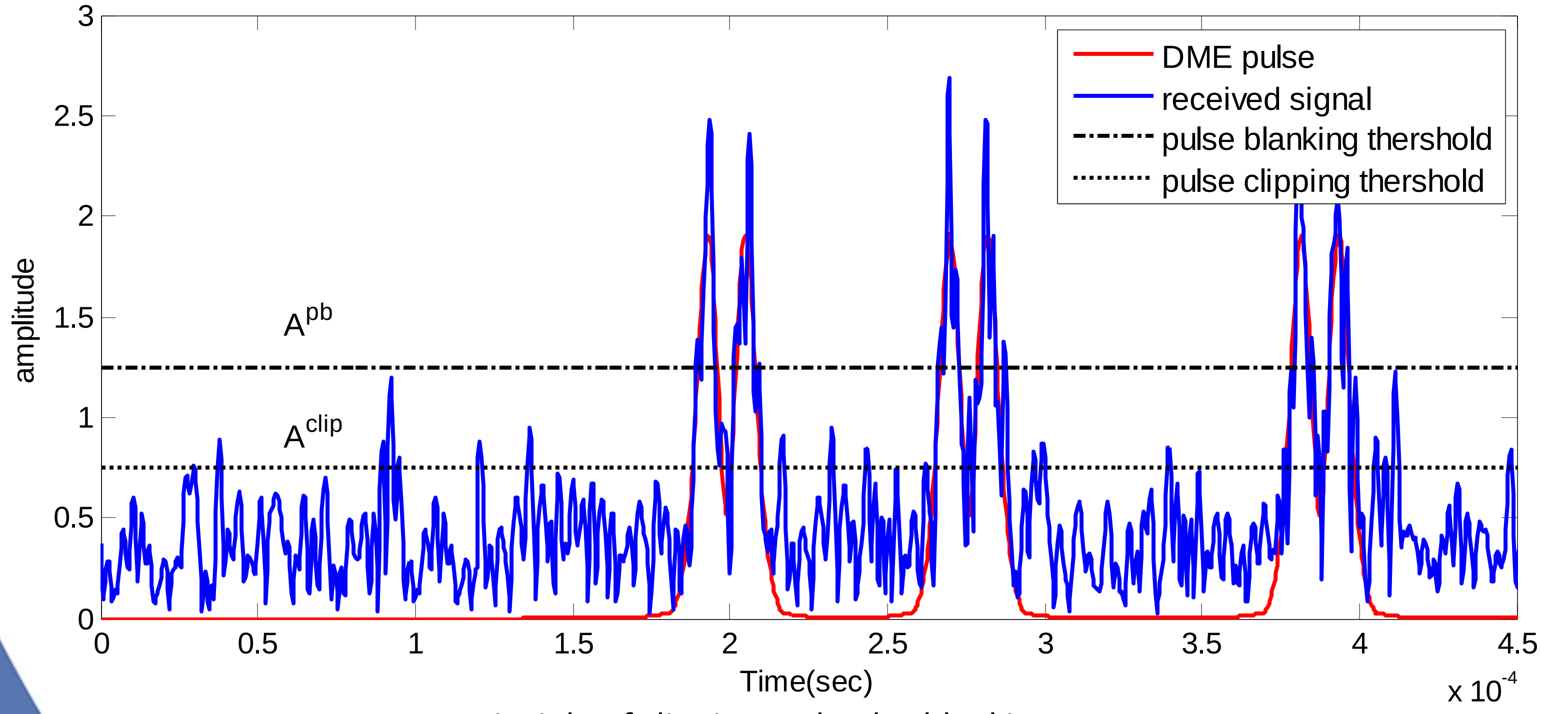


A DME pulse pairs train

Current DME Mitigation Techniques

- Frequency domain approach [Grace Xingxin Gao, 2007]
  - Notch filter

- Time domain approach [S. Brandes et al., 2009]
  - Pulse clipping
  - Pulse blanking



Principle of clipping and pulse blanking

Multidimensional Lattice Constellations

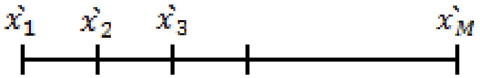
- Modulation diversity has no detrimental effect on the spectral efficiency [Boulle et al., 1992]
- It is widely used in literature for constructing high-rate full-diversity space time codes i.e. DAST [Damen et al., 2003], TAST [Gamal et al., 2003],....etc

