Spread Spectrum Techniques for Simultaneous Multi-Source Seismic Acquisition

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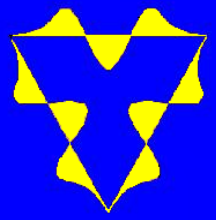


CREWES

OUTLINE

1. *Introduction / Motivation.*
2. *PRBS pilots for seismic vibrators.*
3. *Results*
4. *Discussion and Summary.*

Introduction :Simultaneous Sources

1. *Multiple airguns (Beasley, 2007).*
2. *DSSS (Bouska, 2010).*
3. *HFVS (Krohn et al., 2010 - variphase).*

Pecholcs et al., 2010 :

- *24 vibrators running simultaneously;*
- *> 40,000 vibe points in 24 hours.*

Sallas et al., 2010, 2011 :

- *vibrator pilots = modified Gold codes;*
- *Gold codes are weakly correlated.*

Pseudorandom Binary Sequences (PRBS)

- *m-Sequences (maximal-length sequences);*
- *Gold codes (Gold, 1967);*
- *basis for spread-spectrum techniques widely used in science and engineering.*

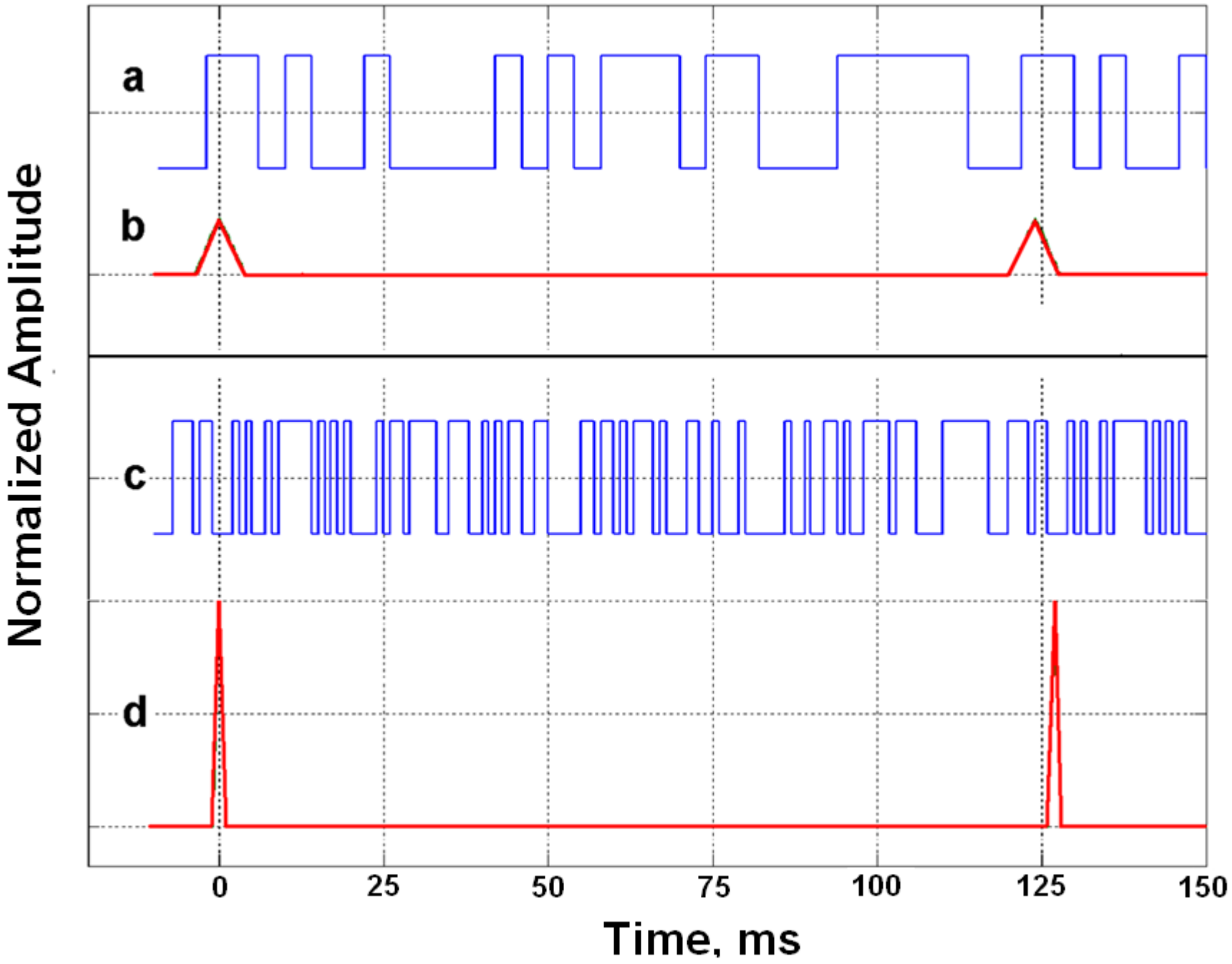
m-Sequences and Gold codes:

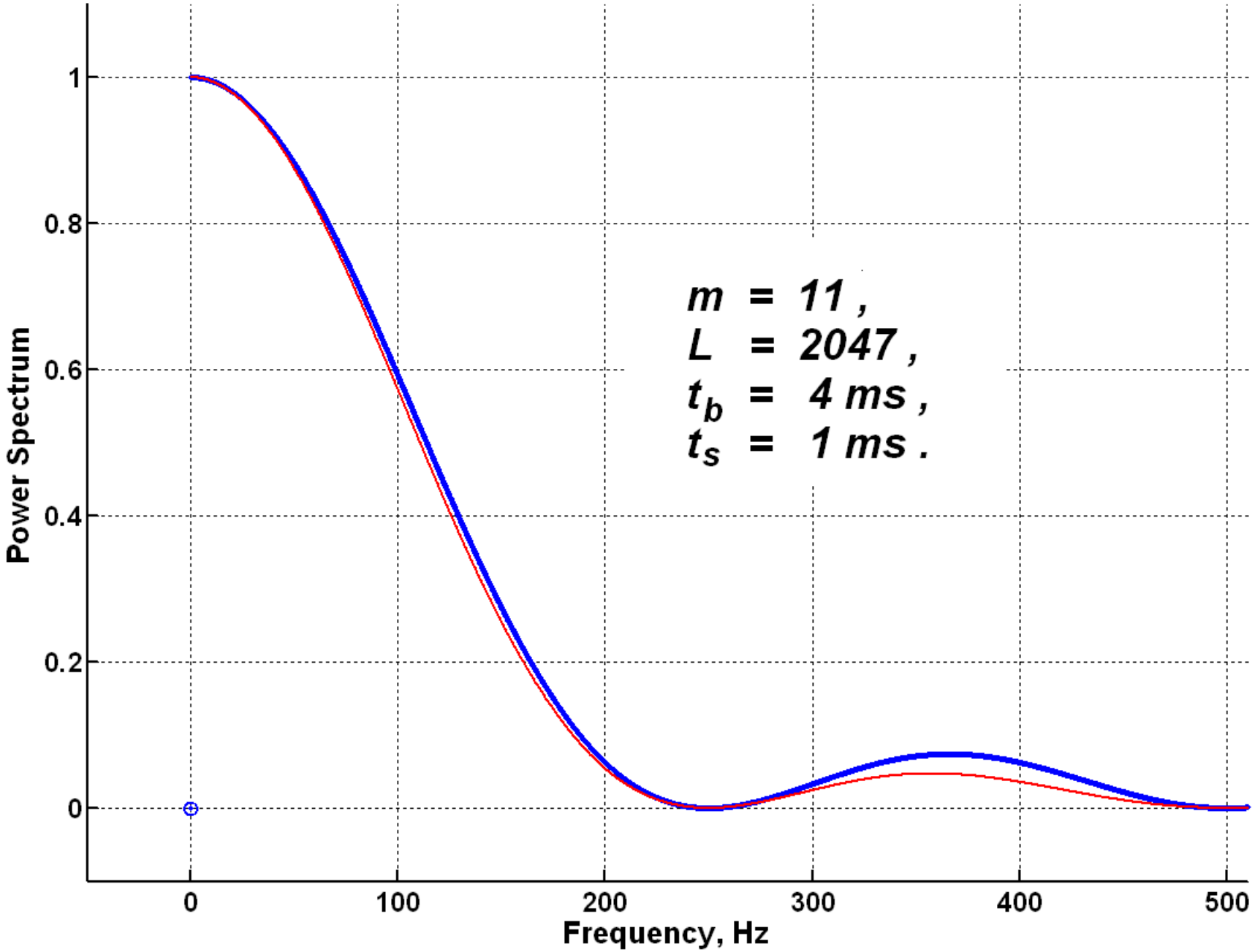
- Periodic entities with -1 and +1 values.
- Auotocorrelations are periodic triangular spikes (mimic white noise).
- Each entity is defined by m, L, and t_b :

