Inter-Pulse Coding and Coherent-on-Receive Modifications of Magnetron-Based Marine Radar – Experimental Results

By

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Upgrading Marine Radar

Civil marine radar

Allow operation in "**short pulse & high PRF**" mode at all ranges, by extending the unambiguous range through PRI periodic coding.

- The estimated number of civil marine radar ≈ 3×10^6
- Most civil marine radar are magnetron-based

SPECIFICATIONS OF MODEL 1623

ANTENNA

Type	Microstrip radiator enclosed in ø380 mm radome
Beamwidth	Hor. 6.2°, Vert. 25°
Rotation Speed	41 rpm (0.125 to 0.75 nm) 31 rpm (1 to 2 nm) 24 rpm (3 to 16 nm)

RF TRANSCEIVER

Frequency	9410±30 MHz (X-band)
Pulselength & PRR	0.08 µs/3000 Hz (0.125 to 0.75 nm) 0.3 µs/1200 Hz (1 to 2 nm) 0.8 µs/600 Hz (3 to 16 nm)
Peak Output Power	2.2 kW nominal
IF Amplifier	IF: 60 MHz BW: 15 MHz (0.125 to 0.75 nm) 5 MHz (1 to 16 nm)

DISPLAY

Display Unit	6" monochrome LCD, 4 gray tones, 240 x 320 pixels, 90 mm (W) x 120 mm (H)
Accuracy	
Range:	1.0 % of range in use or 8 m, whichever is greater
Bearing:	EBL accuracy ±1°

Range and Range Ring Interval

Range:	0.125,	0.25,	0.5,	0.75,	1,	1.5,	2,	3,	4,	6,	8,	12,	16 nm
Ring:	.0625	.125	.125	.25	.25	.5	.5	1	1	2	2	3	4 nm

Echo Trail	Interval: 30 s, 1, 3, 6 min, or continuous

Civil marine radar

$PRF = 3000$ pps

$\text{pulse width} = t_p = 0.08\,\mu\text{sec}$

$\text{duty cycle} = d = t_p\,PRF = 0.00024$

$\text{Range resolution} = t_p C/2 = 12\,\text{m}$

$PRF = 600$ pps

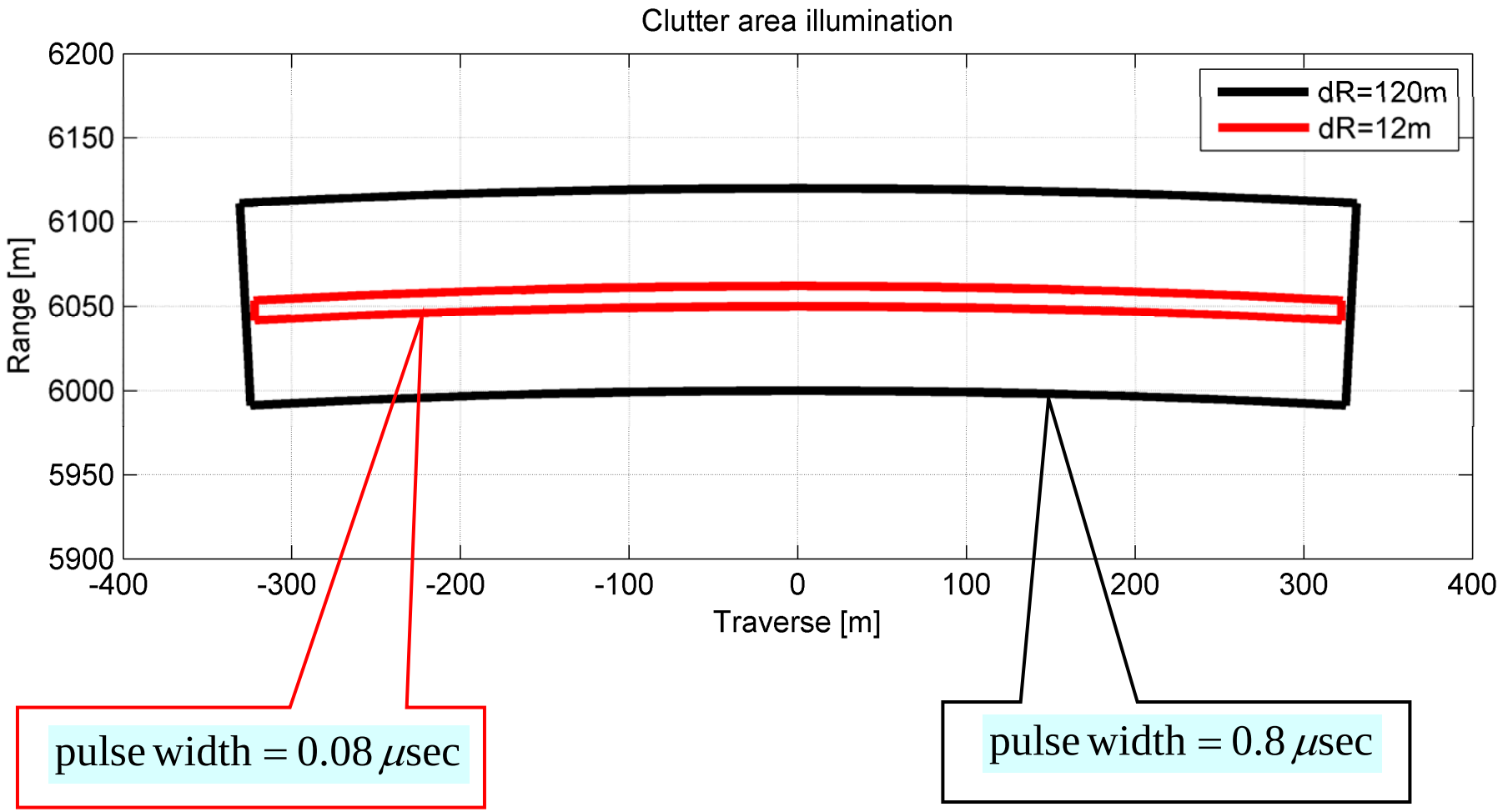
$\text{pulse width} = t_p = 0.8\,\mu\text{sec}$

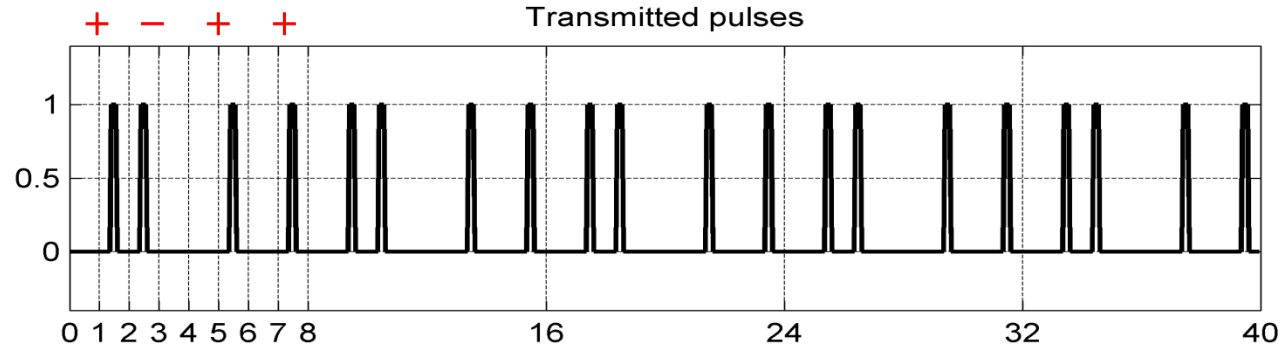
$\text{duty cycle} = d = t_p\,PRF = 0.00048$

$\text{Range resolution} = t_p C/2 = 120\,\text{m}$

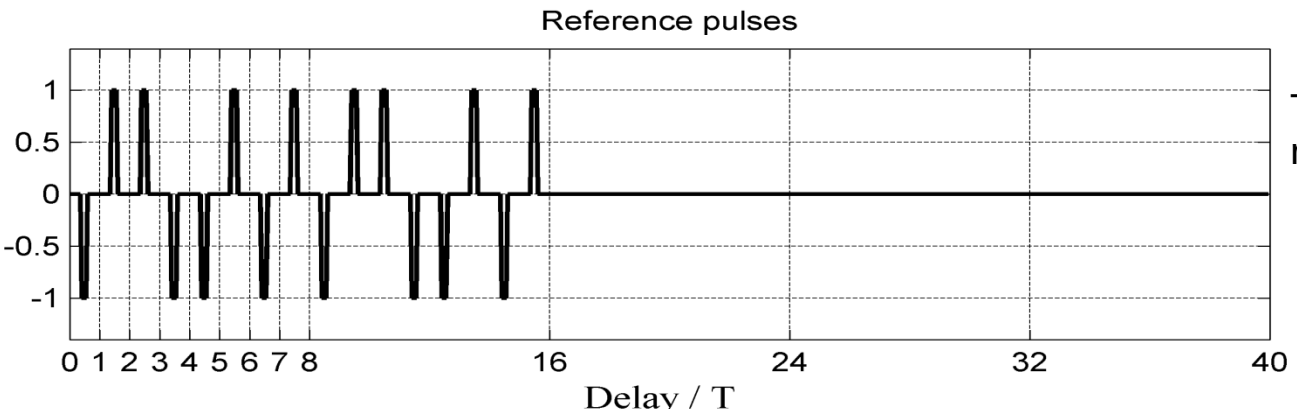
Range	0.125, 0.25, 0.5, 0.75	1, 1.5, 2	3, 4, 6, 8, 12, 16, 24, 36
Pulse Length	0.08 µs (short)	0.3 µs (medium)	0.8 µs (long)
Pulse Repetition Rate	3000 Hz nominal	1200 Hz nominal	600 Hz nominal

- Coherent radar allows pulse compression (using frequency modulation or phase coding).
- With pulse compression, we can transmit a long pulse (= more energy) without increasing the range resolution.
- Magnetron cannot be frequency or phase modulated, hence no pulse compression.
- In magnetron-based radar long pulse implies poor range resolution.
- To increase the energy on target we resort to denser pulses (high PRF).
- This paper demonstrates how to increase the PRF without reducing the unambiguous range.

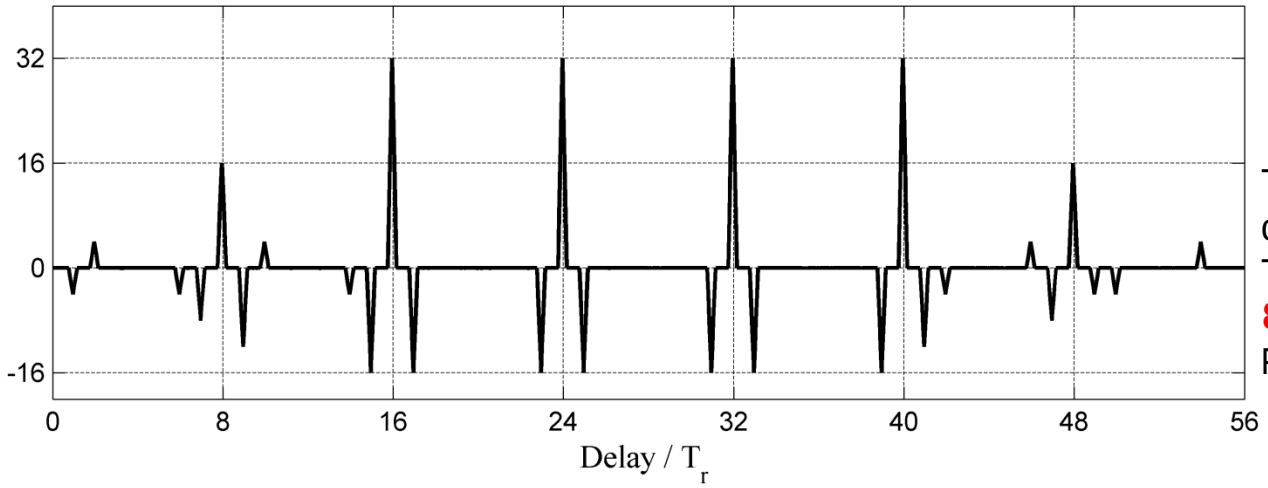

Clutter area illumination
dR=120m
dR=12m
Range [m]
6200
6150
6100
6050
6000
5950
5900
-400
-300
-200
-100
0
100
200
300
400
Traverse [m]
pulse width = 0.08 μsec
pulse width = 0.8 μsec