- Let an information symbol vector $\boldsymbol{d}=[d_1\ d_2\ \ldots\ d_M]^T$ where d_j, $j=1,2,\ldots,M$ belongs to real or complex constellations (PAM, or QAM)
- The encoded symbol vector $\boldsymbol{x}=[x_1\ x_2\ \ldots\ x_M]^T$ belongs to the *M*-dimensional lattice constellation $\boldsymbol{A}$

$$\boldsymbol{A}=\{\boldsymbol{x}=\boldsymbol{G}_M\boldsymbol{d},\quad \boldsymbol{d}\in\mathbb{Z}^M\}$$

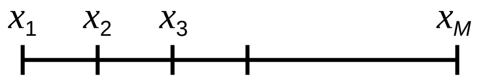
- For Rayleigh fading channel, optimum $\boldsymbol{G}_M$ should:
  - Maximize the *modulation diversity* (min. Hamming distance)

$$L=\min(l)=\underbrace{\min}_{x\neq\grave{x}}\#\{j|x_j\neq\grave{x}_j, j=1,\ldots,M\}$$



  - Maximize the *minimum product distance*

$$d_{p,min}=\underbrace{\min}_{x\neq\grave{x}}\prod_{x_j\neq\grave{x}_j}|x_j-\grave{x}_j|$$



- The lattices from $\mathbb{Q}[\theta_N]$, the cyclotomic field extension of order N, proposed by [Giraud et al., 1997] provide full-diversity in Rayleigh fading channel and have no performance loss over AWGN

$$\boldsymbol{G_M} = \left(\frac{1}{\sqrt{M}}\right)\boldsymbol{VDM}(\theta_1,\theta_2,\dots,\theta_M), \quad \boldsymbol{VDM}\text{:Vandermonde matrix}$$

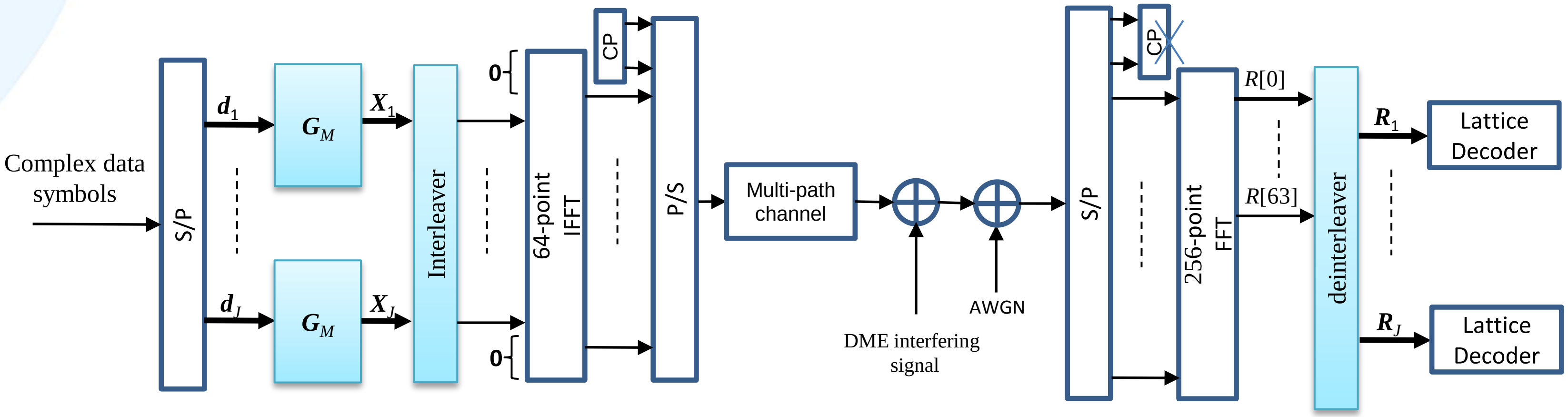
  - For $M=2^r$ ($r \geq 1$) $\quad \theta_k = \exp\left(j\frac{4k-3}{2M}\pi\right), k = 1,2,\dots,M$
  - For $M=3\text{x}2^r$ ($r \geq 0$) $\quad \theta_k = \exp\left(j\frac{6k-1}{3M}\pi\right), k = 1,2,\dots,M$

- [Damen et al., 2003] proposed an explicit construction of fully-diverse unitary transformations and show that the Vandermonde based transformations are special cases.