$$L = 2^m - 1 \ .$$

- The period in milliseconds is

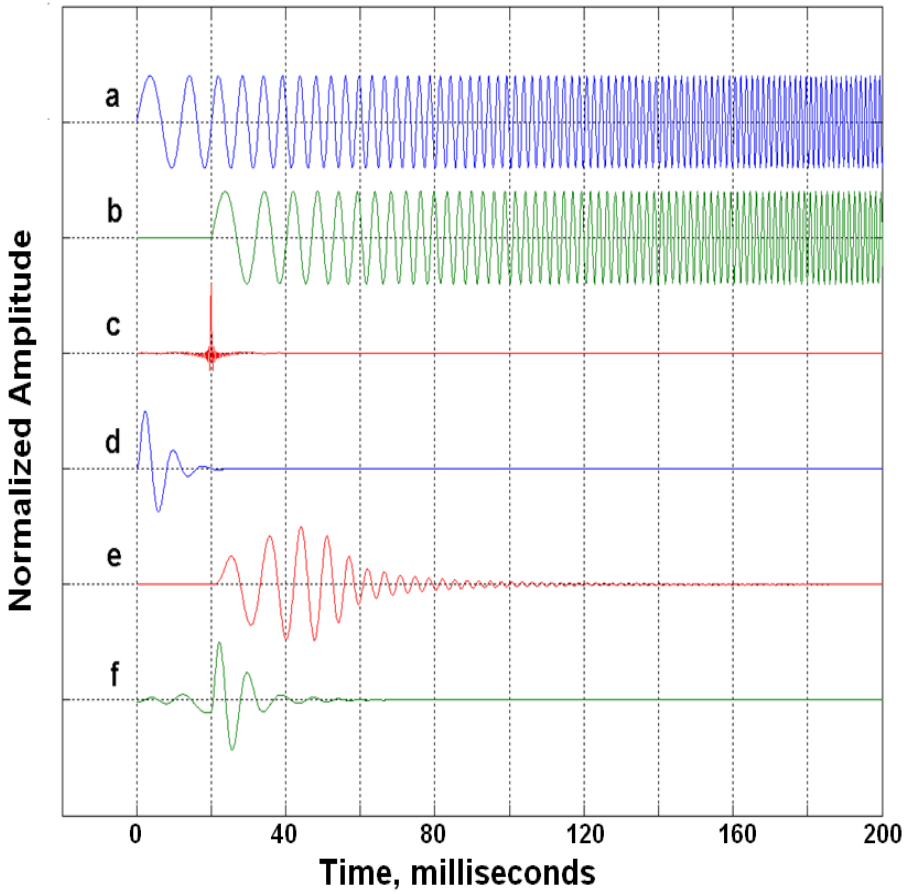
$$T_m = L t_b \ .$$


a
b
c
d
Normalized Amplitude
0
25
50
75
100
125
150
Time, ms

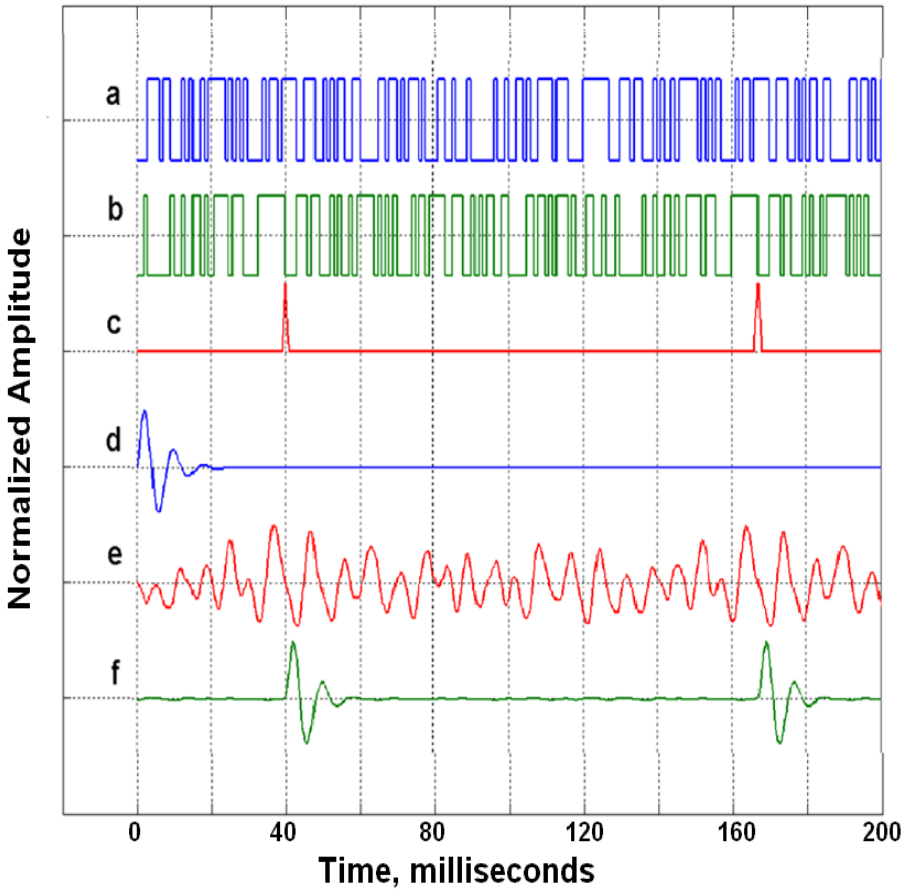

Power Spectrum
Frequency, Hz
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
m = 11 ,
L = 2047 ,
t_b = 4 ms ,
t_s = 1 ms .