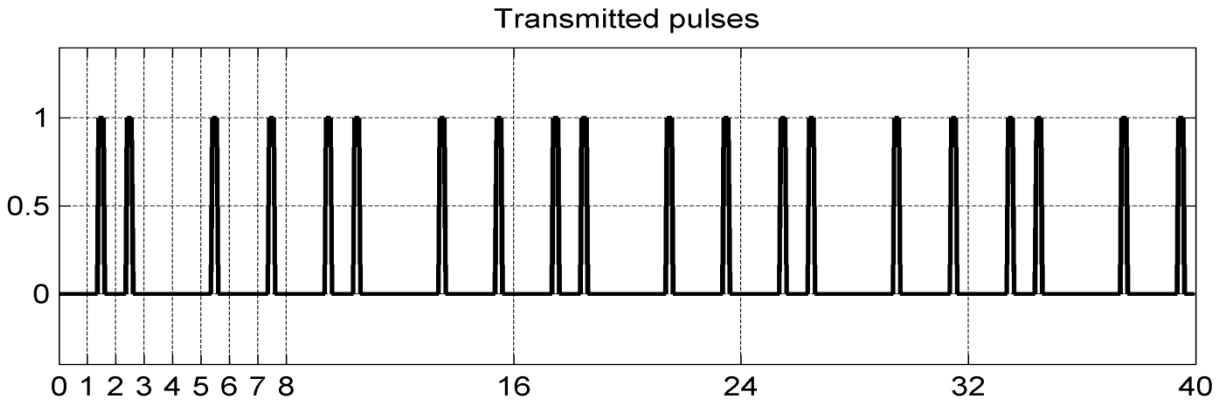
Transmitted pulses:
Periodic, Manchester-coded
Barker 4. { + − + + }



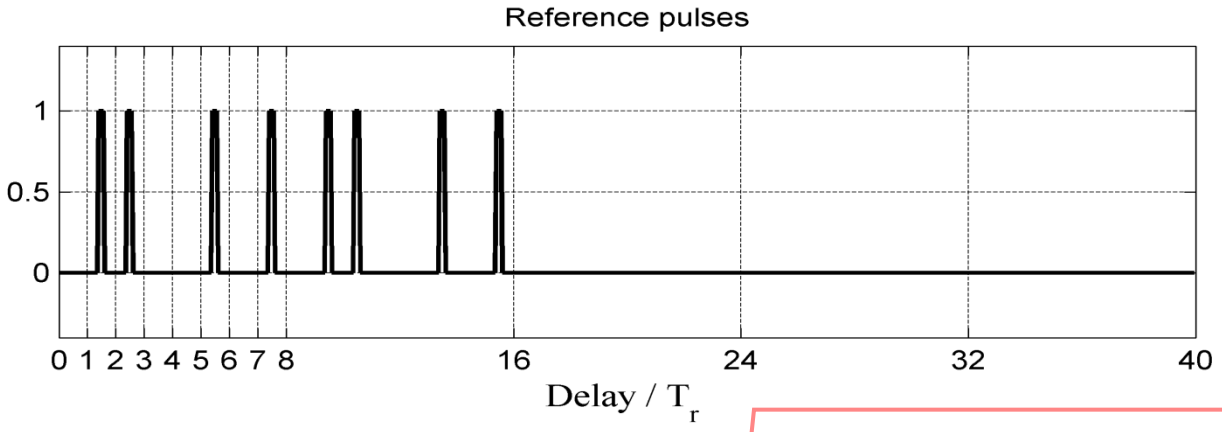
Two periods of the periodic reference pulse train



The resulted cross-correlation.
The response's periodicity is **8** times the original basic PRI

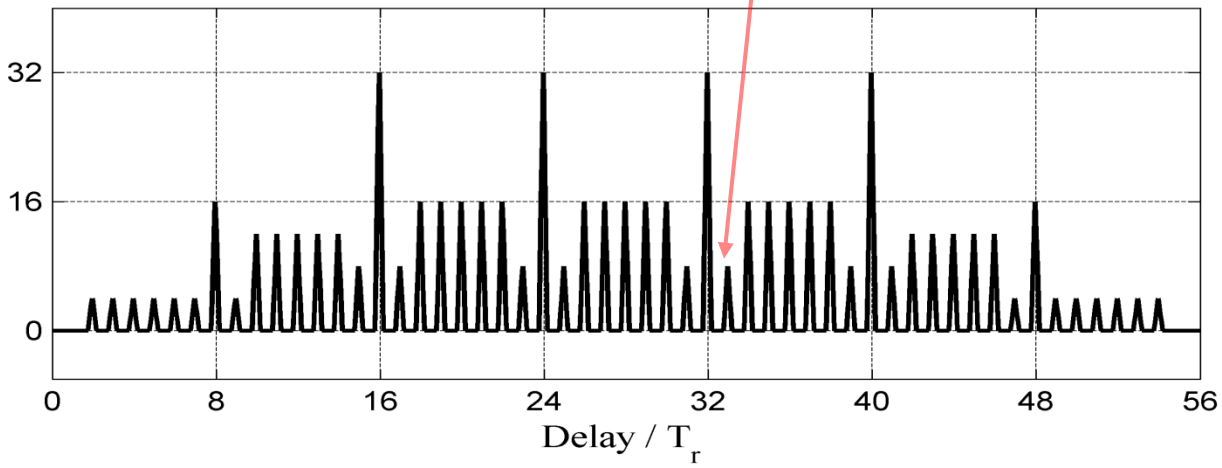


Transmitted pulses:
Periodic, Manchester-coded Barker 4. { + − + + }

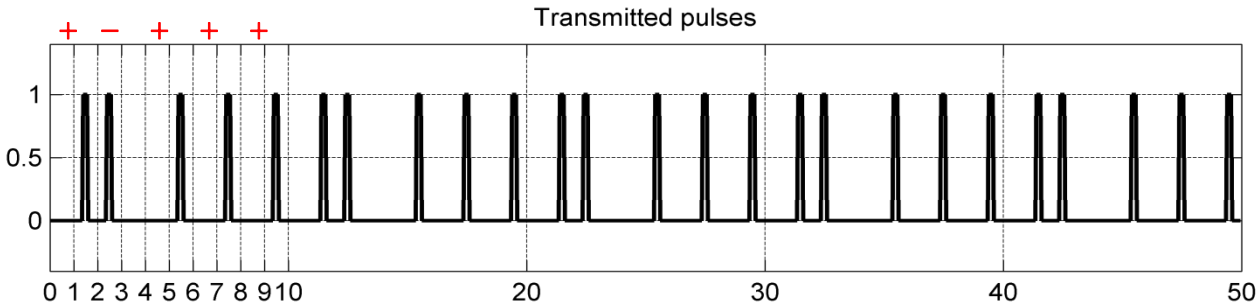


Two periods of <u>matched</u> reference.

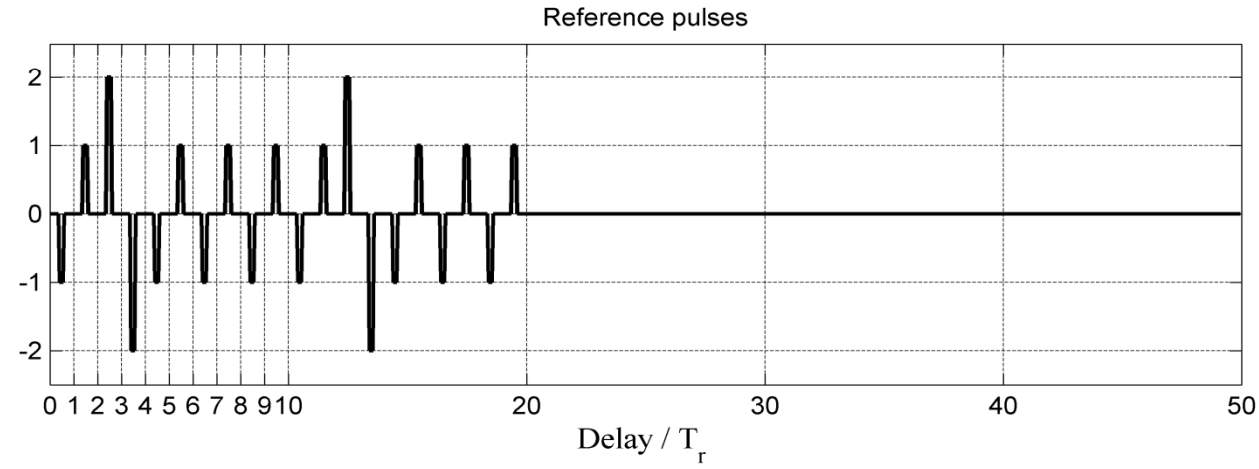
1st recurrent lobe intensity is ¼ of main periodic lobe.



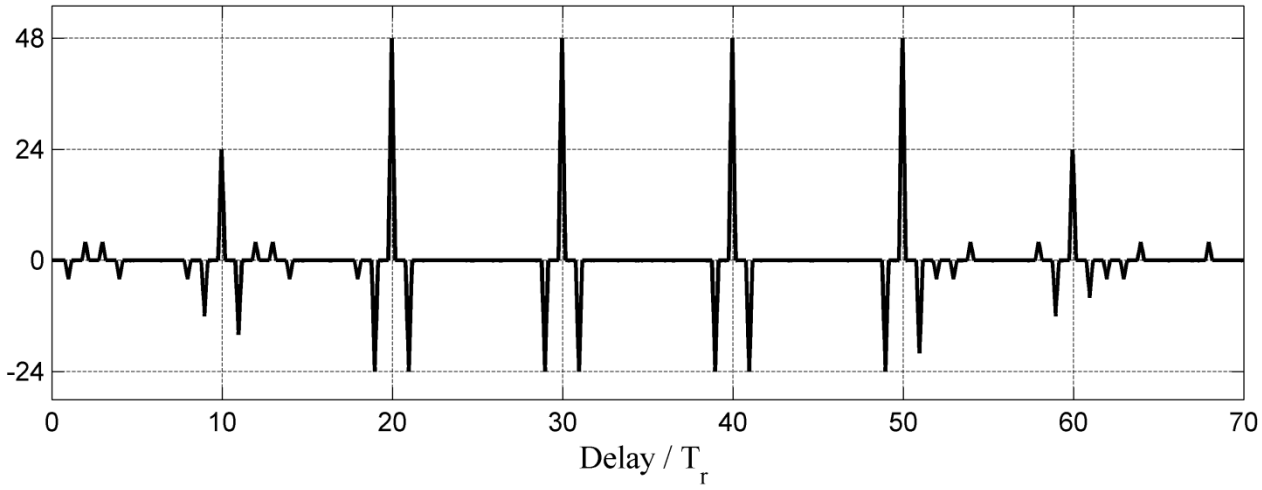
The resulted cross-correlation. The response's periodicity remains the original basic PRI.