$$\boldsymbol{G_M} = \boldsymbol{W_M^H}\,\text{diag}(1,\theta^{1/M},\dots,\theta^{(M-1)/M})$$

  - $\boldsymbol{W}_M$ is the MxM discrete Fourier transform (DFT) matrix, and θ is chosen algebraically to guarantee the full diversity of the rotation

DME Signal Mitigation by Interleaved Lattice code



f_s: OFDM bandwidth
$i(t)$: DME interfering signal

- A block of N_s information symbols are subdivided into $J=(N_s\,/M)$ equal size subblocks $\boldsymbol{d}_j$
- Each subblock $\boldsymbol{d}_j$ is encoded into a lattice codeword $\boldsymbol{X}_j$

$$\boldsymbol{X}_j = \boldsymbol{G}_M \boldsymbol{d}_j, \qquad j = 1,2,\dots,J$$

- Then the received signal

$$r^{\mathrm{ov}}[k] = x^{\mathrm{ov}}[k] + z^{\mathrm{ov}}[k] + i[k], \quad k = 0,\dots,255$$

- After FFT operation

$$R[k] = X[k] + Z[k] + I[k], \quad k = 0,\dots,63$$

- After applying lattice decoder

$$\tilde{\boldsymbol{d}}_j = \arg\min\left\{\left|\boldsymbol{R}_j - \boldsymbol{G}_M \boldsymbol{d}_j\right|^2\right\}, \quad j = 1,2,\dots,J$$

→ using QR factorization

$$\boldsymbol{G}_M = \boldsymbol{Q}\boldsymbol{R} = \boldsymbol{W}_M^H \boldsymbol{D}_\theta$$

→ searching through all the symbol sequences for which

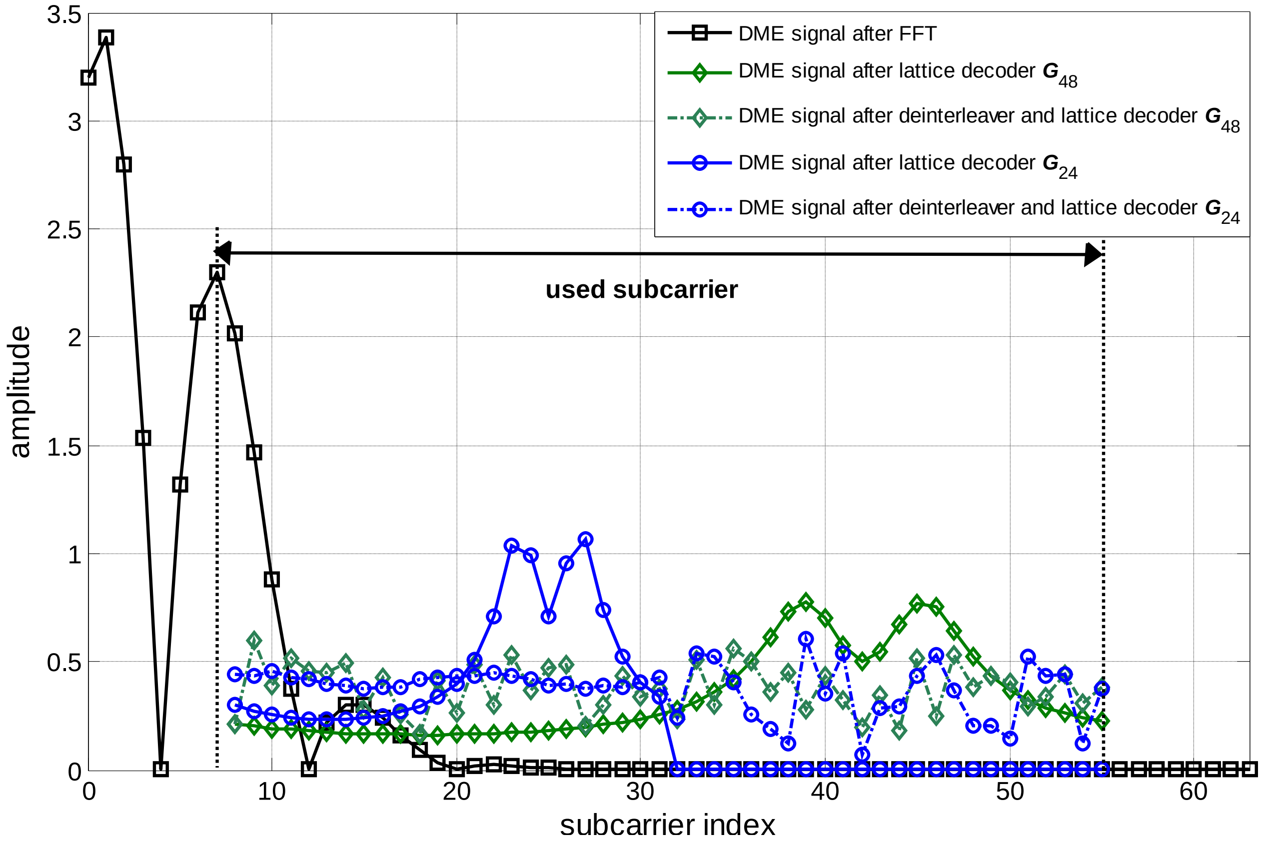
$$|\boldsymbol{W}_M \boldsymbol{R}_j - \boldsymbol{W}_M \boldsymbol{W}_M^H \boldsymbol{D}_\theta \boldsymbol{d}_j|^2 = |\dot{\boldsymbol{R}}_j - \boldsymbol{D}_\theta \boldsymbol{d}_j|^2 < C$$