Controlled Source Acquisition

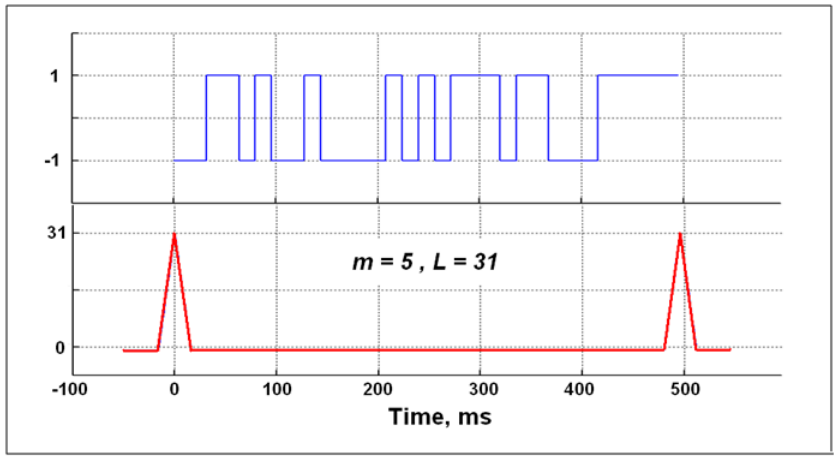
Frequency Sweep

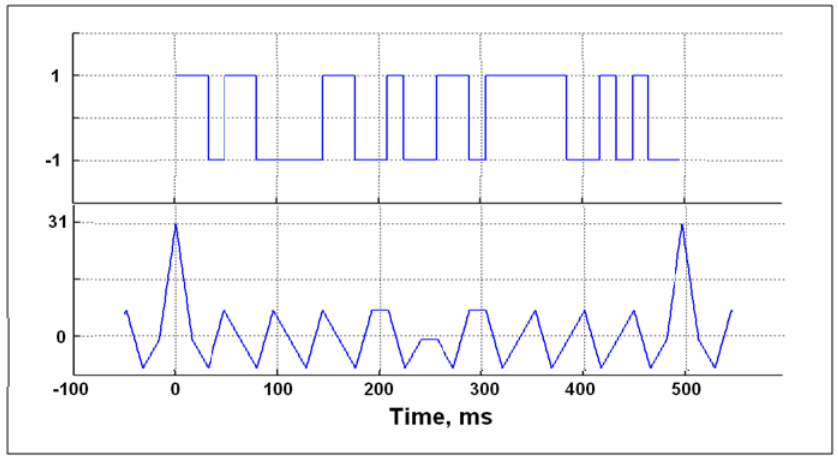


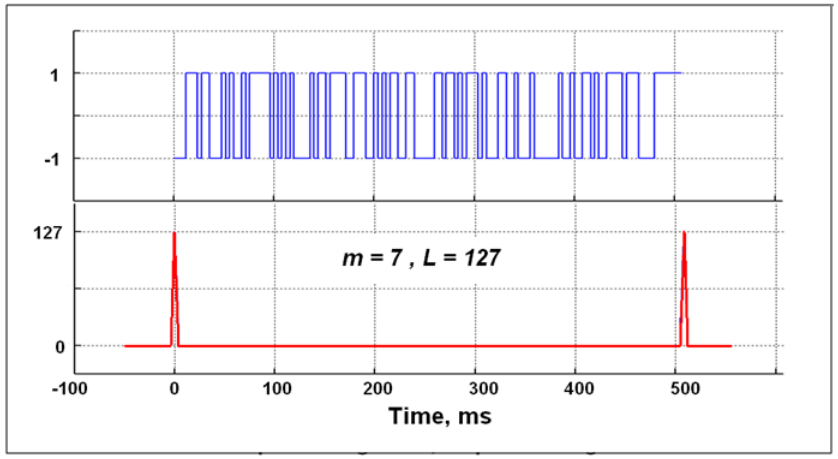
m-Sequence

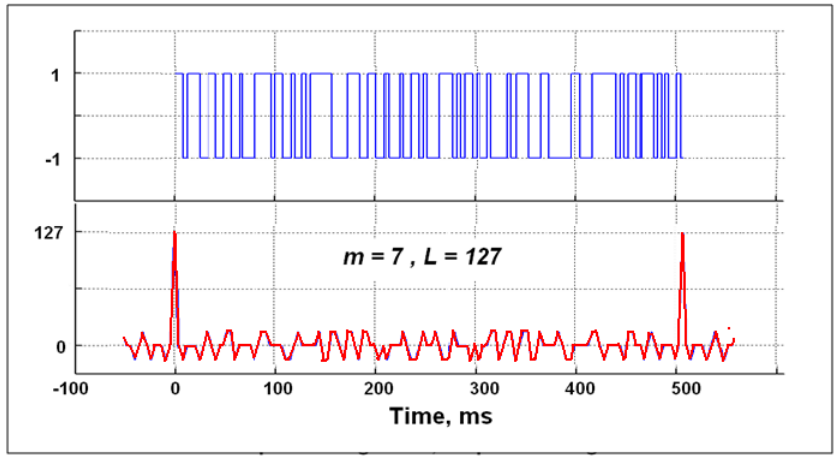


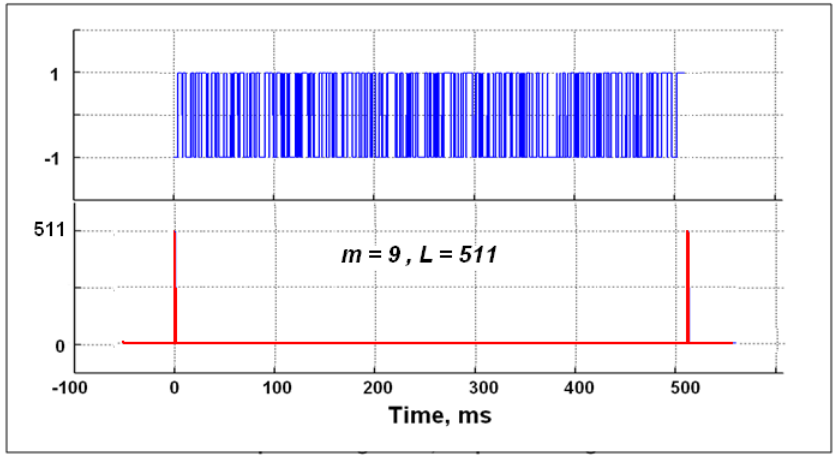
Spread Spectrum Acquisition and Simultaneous Multiple Sources