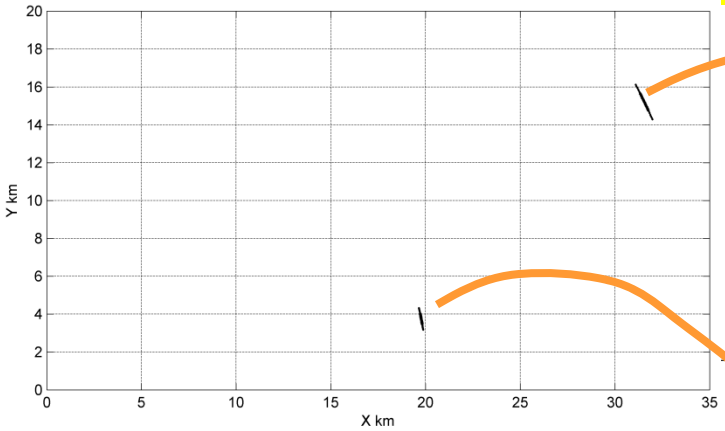
Transmitted pulses:
Periodic, Manchester-coded
Ipatov 5. {+−+++}

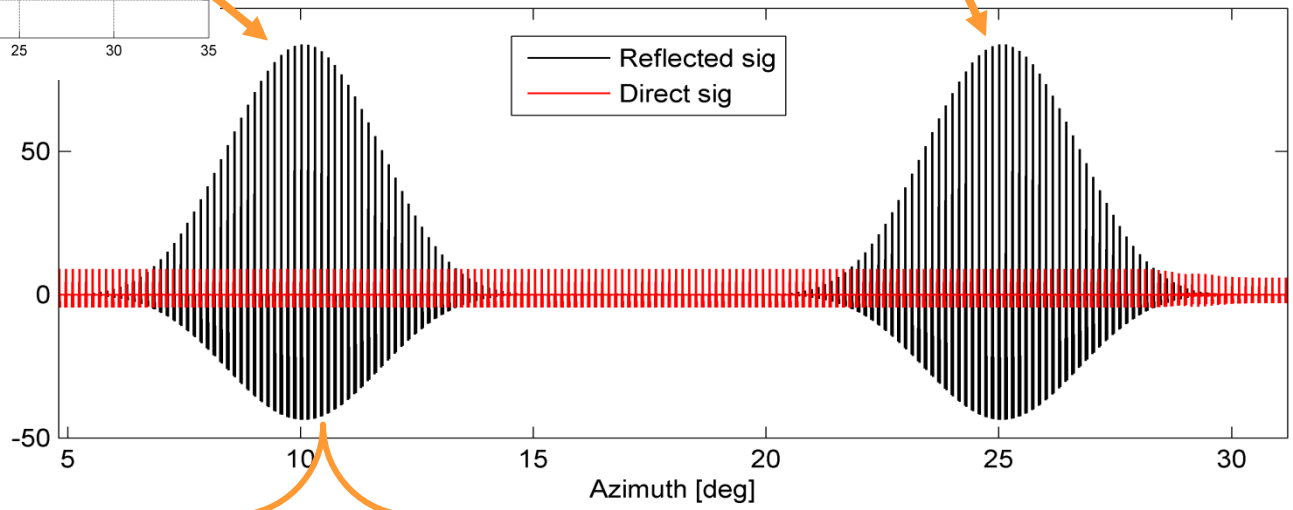


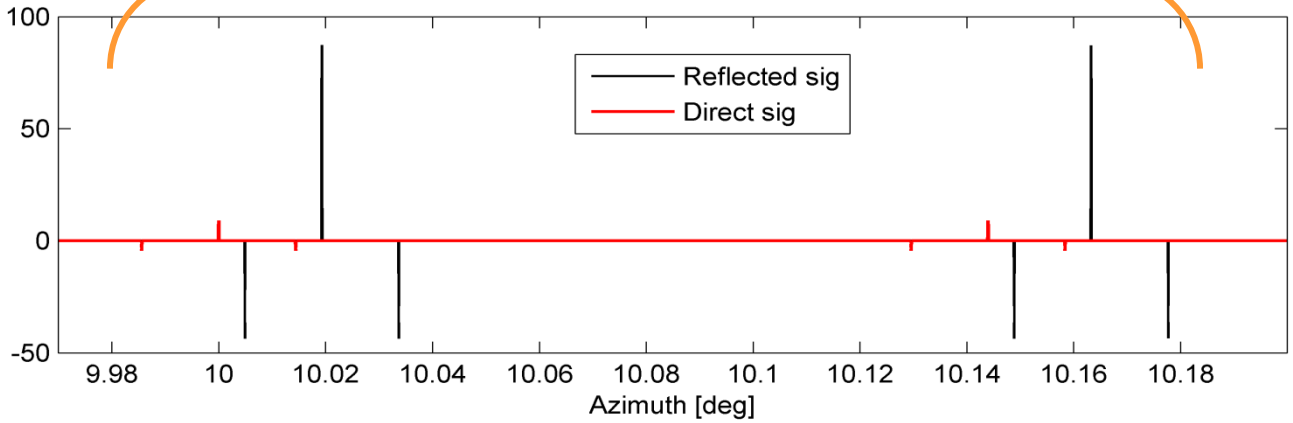
Two periods of the periodic reference pulse train

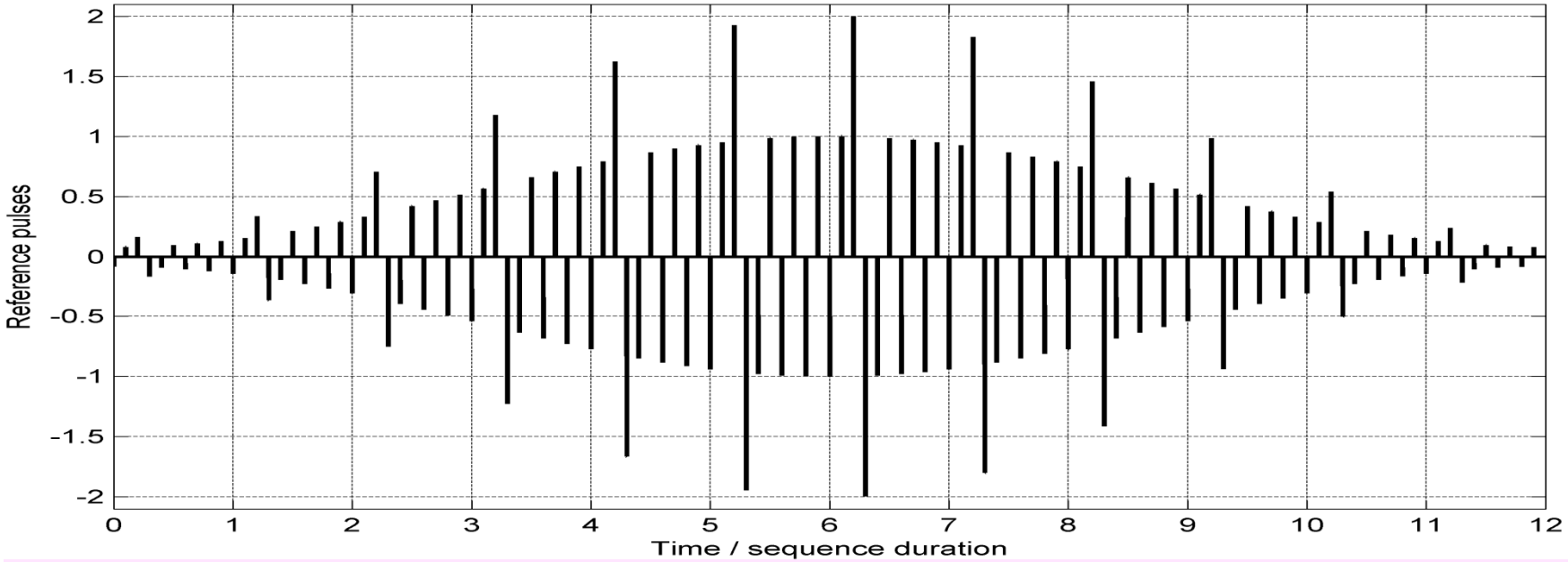


The resulted cross-correlation.
The response's periodicity is **10** times the original basic PRI

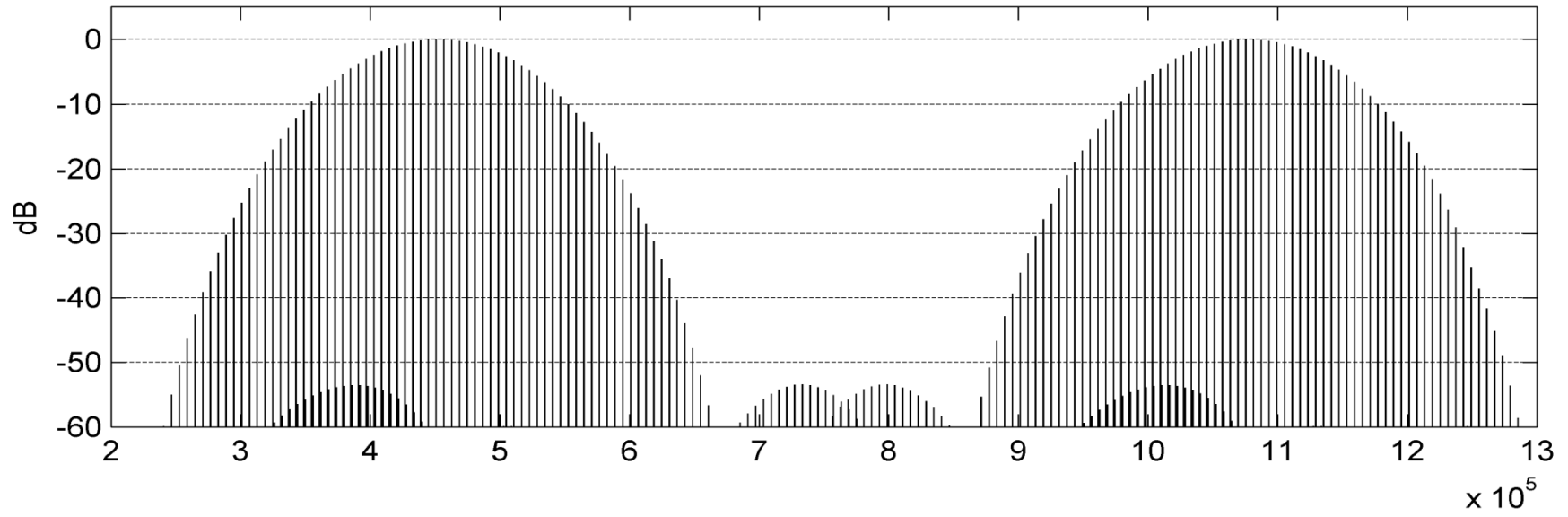

Y km
X km

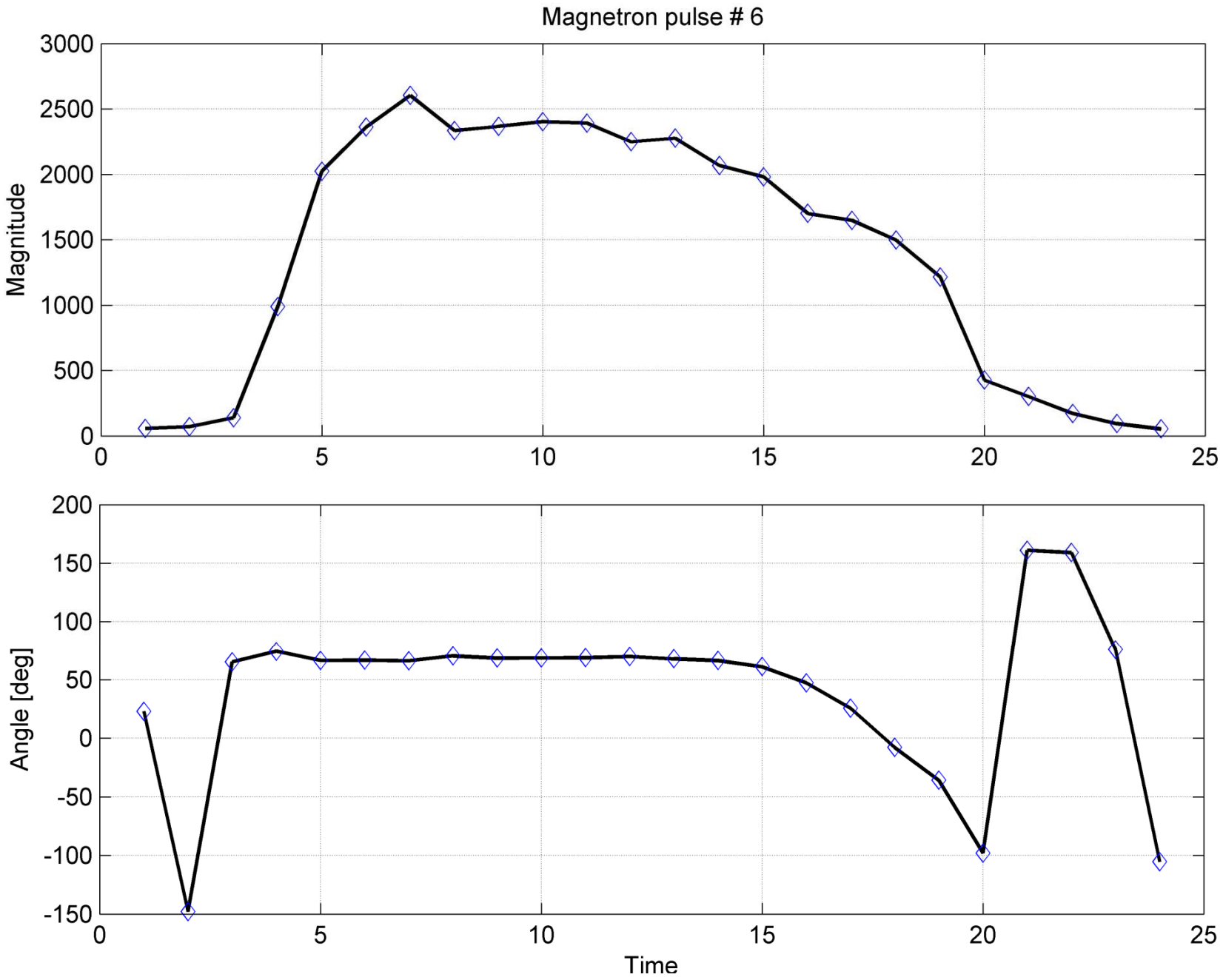

Reflected sig
Direct sig
Azimuth [deg]


Reflected sig
Direct sig
Azimuth [deg]



⇑ Hamming weighted reference is used in order to accommodate the imperfect periodicity caused by getting in and out of the rotated antenna beam. ⇓ The result is reduction of cross-correlation sidelobes below -50dB.