where $\dot{\boldsymbol{R}}_j = \boldsymbol{W}_M \boldsymbol{X}_j + \boldsymbol{W}_M \boldsymbol{Z}_j + \boxed{\boldsymbol{W}_M \boldsymbol{I}_j}$

↓

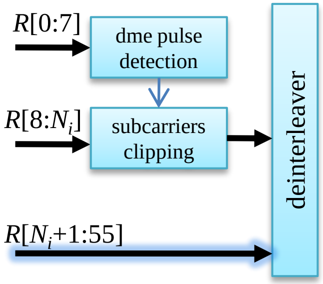
Interference is subject to another transform

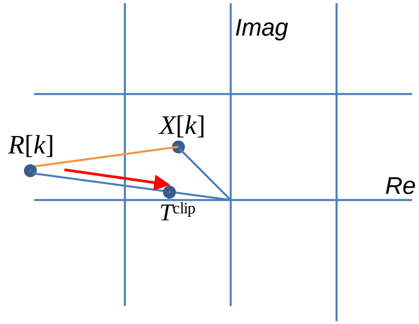
- One DME interferer at f_c= -0.5MHz offset to the OFDM system. The peak power of the interferer is -75 dBm and the pulse rate is 10800 pulse pairs per sec.



Spectrum of DME signal after FFT and lattice decoder with $\boldsymbol{G}_{24}$ and $\boldsymbol{G}_{48}$

Proposed DME Spectrum Clipping Techniques





- **Method 1**: the amplitude of Rx code component on the affected subcarrier is clipped to a certain threshold T^{clip} if it exceeds T^{clip}

$$R[k] = \begin{cases} R[k] & |R[k]| < T^{clip} \\ T^{clip}\exp\{j\arg\{R[k]\}\} & |R[k]| \geq T^{clip} \end{cases}$$
$$k = 8,9,..N_i$$