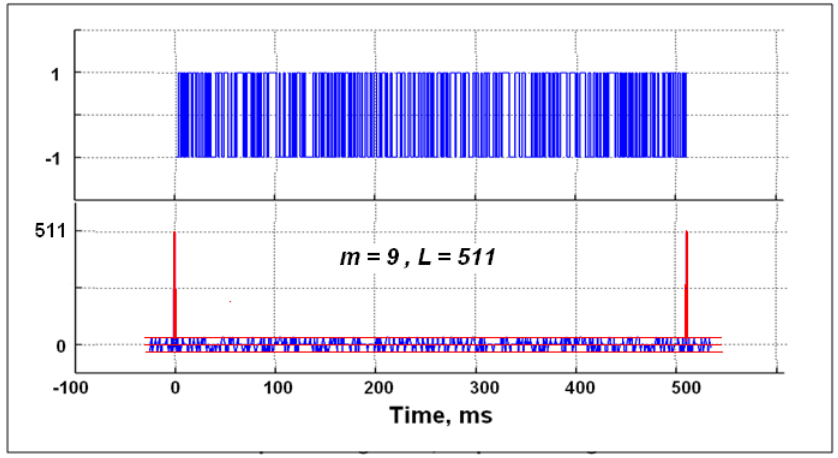

1
-1
31
0
m = 5 , L = 31
-100
0
100
200
300
400
500
Time, ms


1
-1
31
0
-100
0
100
200
300
400
500
Time, ms


1
-1
127
0
m = 7 , L = 127
-100
0
100
200
300
400
500
Time, ms

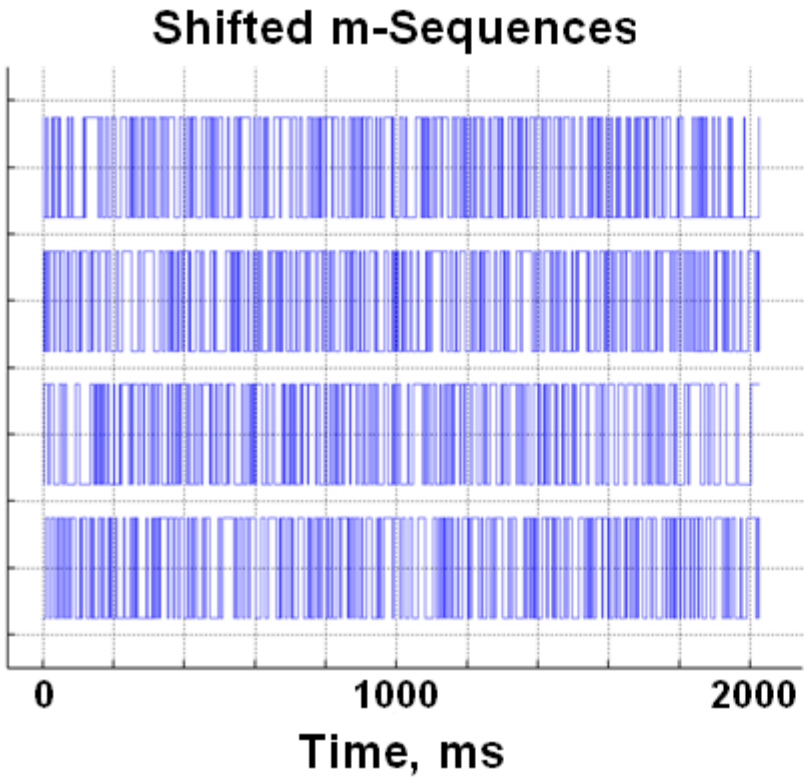

1
-1
127
0
m = 7 , L = 127
-100
0
100
200
300
400
500
Time, ms

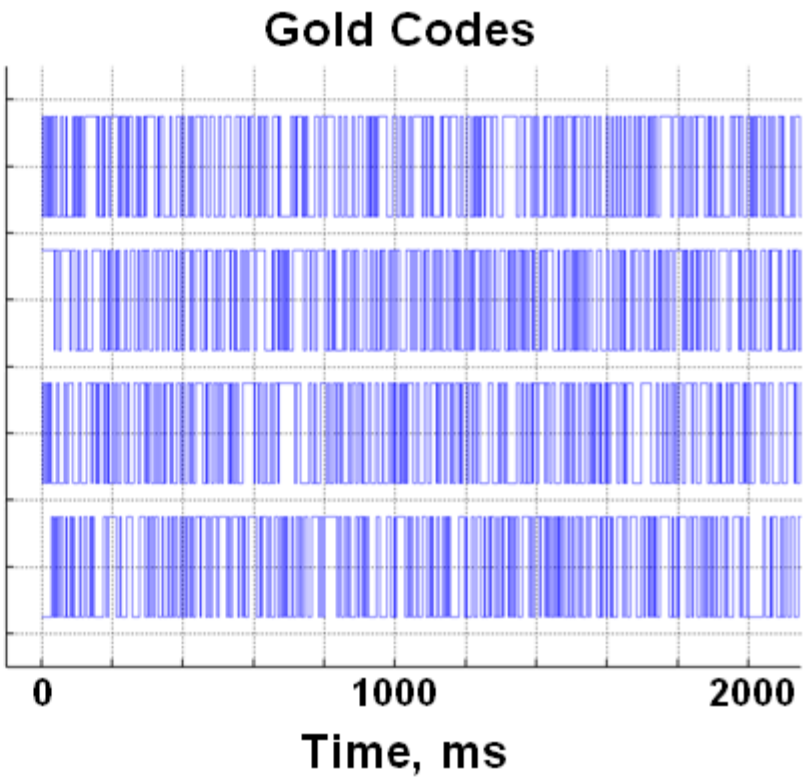

1
-1
511
0
m = 9 , L = 511
-100
0
100
200
300
400
500
Time, ms

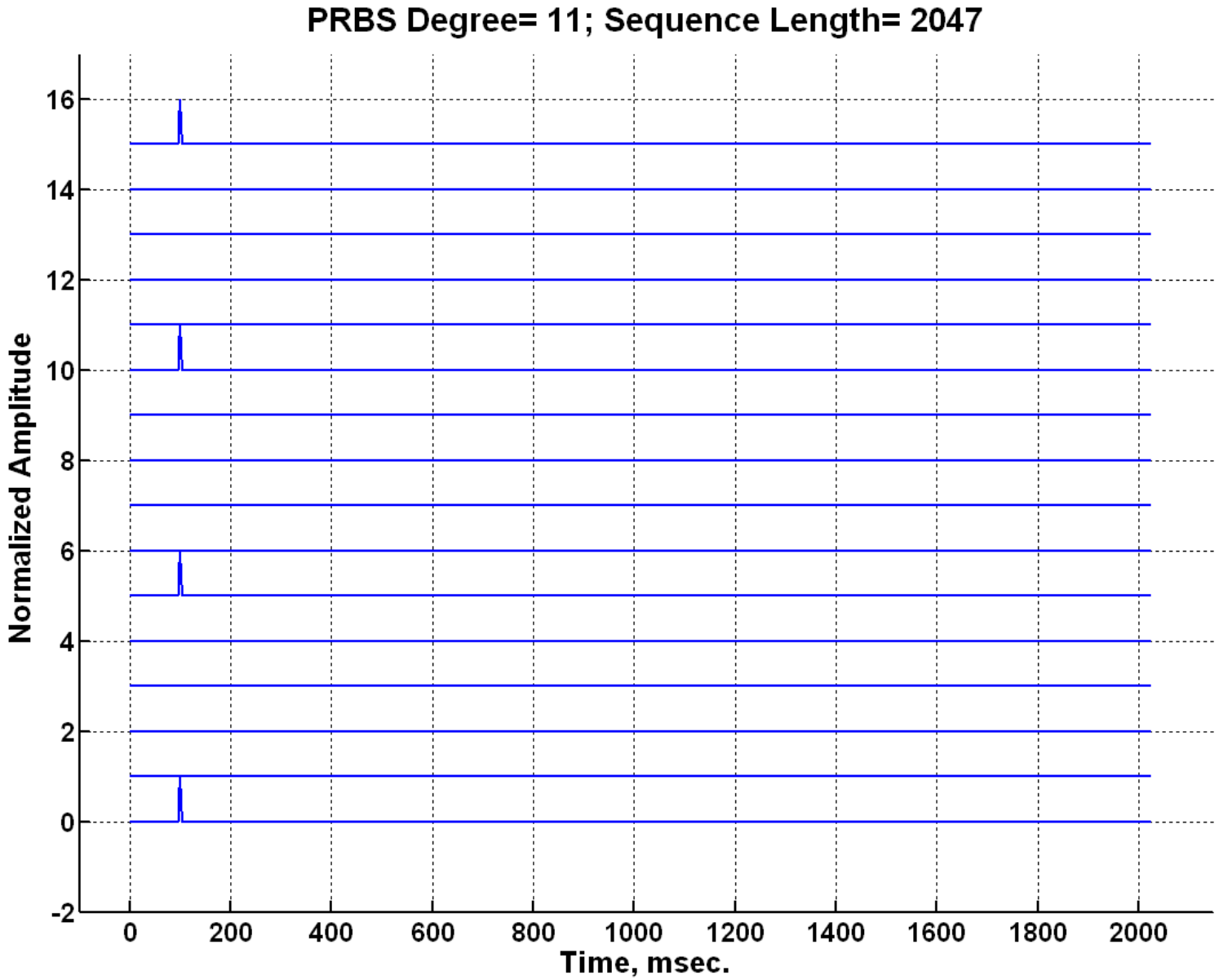

1
-1
511
0
m = 9 , L = 511
-100
0
100
200
300
400
500
Time, ms

Quality of separated signals depend on how "orthogonal" the set of pilots are under (circular) correlation.

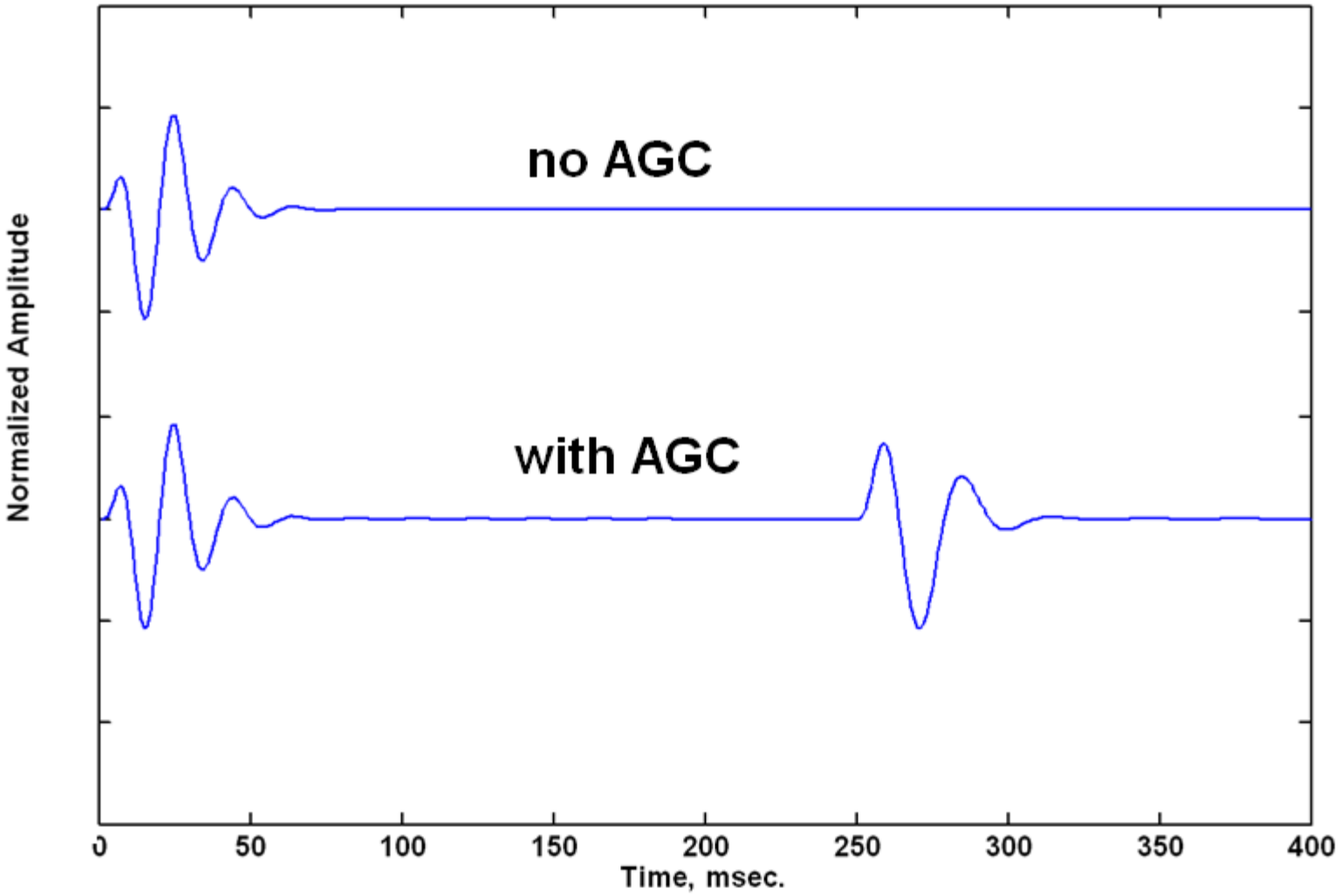
The less crosstalk in the cross-correlations of the pilots, the more "orthogonal" they are.