Magnetron pulse # 6
Magnitude
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
Angle [deg]
200
150
100
50
0
-50
-100
-150
0
5
10
15
20
25
Time

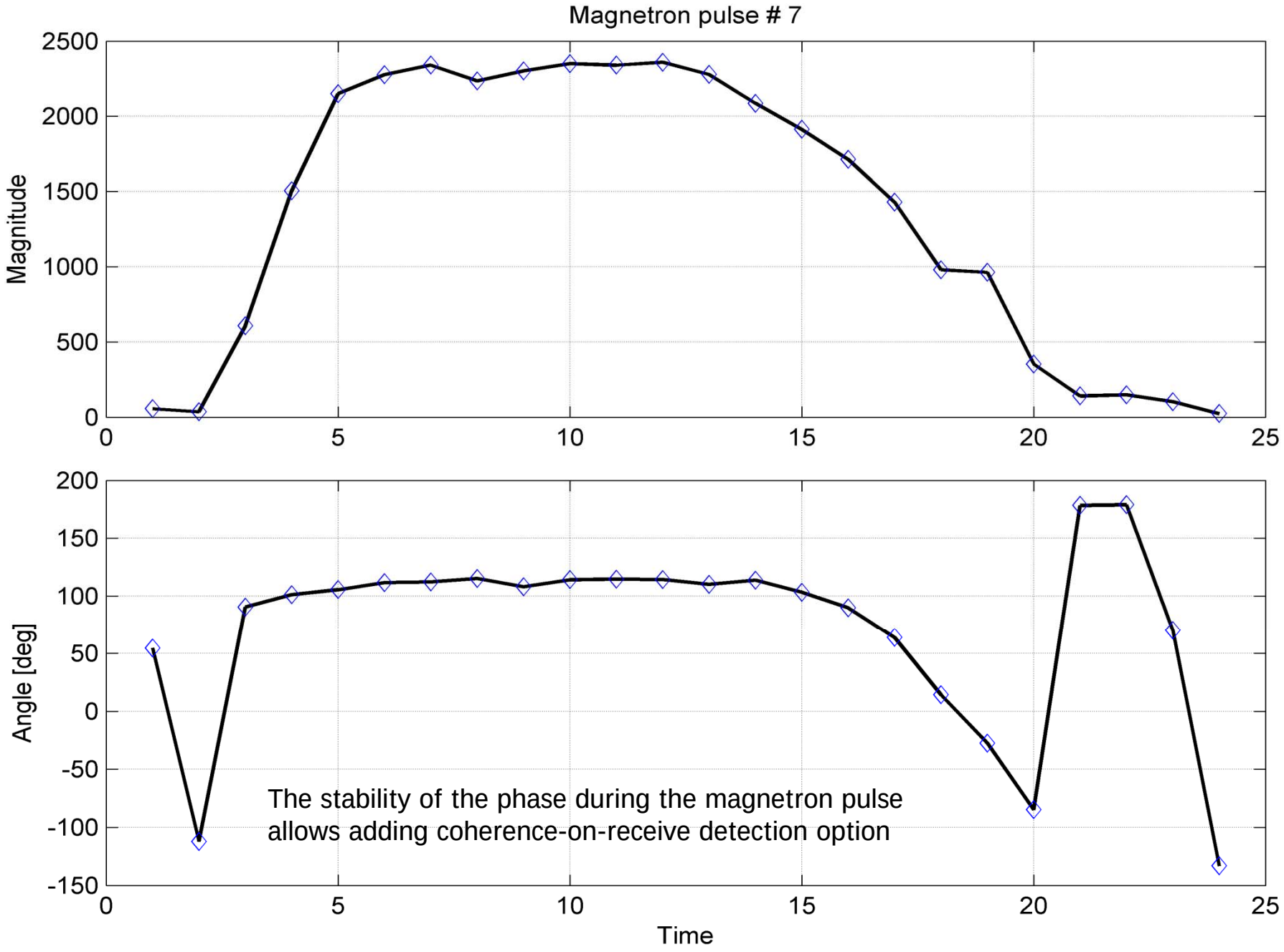

Magnetron pulse # 7
Magnitude
2500
2000
1500
1000
500
0
0
5
10
15
20
25
Angle [deg]
200
150
100
50
0
-50
-100
-150
0
5
10
15
20
25
Time
The stability of the phase during the magnetron pulse
allows adding coherence-on-receive detection option

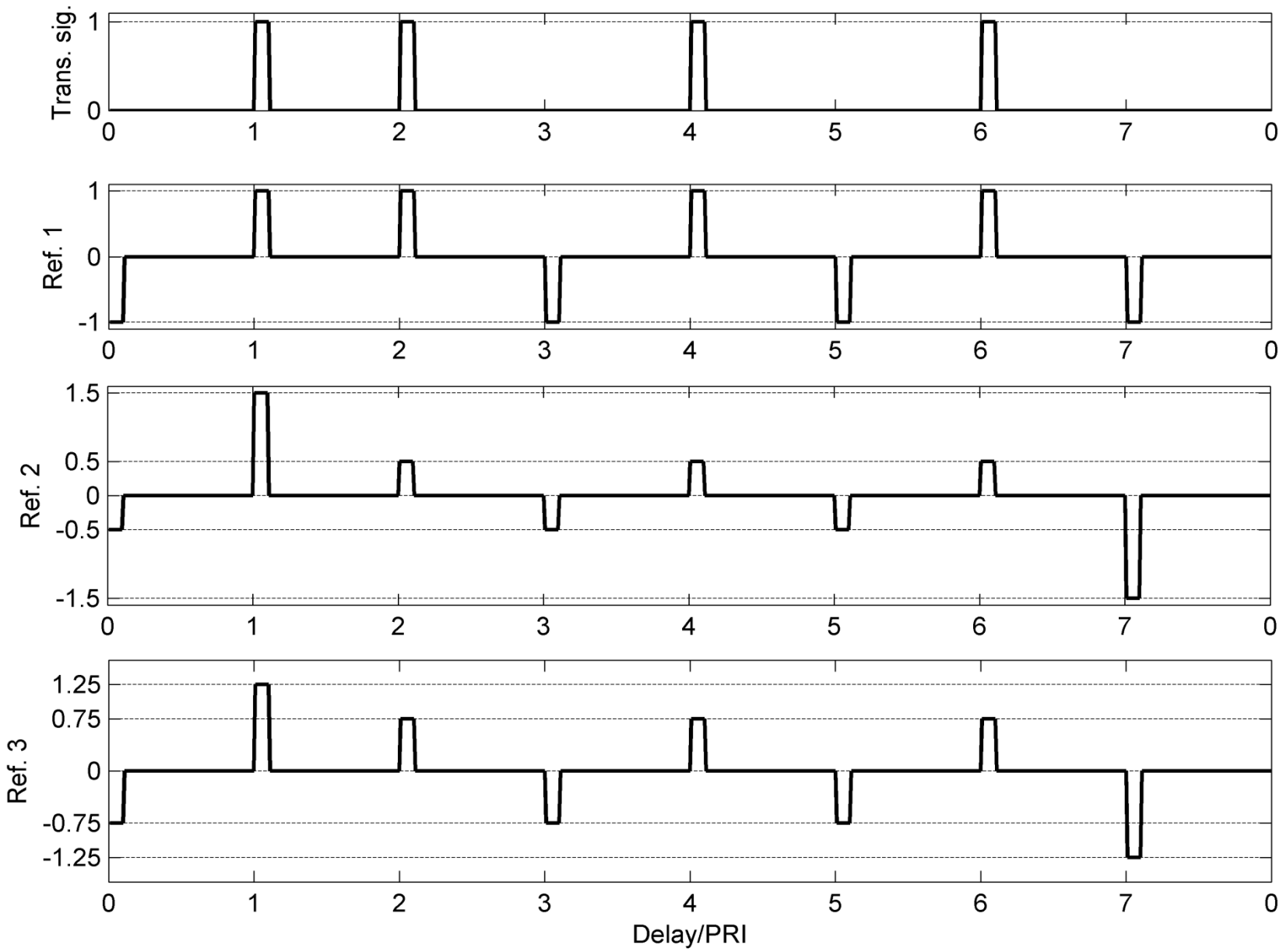
Table 1. Transmitted and references inter-pulse coding based on Barker 4

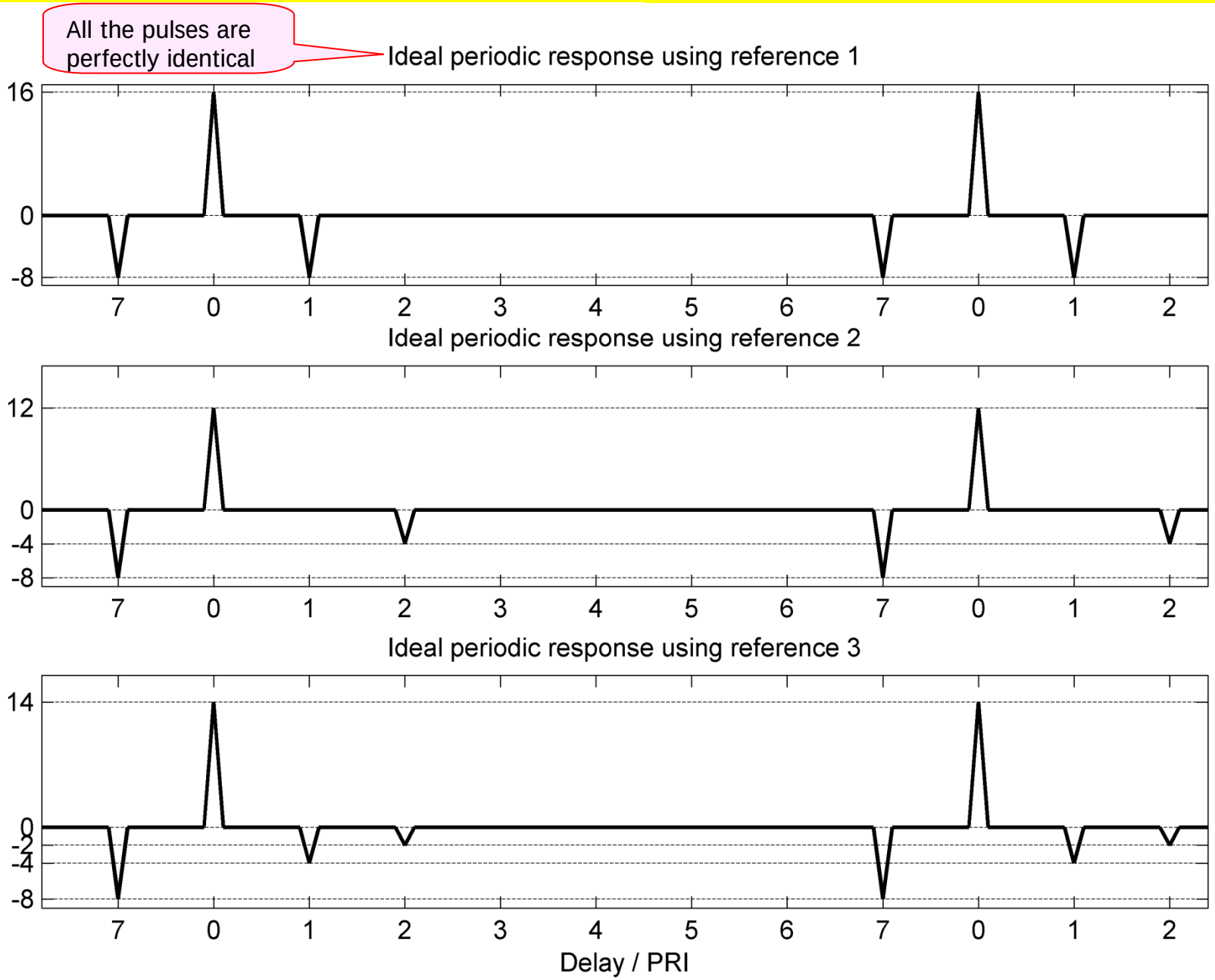
Pulse #	1	2	3	4	5	6	7	8
Trans.	0	1	1	0	1	0	1	0
Ref. 1	–1	1	1	–1	1	–1	1	–1
Ref. 2	–0.5	1.5	0.5	–0.5	0.5	–0.5	0.5	–1.5
Ref. 3	–0.75	1.25	0.75	–0.75	0.75	–0.75	0.75	–1.25
Ref. NC	0	1	1	0	1	0	1	0