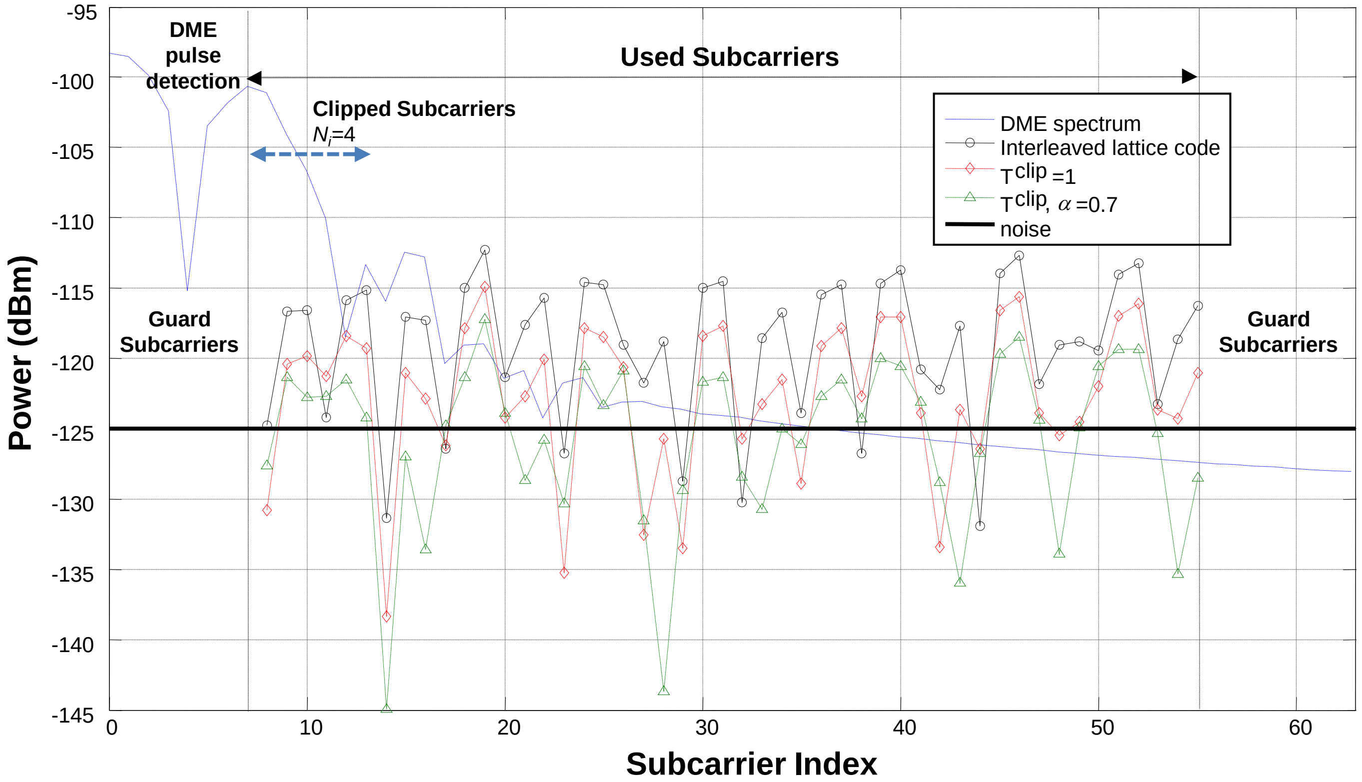
- **Method 2**: the amplitude of Rx code component on the affected subcarrier is clipped to a value that depends on the expected amplitude of the interferences (DME + noise) on this subcarrier

$$R[k] = \begin{cases} R[k] & |R[k]| < T^{clip} \\ (|R[k]| - \alpha \mathrm{E}[|\eta[k]|])\exp\{j\arg\{R[k]\}\} & |R[k]| \geq T^{clip} \end{cases}$$
$$k = 8,9,\ldots,N_i$$

  - During the first frame of transmission the affected subcarriers are turning off