Shifted m-Sequences
0
1000
2000
Time, ms

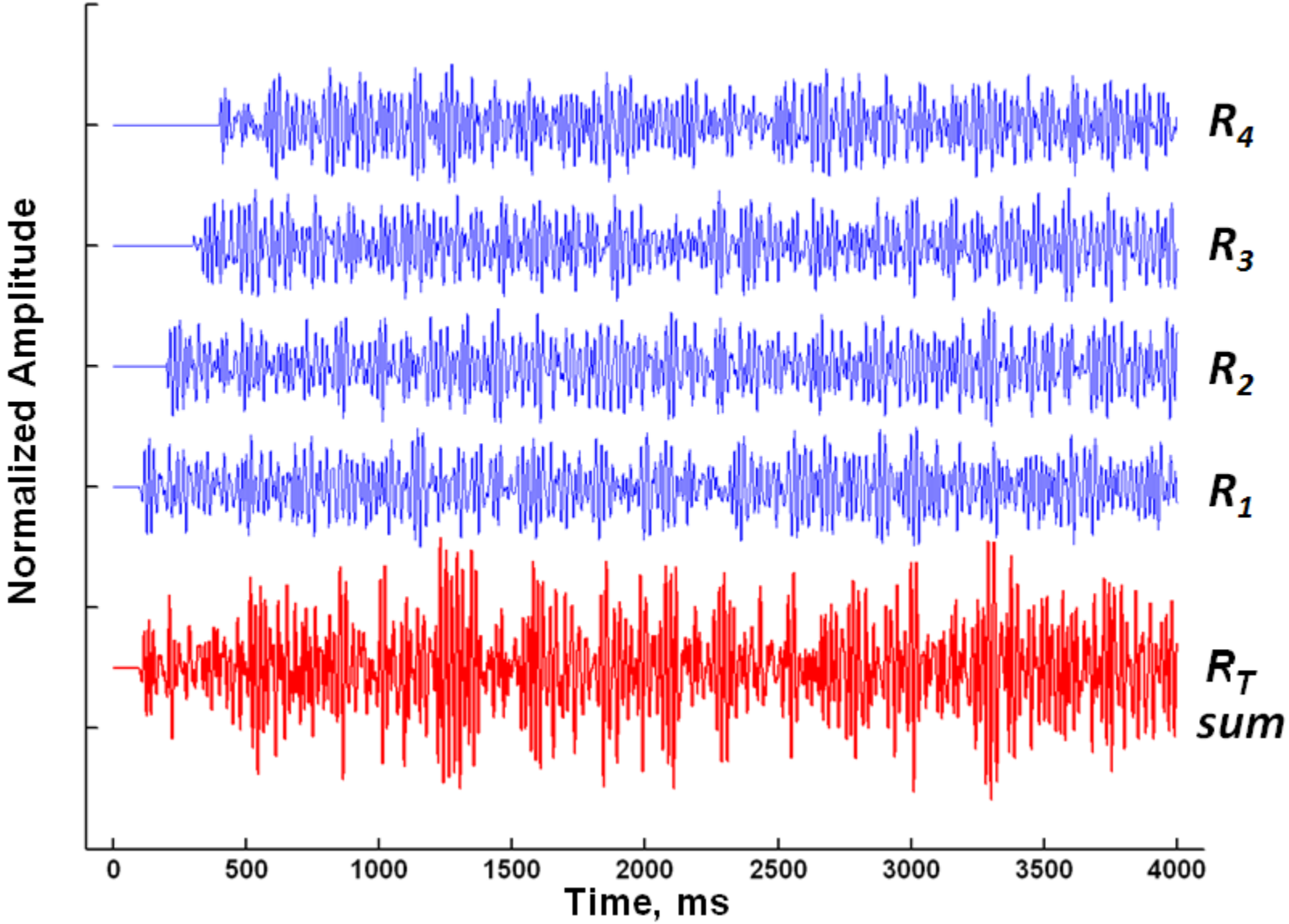

Gold Codes
0
1000
2000
Time, ms

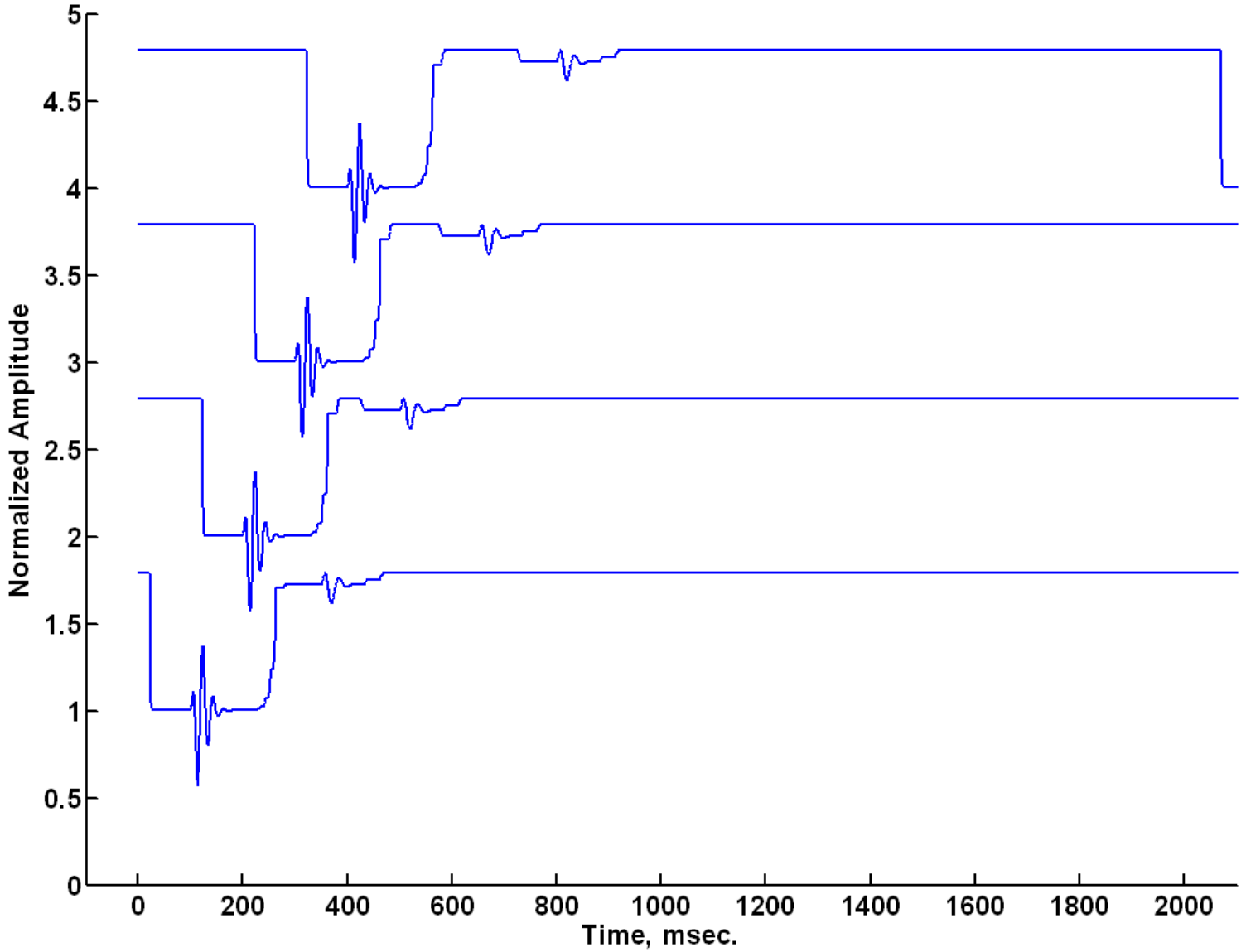

PRBS Degree= 11; Sequence Length= 2047
Normalized Amplitude
16
14
12
10
8
6
4
2
0
-2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time, msec.

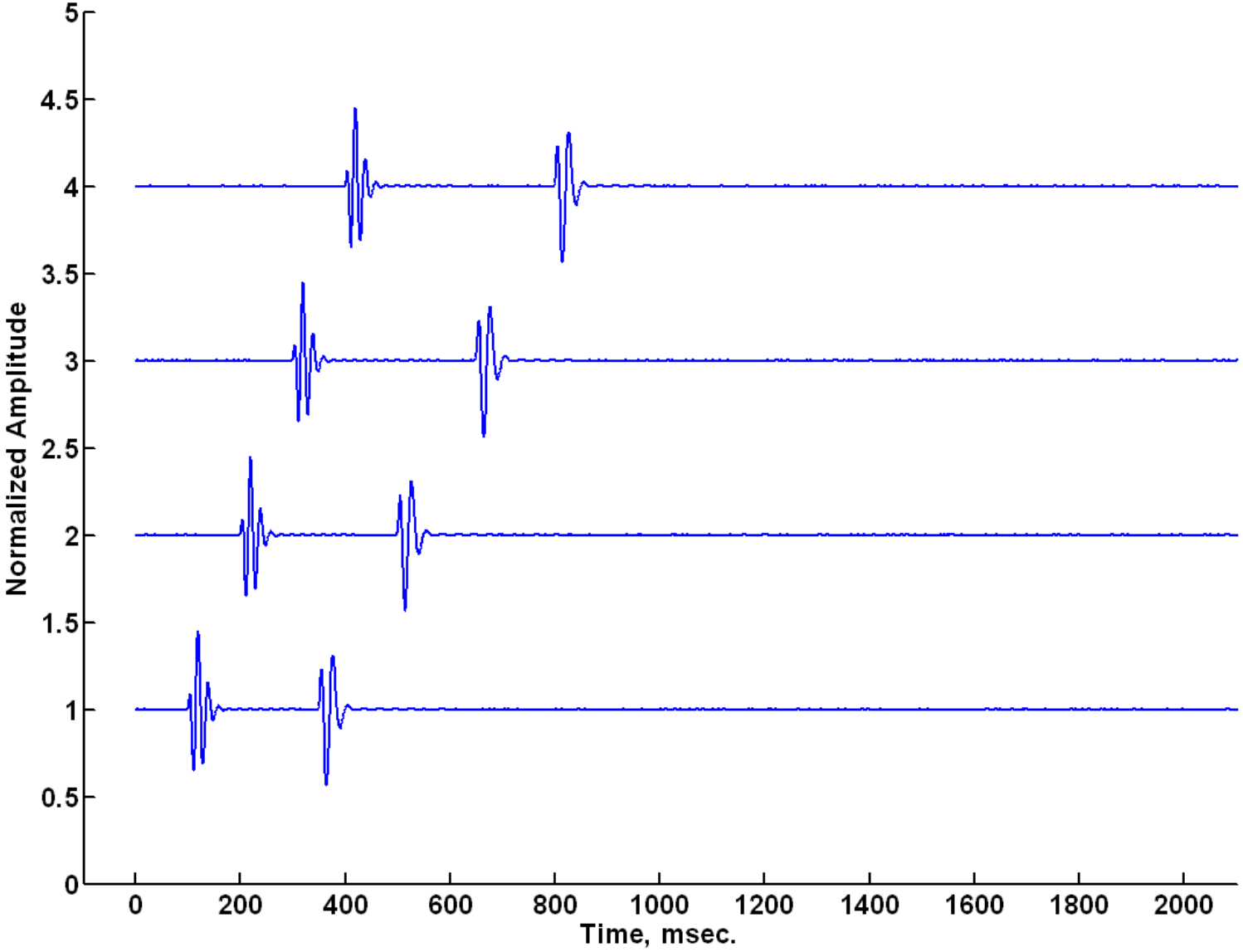
Source function with a strong and a very weak event