Table 2. Trans. and ref. pulse coding based on Ipatov 5

Pulse	1	2	3	4	5	6	7	8	9	10
Trans.	1	0	1	0	1	0	0	1	1	0
Ref. 1	1	–1	1	–1	1	–1	–2	2	1	–1
Ref. 2	0.5	–0.5	0.5	–0.5	0.5	–2	–1	2.5	0.5	–0.5
Ref. 3	0.75	–0.75	0.75	–0.75	0.75	–1.75	–1.25	2.25	0.75	–0.75

Barker 4 coding




All the pulses are perfectly identical
Ideal periodic response using reference 1
16
0
-8
7 0 1 2 3 4 5 6 7 0 1 2
Ideal periodic response using reference 2
12
0
-4
-8
7 0 1 2 3 4 5 6 7 0 1 2
Ideal periodic response using reference 3
14
0
-2
-4
-8
7 0 1 2 3 4 5 6 7 0 1 2
Delay / PRI

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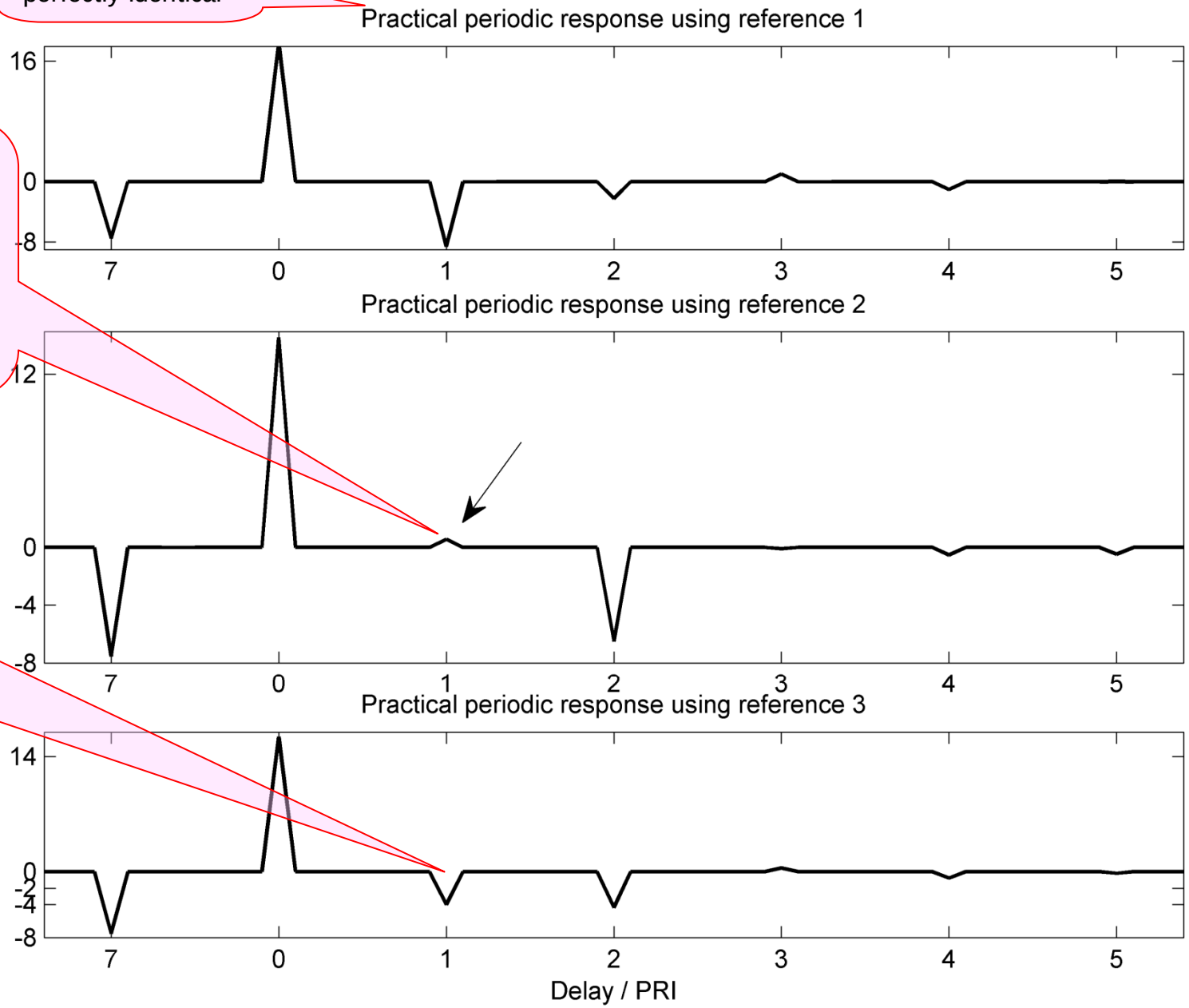
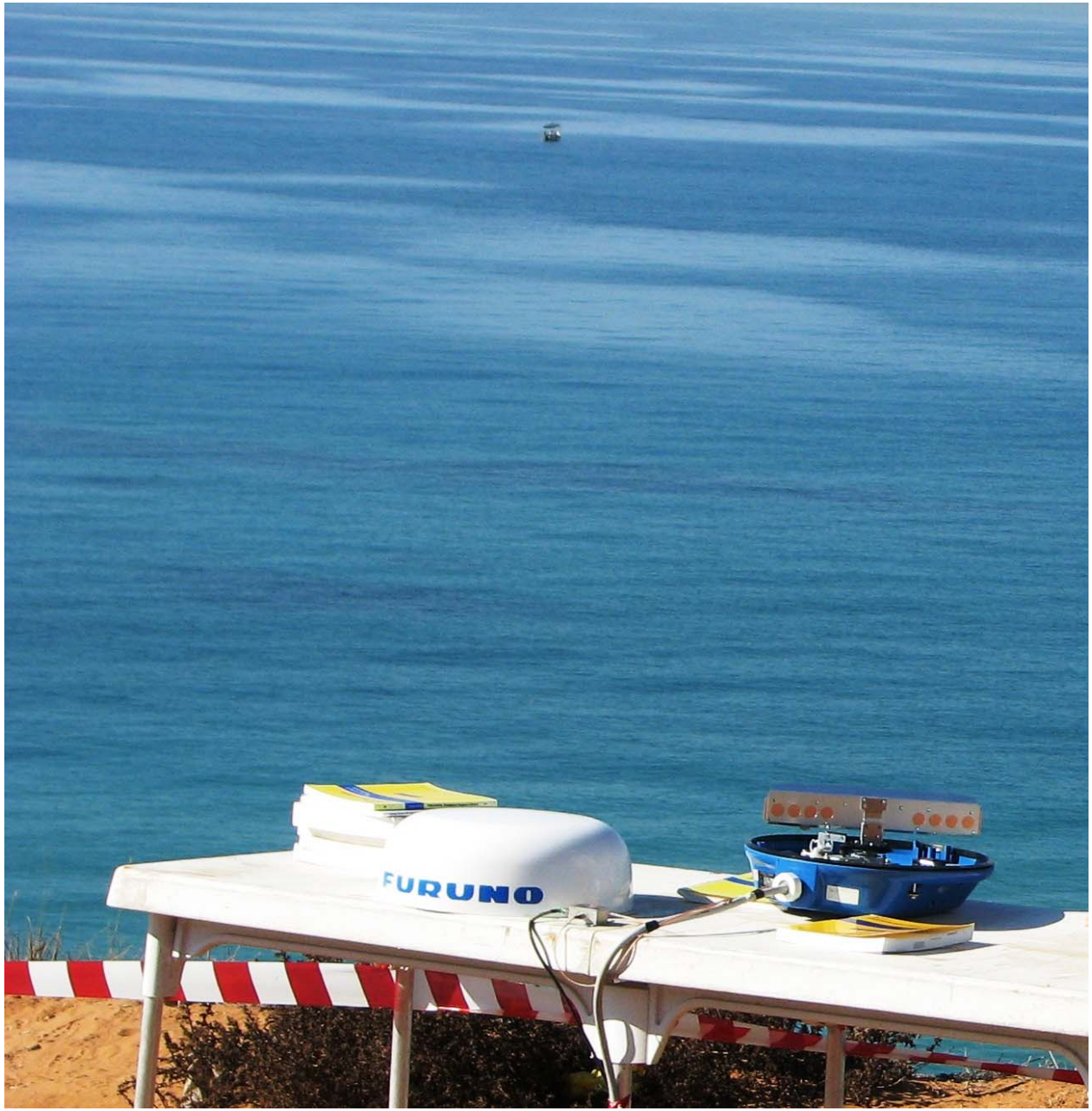
The pulses are not perfectly identical

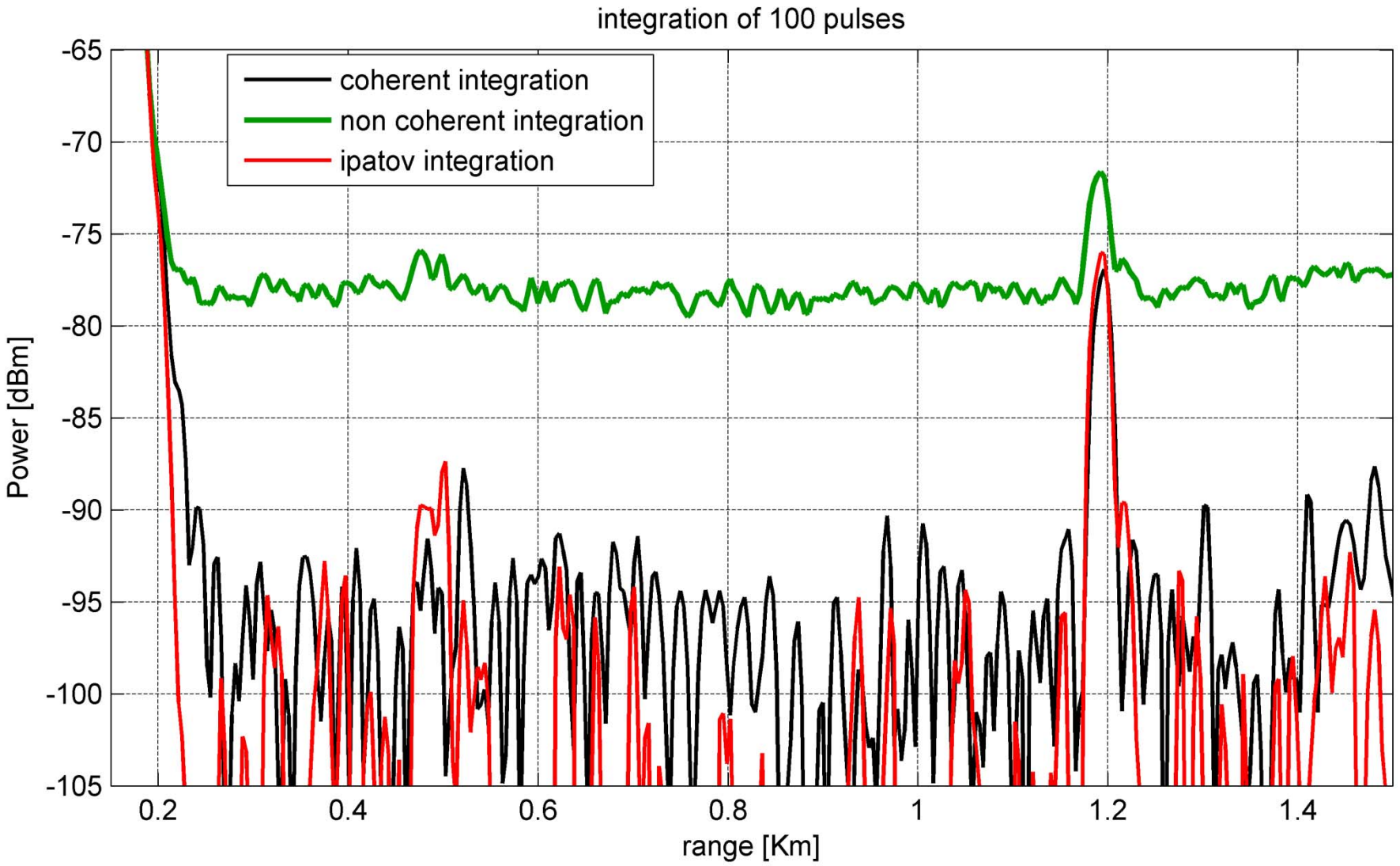
This positive sidelobe implies that the strong direct reception and near clutter are replicated at a delay equal to the basic PRI.