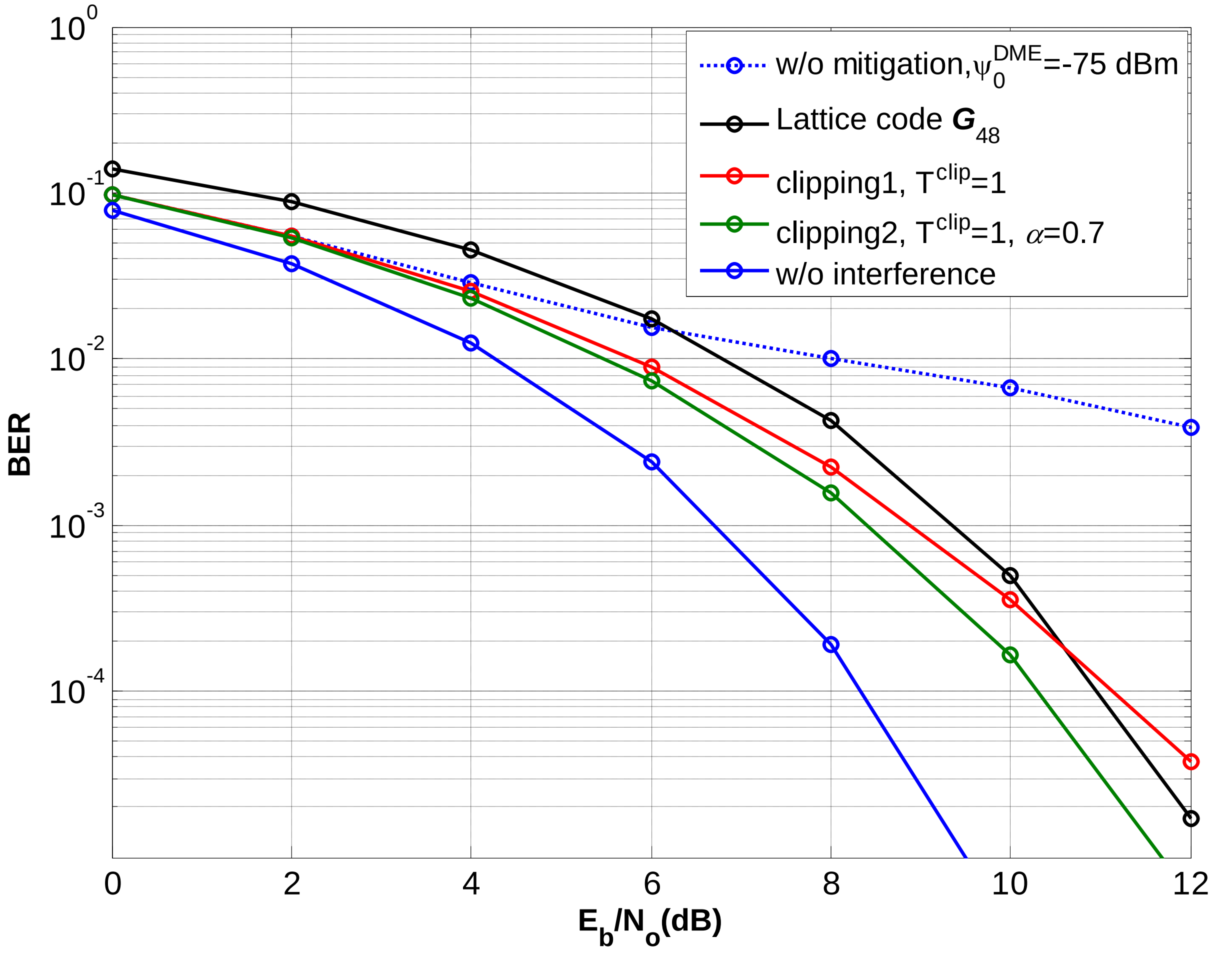
$$\mathrm{E}[|\eta[k]|] = \mathrm{E}[|R[k]|] = \mathrm{E}[|Z[k] + I[k]|], k = 8,9,\ldots,N_i$$

Simulation results



Spectrum of DME signal after proposed interference mitigation, f_c=-0.5MHz, the peak power= -75 dBm and the pulse rate is 10800 pulse pairs per sec.

Simulation results



BER performance, clipping threshold $T^{clip} = 1$, QPSK, AWGN channel, lattice coding, $\boldsymbol{G}_{48}$.

Next steps

- Derive the optimal parameters for the proposed mitigation techniques T^{clip} ,N_i and α
- Evaluate the performance in more realistic interference scenario derived from real channel assignments

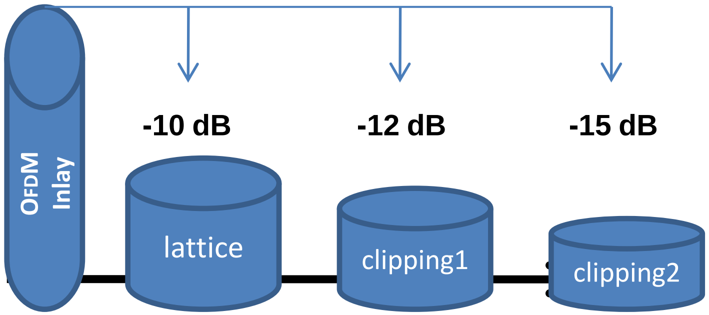
worst case interference scenario

Station	Frequency	Interference power at victim Rx input	Pulse rate
TACAN	994MHz	-72.4 dBm	3600 ppps
TACAN	994MHz	-74 dBm	3600 ppps
TACAN	994MHz	-88.2 dBm	3600 ppps
L-DACS1	994.5MHz		
TACAN	995MHz	-67.9 dBm	3600 ppps

- Evaluate the performance for different flight phases (en-route, take-off/landing, and parking)

Summary/Conclusion

- Inlay approach for L-DACS is considered
- Lattice code has been introduced to mitigate the effect of pulsed interference
- Interleaver is used to average the interference power over all used subcarriers
- Two clipping schemes are applied in frequency domain to reduce the interference power



SNR=8dB

Thank You