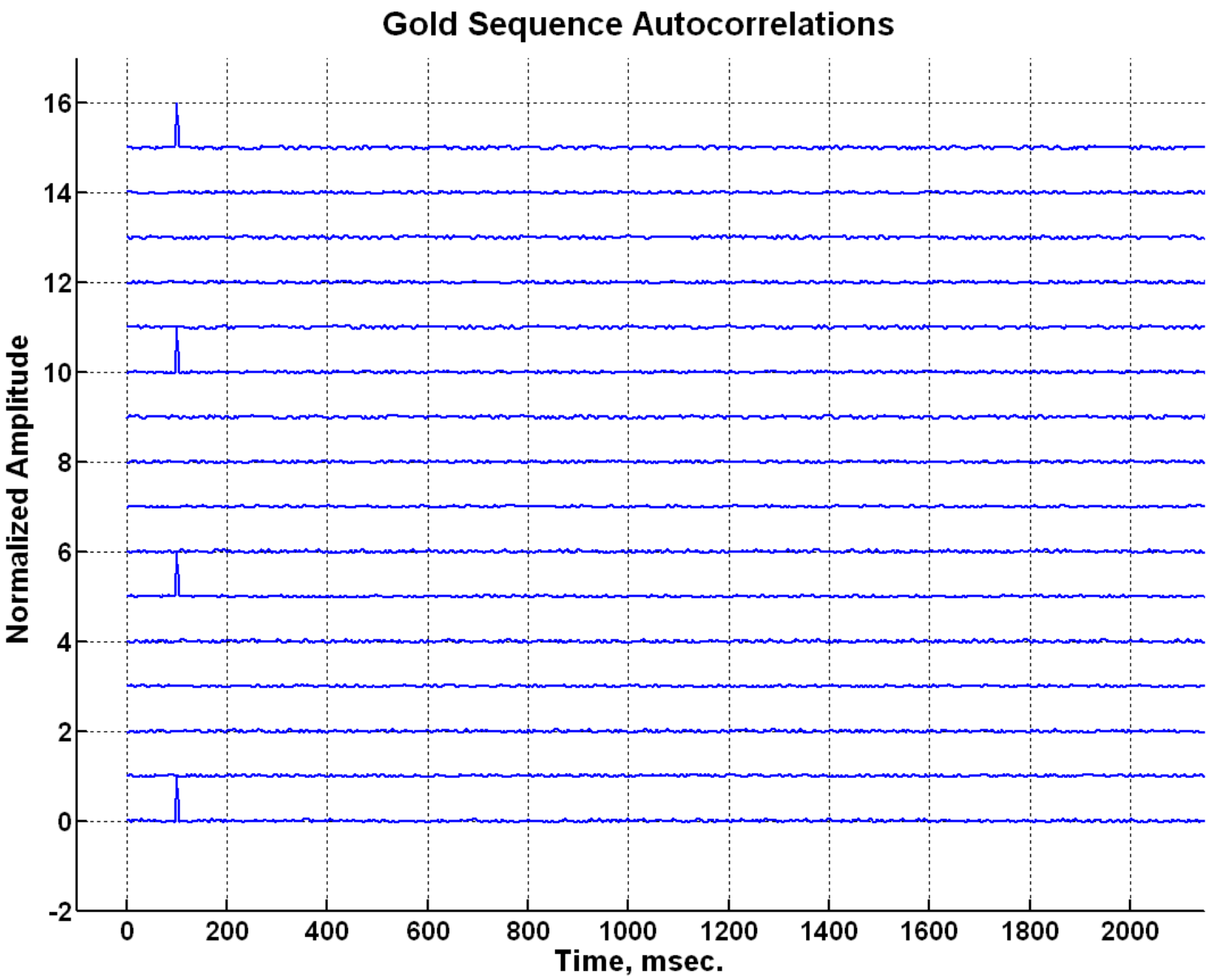
Convolutions $R_i(t) = \int w(t-\tau)\, S_i(\tau)\, d\tau$, delayed by arrival times