This negative sidelobe ("hole") implies that a target at a delay equal to the basic PRI will be concealed.





Tel Baruch field trial (June 2011)


integration of 100 pulses
coherent integration
non coherent integration
ipatov integration
Power [dBm]
-65
-70
-75
-80
-85
-90
-95
-100
-105
0.2
0.4
0.6
0.8
1
1.2
1.4
range [Km]

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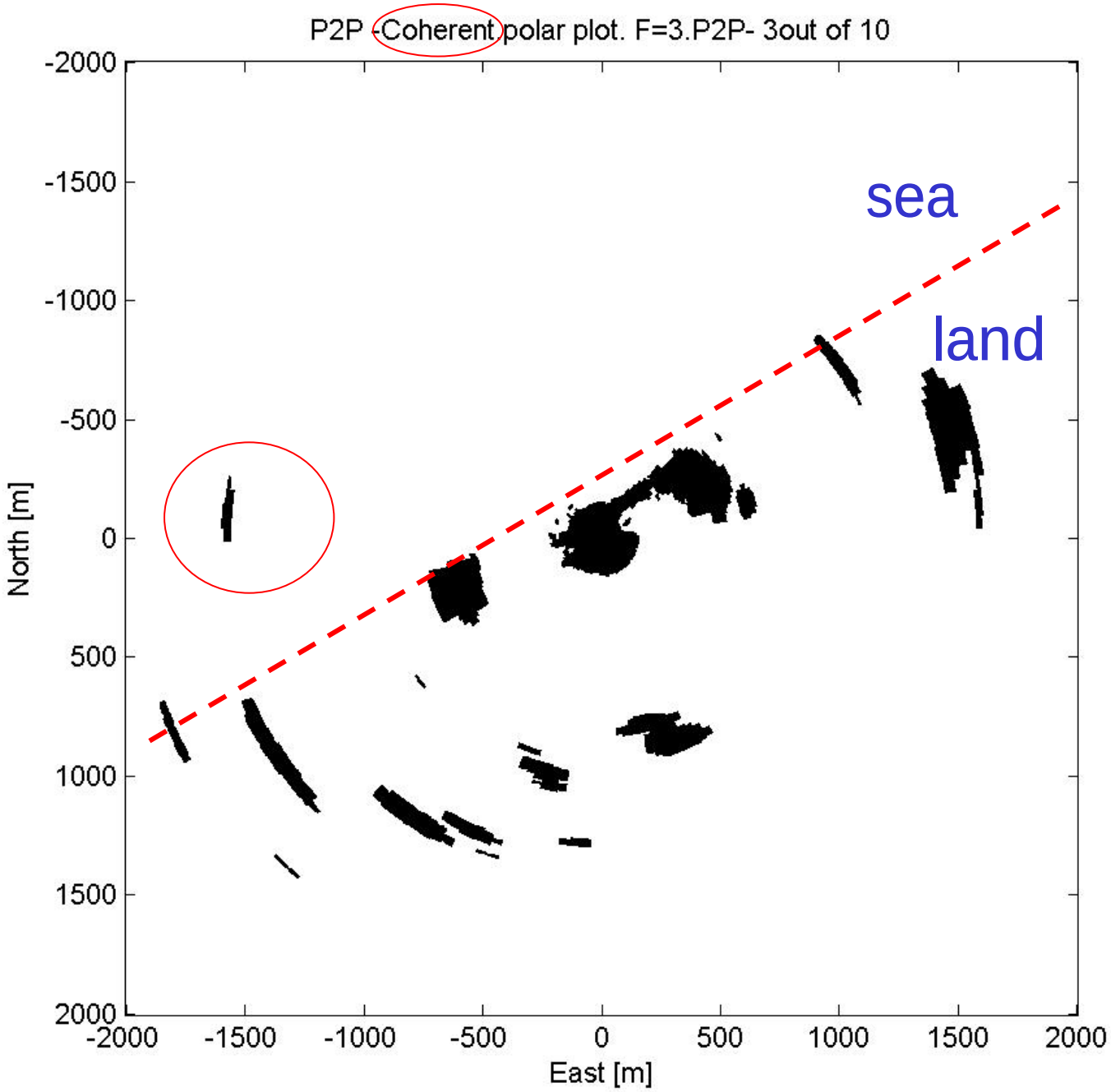

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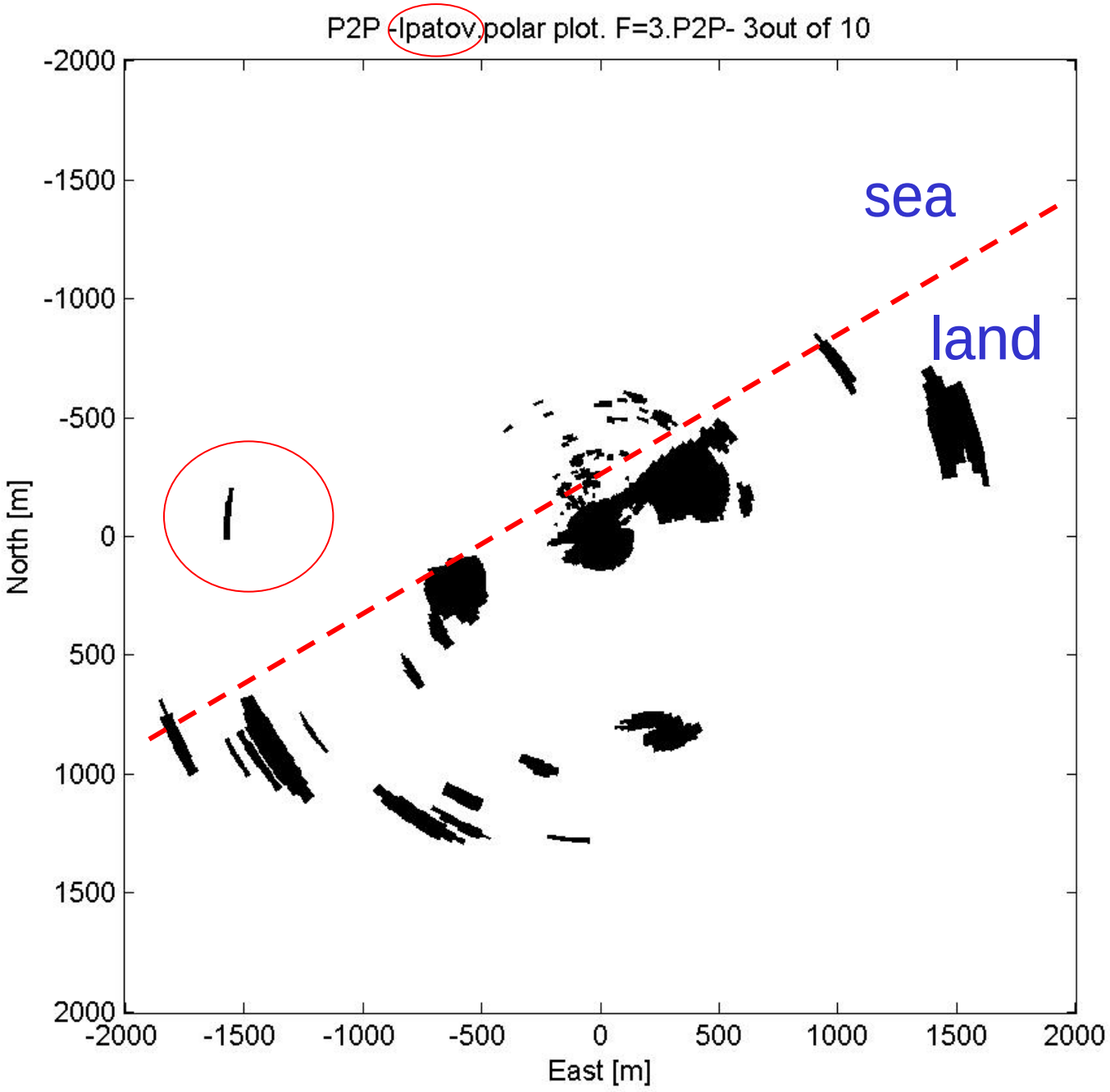
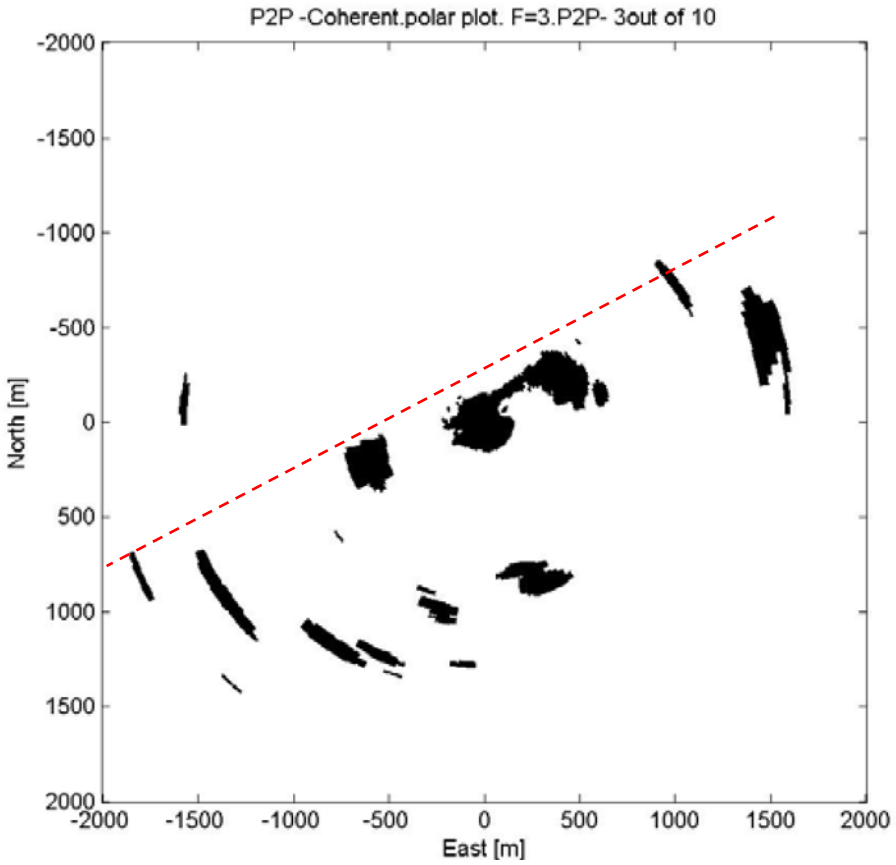
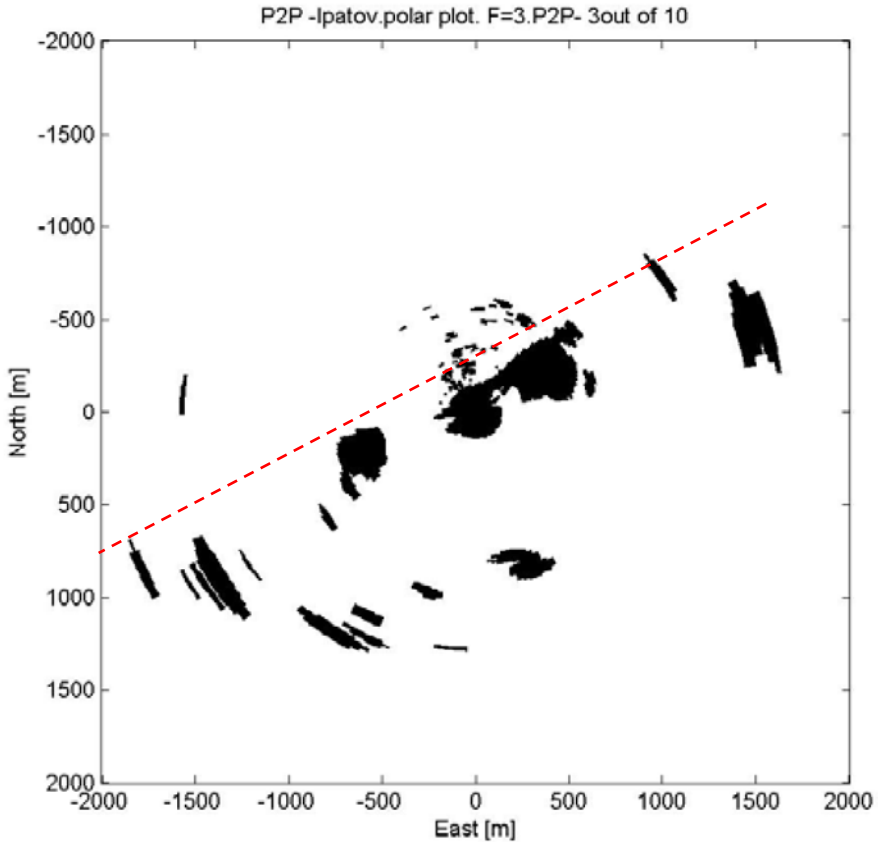



P2P -Coherent.polar plot. F=3.P2P- 3out of 10
North [m]
East [m]
-2000
-1500
-1000
-500
0
500
1000
1500
2000


P2P -Ipatov.polar plot. F=3.P2P- 3out of 10
North [m]
East [m]
-2000
-1500
-1000
-500
0
500
1000
1500
2000


Ashdod field trial
(August 2011)


Carmel

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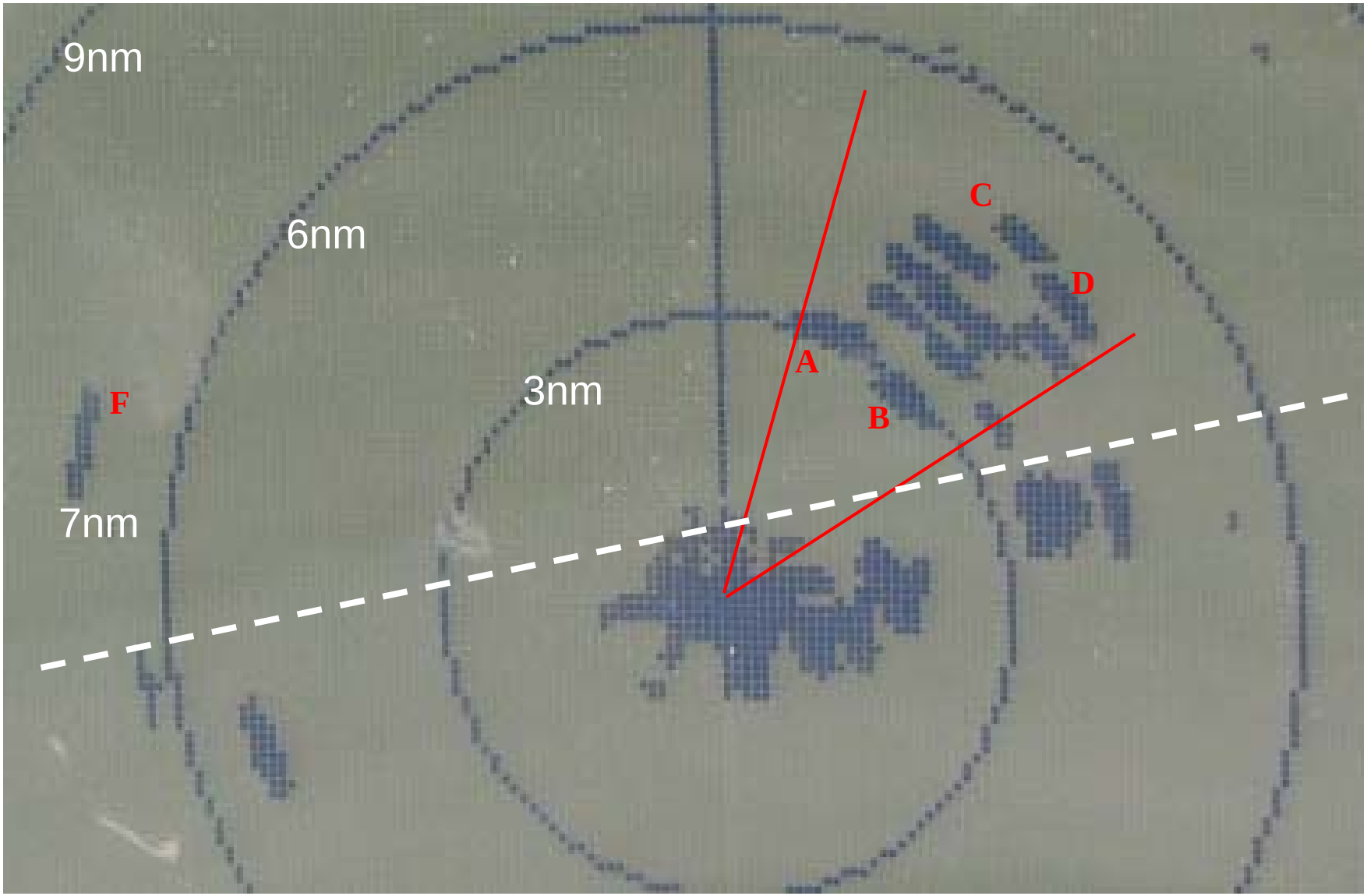
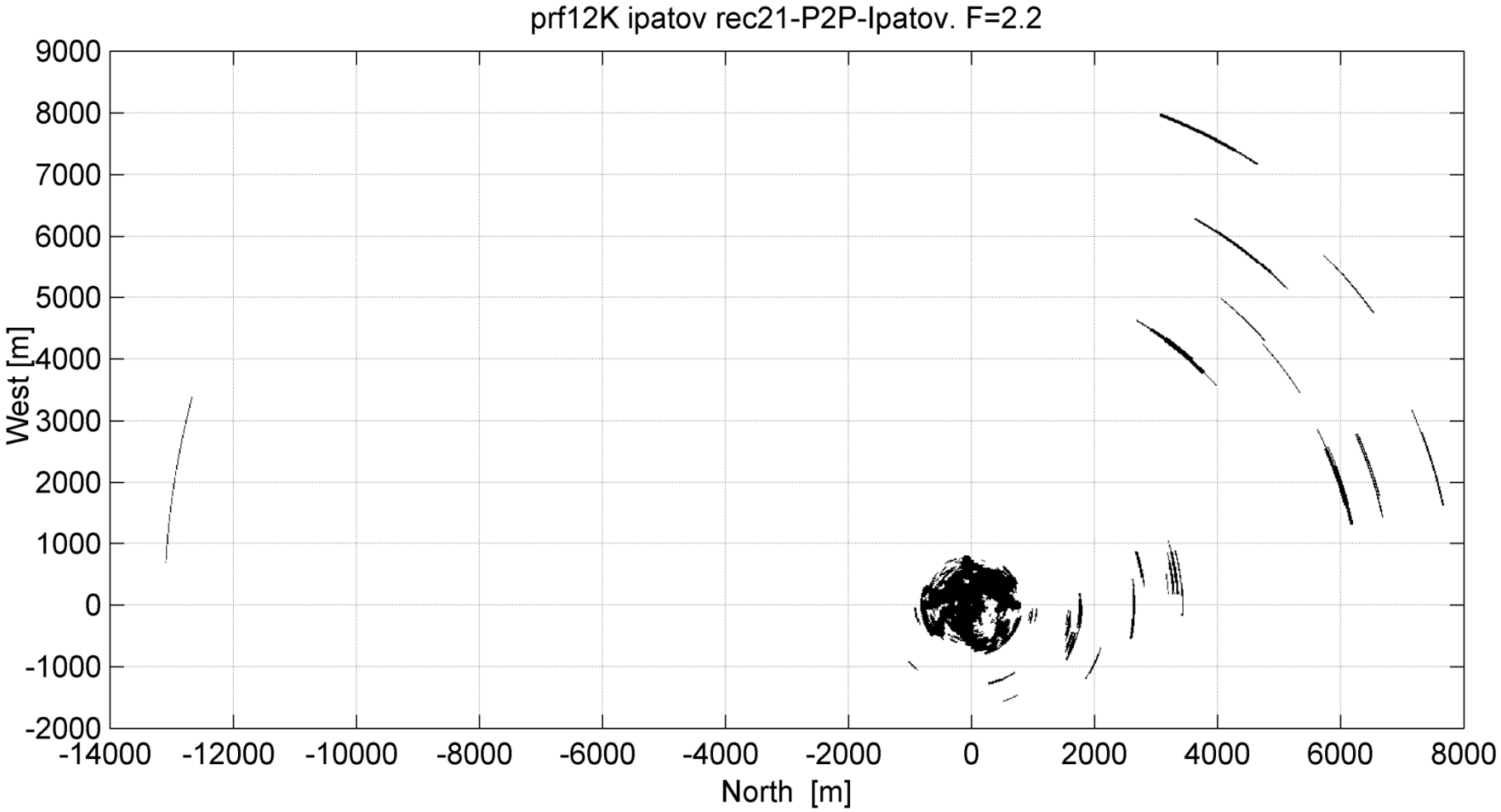


7nm*1.852 = 13km


prf12K ipatov rec21-P2P-Ipatov. F=2.2
West [m]
North [m]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-14000
-12000
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000

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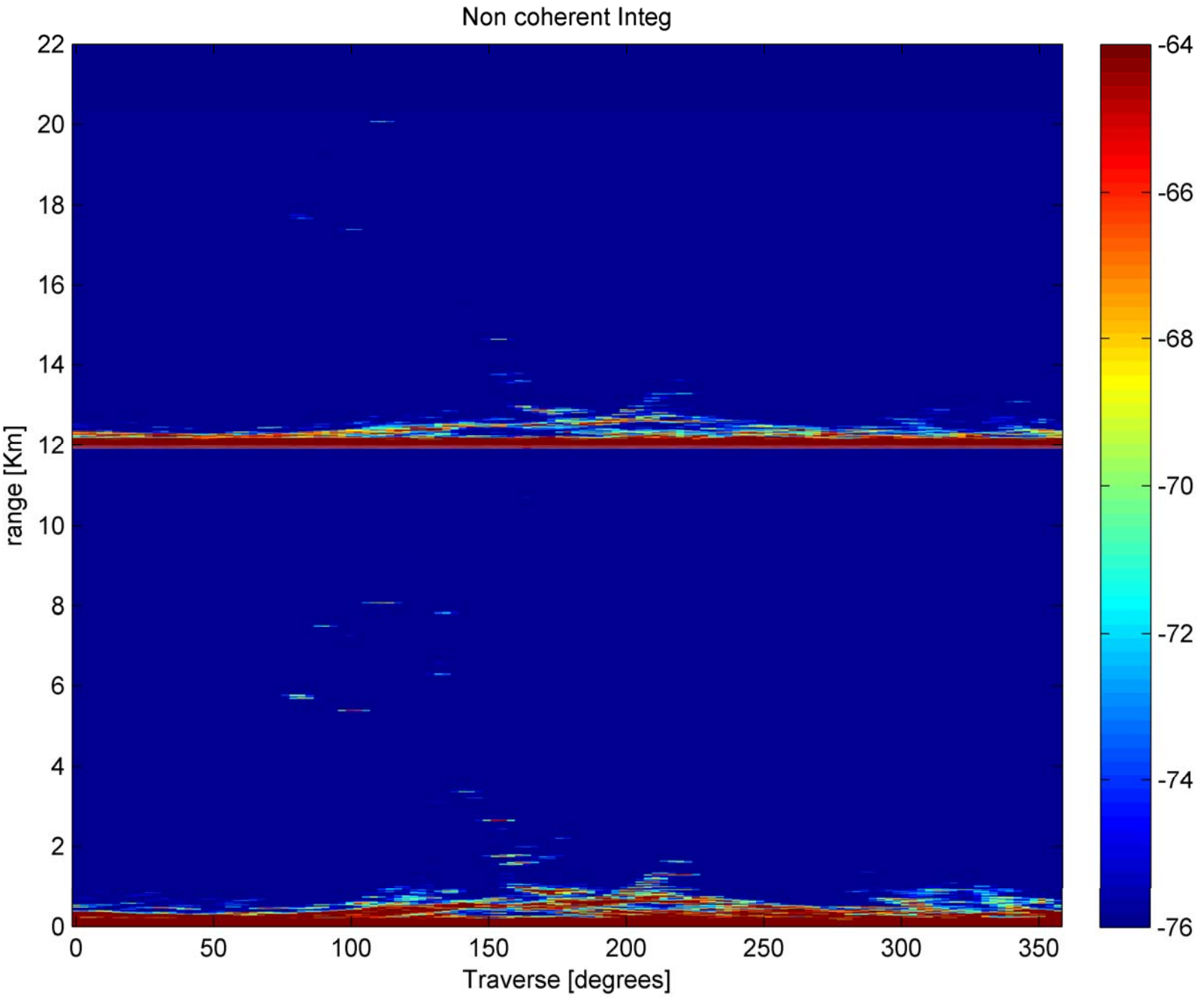