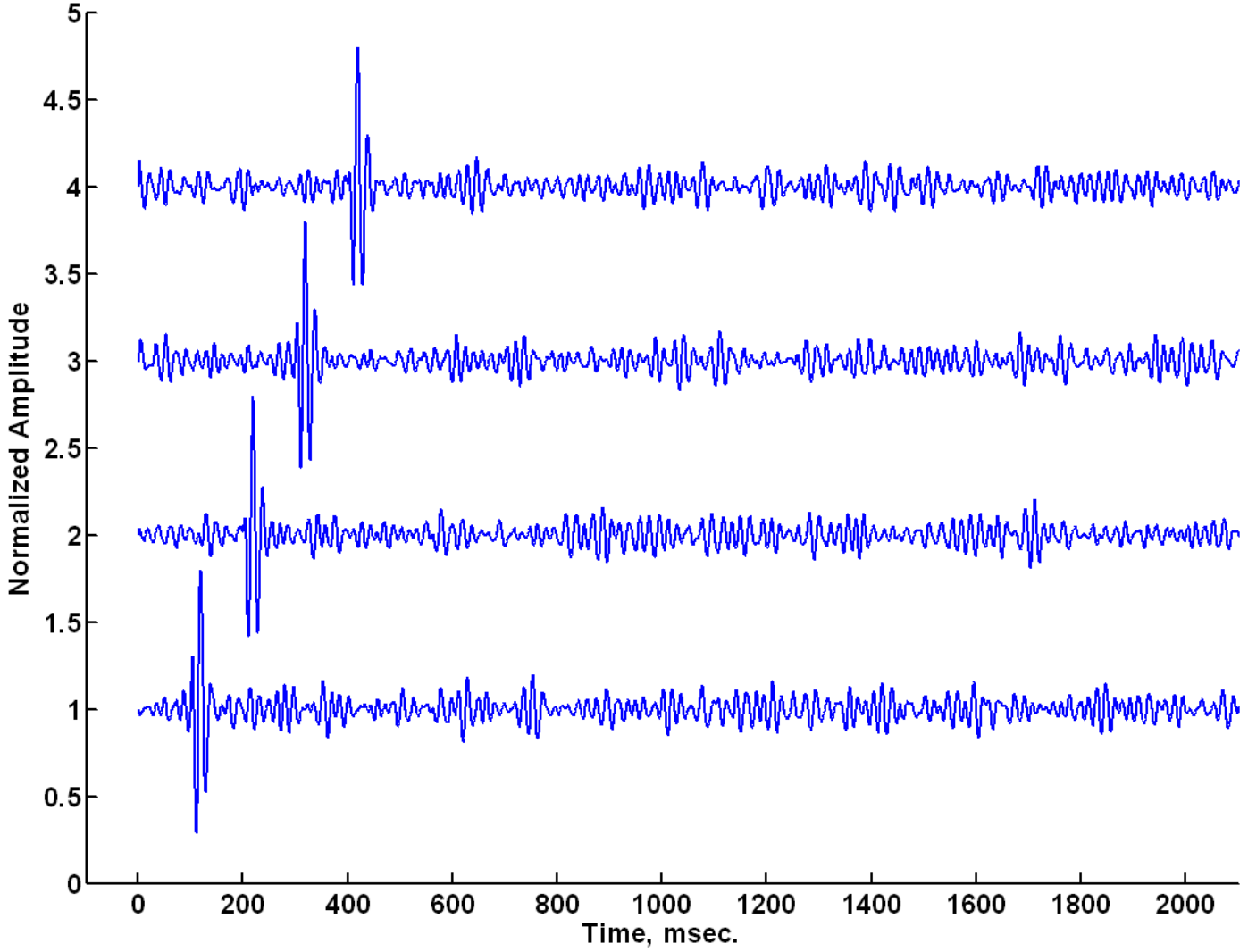


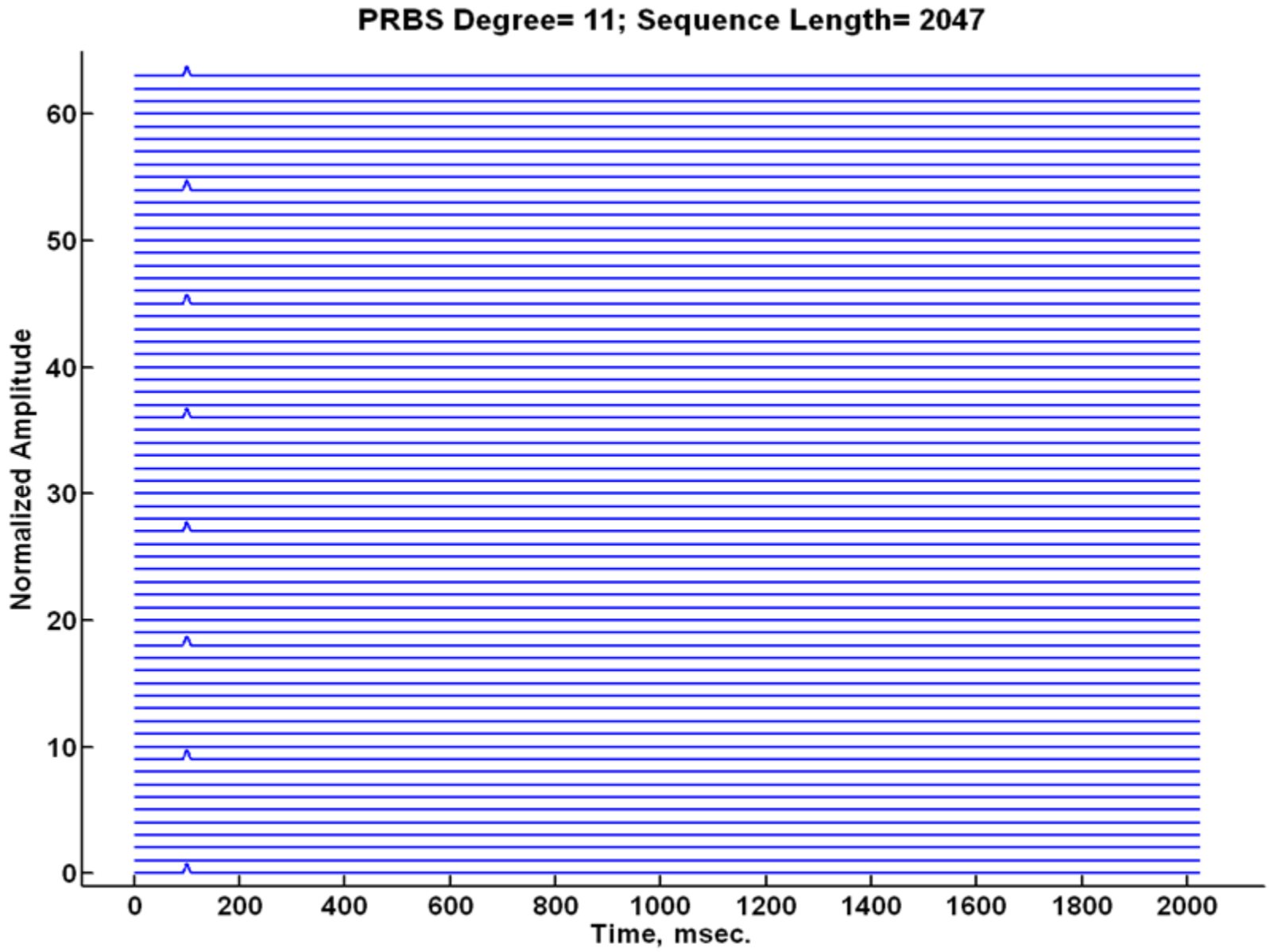

Normalized Amplitude
Time, msec.
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
200
400
600
800
1000
1200
1400
1600
1800
2000

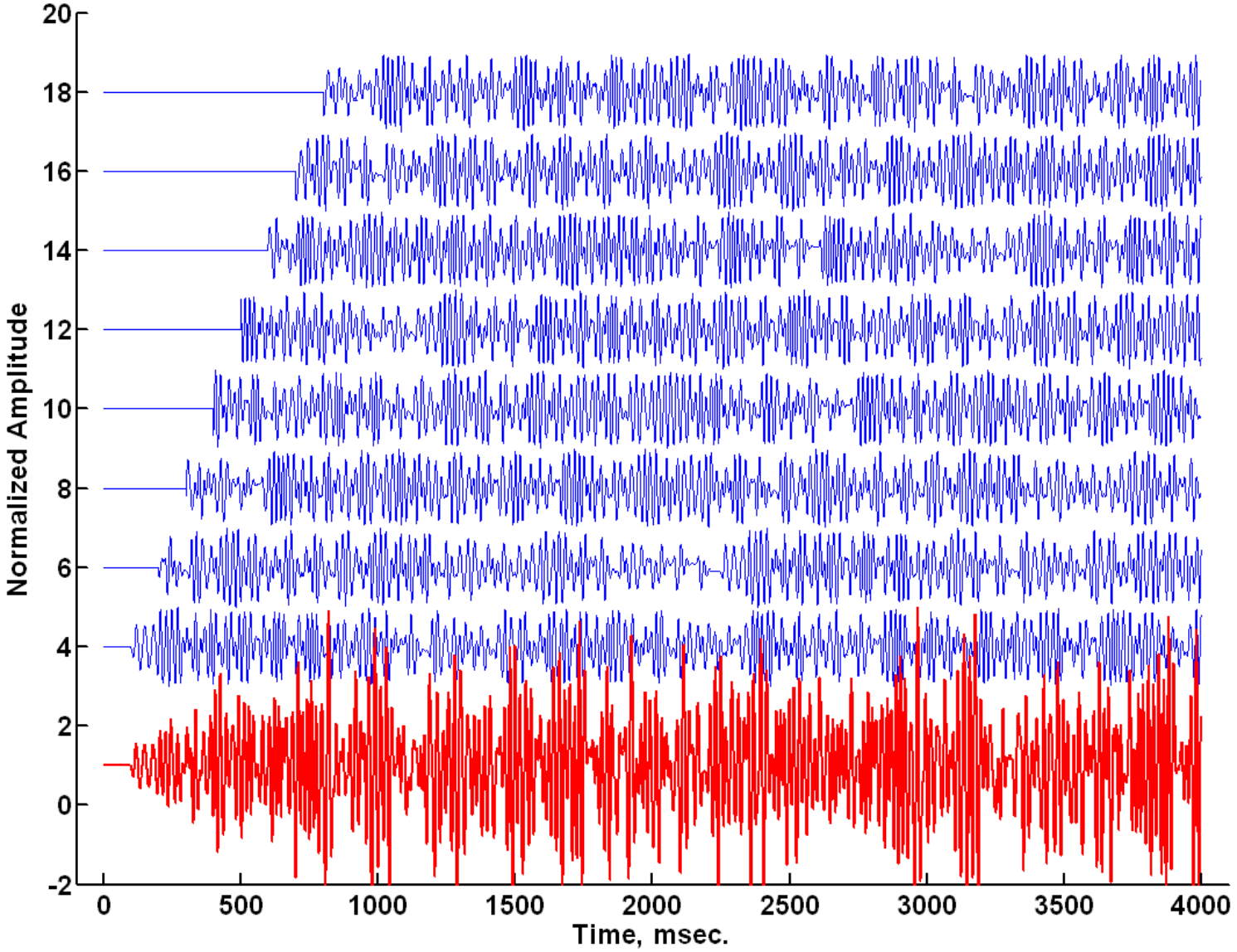

Normalized Amplitude
Time, msec.
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
200
400
600
800
1000
1200
1400
1600
1800
2000

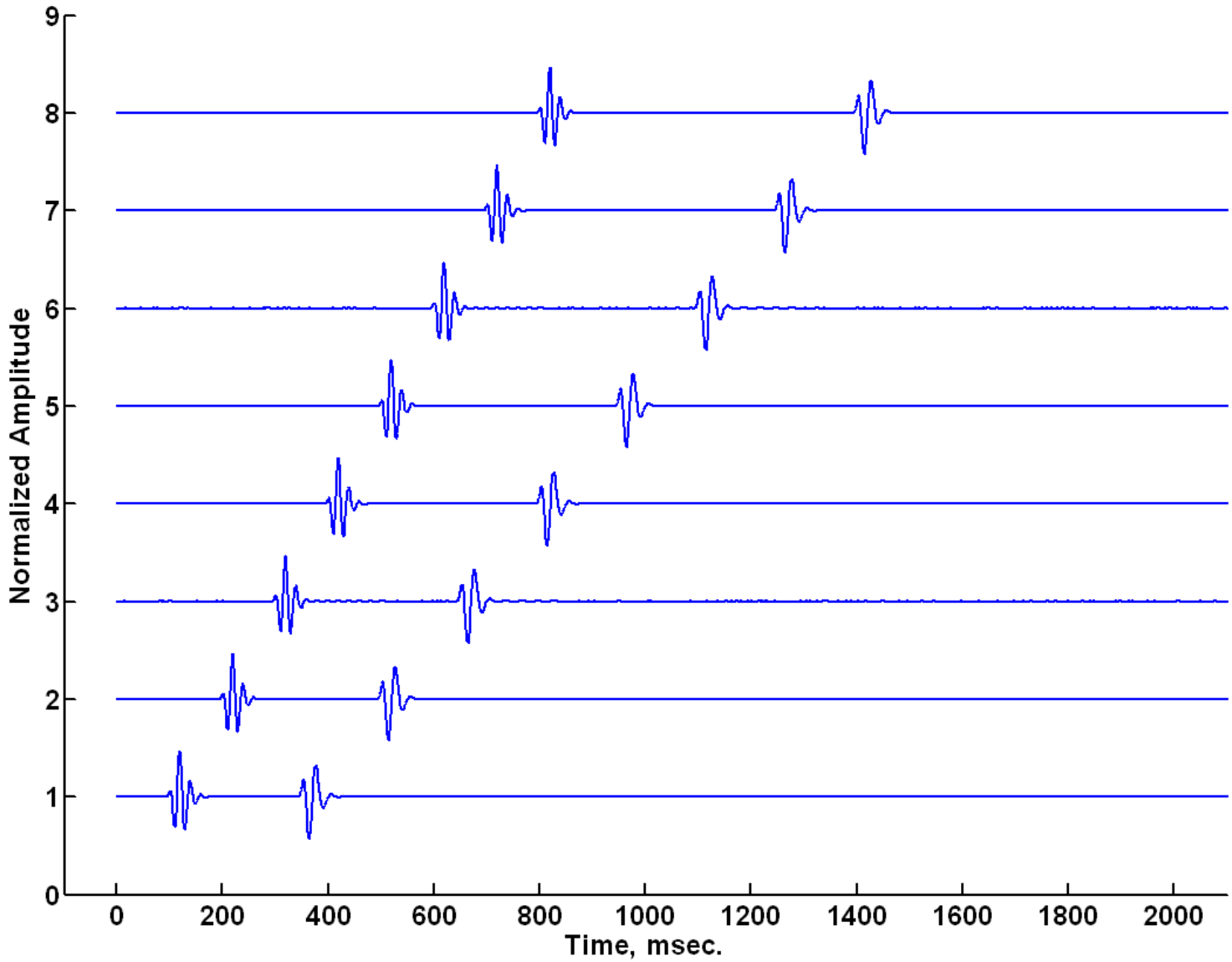
Comparison of Gold-code and m-Sequences as Pilots For Vibrators Operating Simultaneously


Gold Sequence Autocorrelations
Normalized Amplitude
16
14
12
10
8
6
4
2
0
-2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time, msec.


Normalized Amplitude
Time, msec.
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
200
400
600
800
1000
1200
1400
1600
1800
2000


PRBS Degree= 11; Sequence Length= 2047
Normalized Amplitude
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time, msec.


20
18
16
14
12
10
8
6
4
2
0
-2
Normalized Amplitude
0
500
1000
1500
2000
2500
3000
3500
4000
Time, msec.

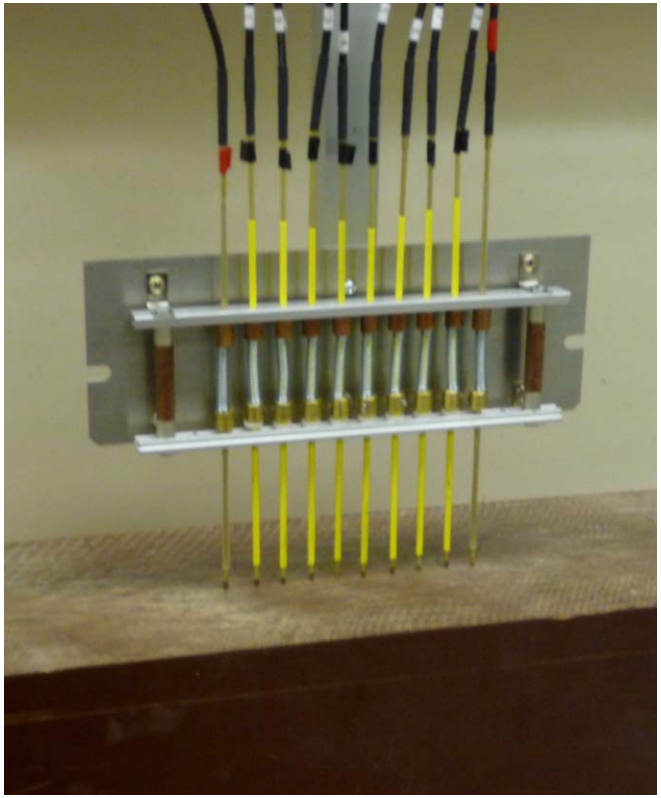

Normalized Amplitude
9
8
7
6
5
4
3
2
1
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time, msec.

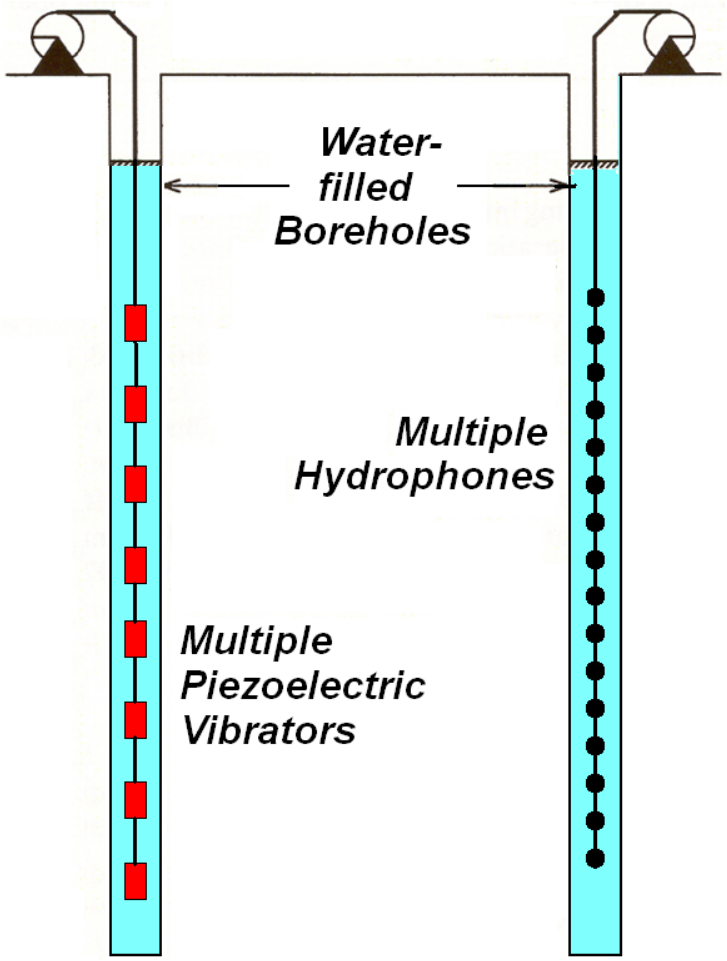
Possible Applications

SIMULTANEOUS MULTIPLE SOURCES

Physical Modeling:

10 piezopin transmitters



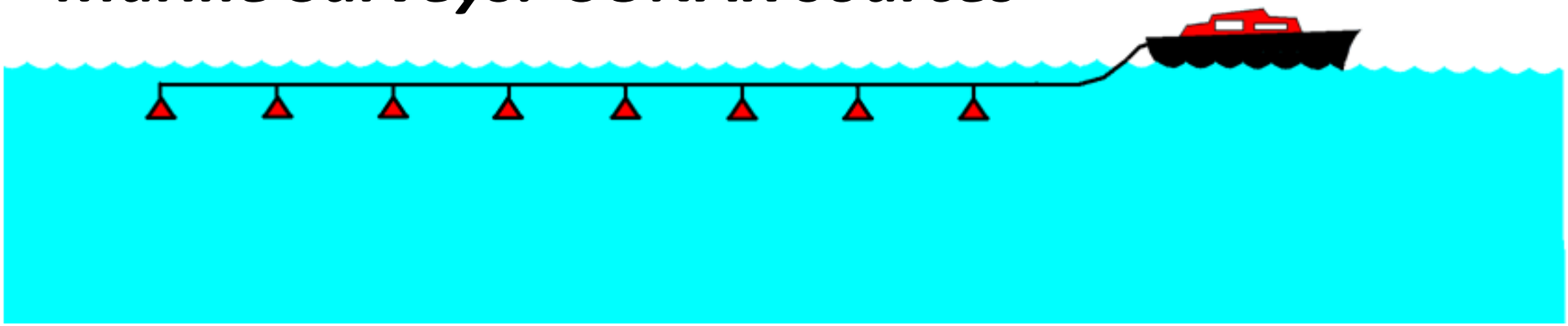


Crosswell Scanning:

8 downhole vibrators

SIMULTANEOUS MULTIPLE SOURCES

Marine Surveys: SONAR sources



Land Surveys: Mechanical vibrators

Summary

Operating multiple vibrators simultaneously results in large gains in filed survey efficiency.

- ***Shifted m-sequences or Gold codes can be used as pilot signals for simultaneous sourcing.***
- ***Numerical simulations suggests m-sequences are the better choice because of much lower correlation noise and crosstalk.***
- ***Extensive experimental testing (real surveys) needed to verify that the PRBS/correlation method adequately separates weak signals due to one source from strong signals due to another source.***

ACKNOWLEDGEMENTS

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Thanks to JODEX Limited for technical contributions.

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