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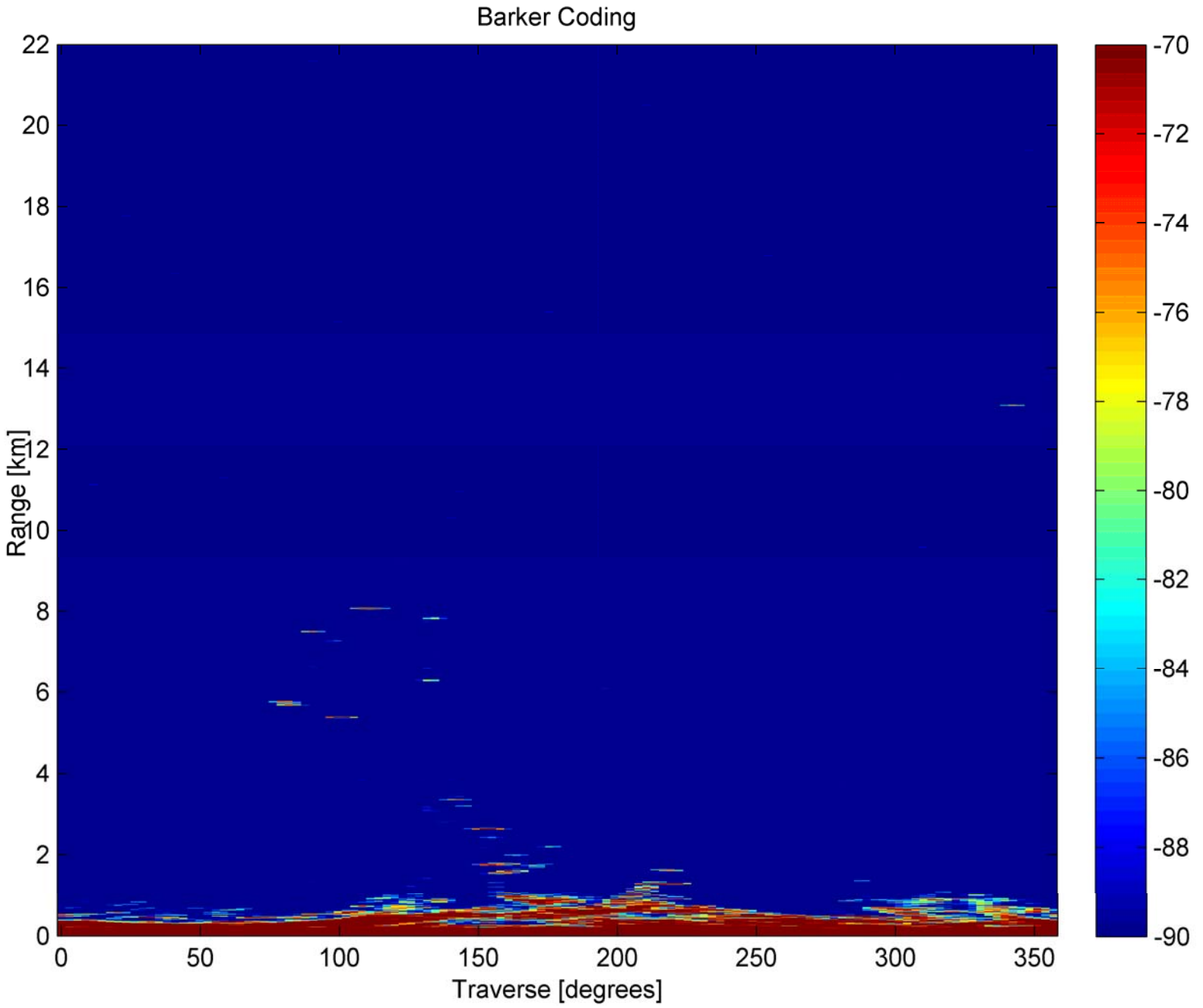

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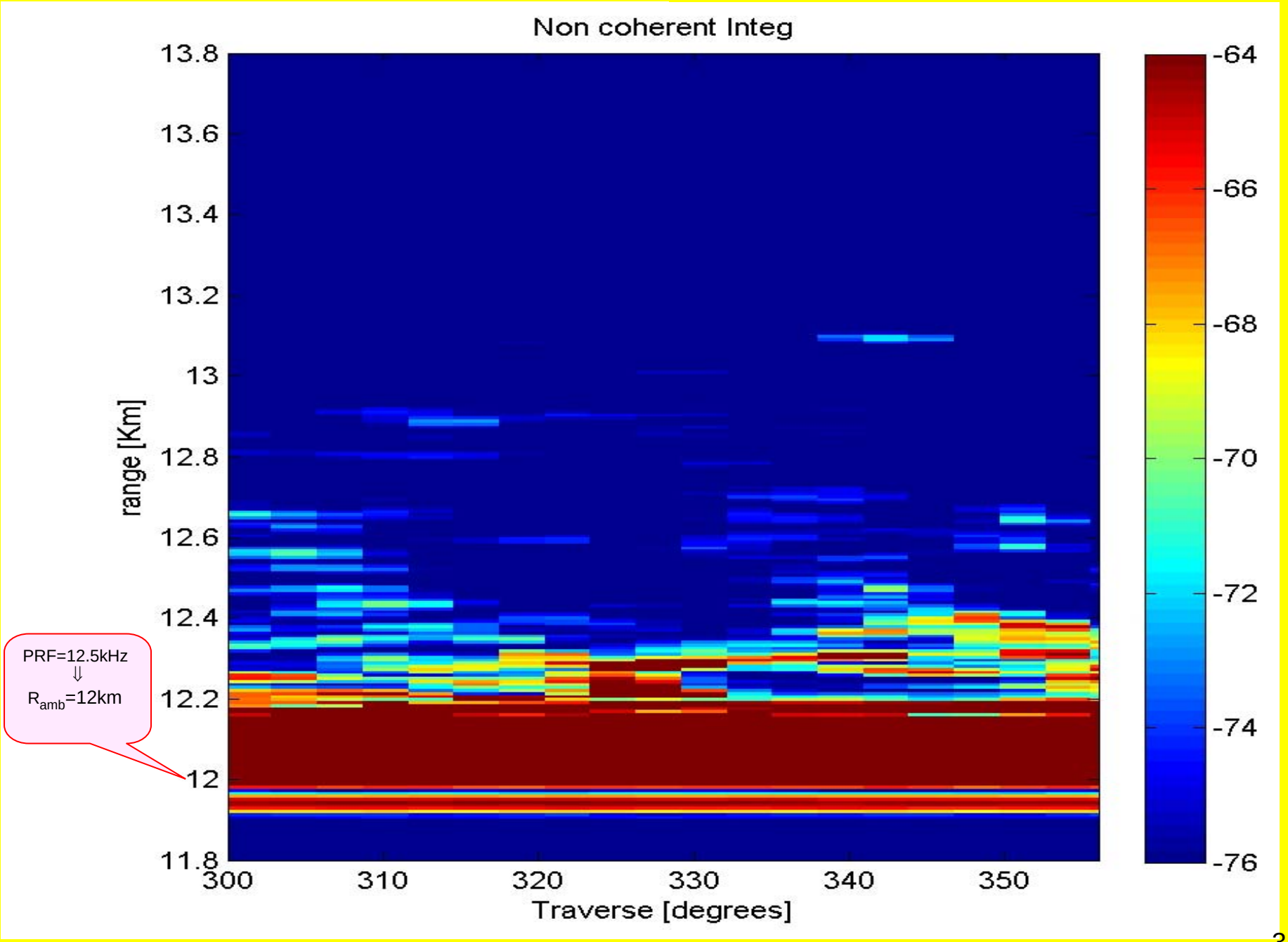
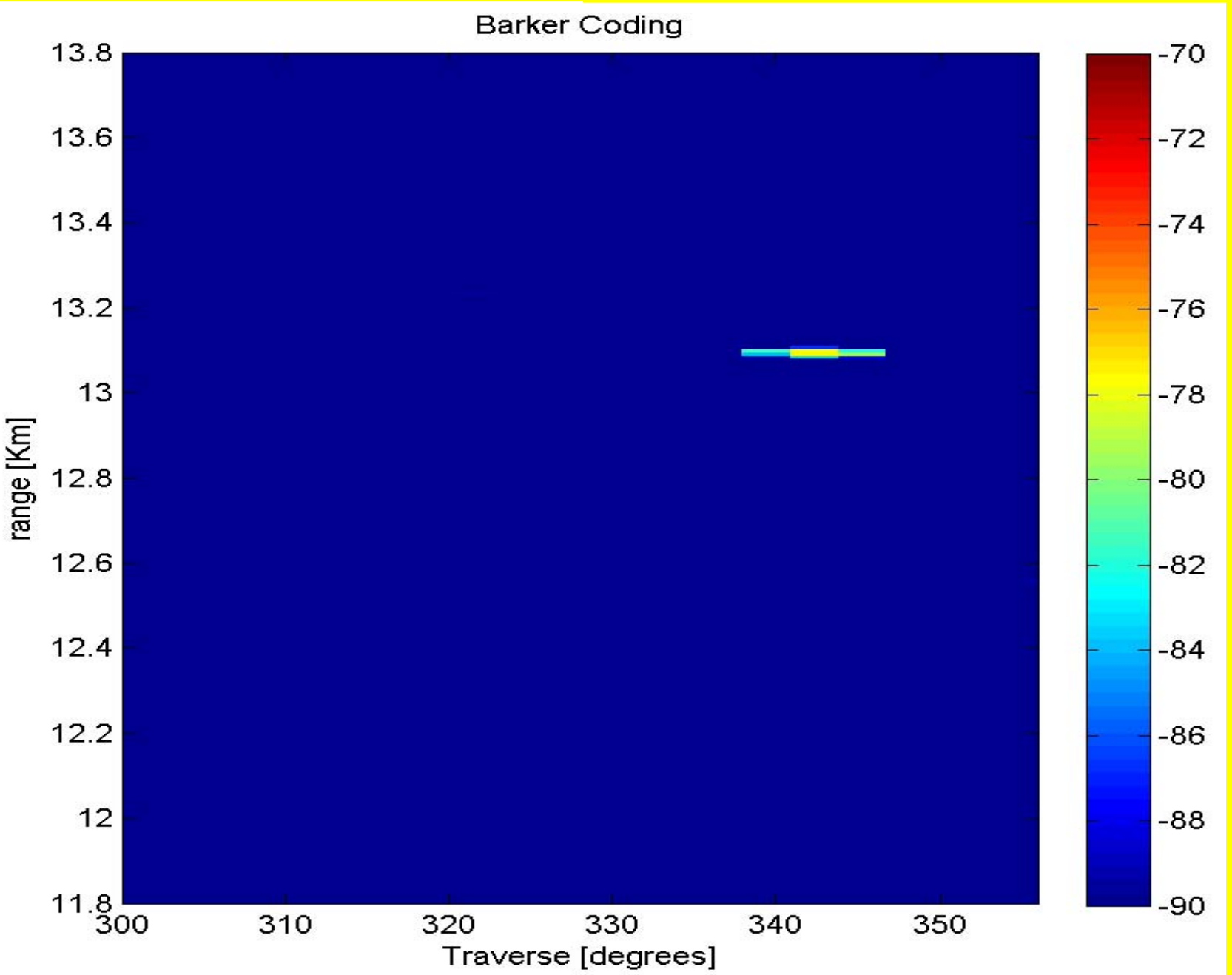



Barker Coding
13.8
13.6
13.4
13.2
13
12.8
12.6
12.4
12.2
12
11.8
range [Km]
300
310
320
330
340
350
Traverse [degrees]
-70
-72
-74
-76
-78
-80
-82
-84
-86
-88
-90

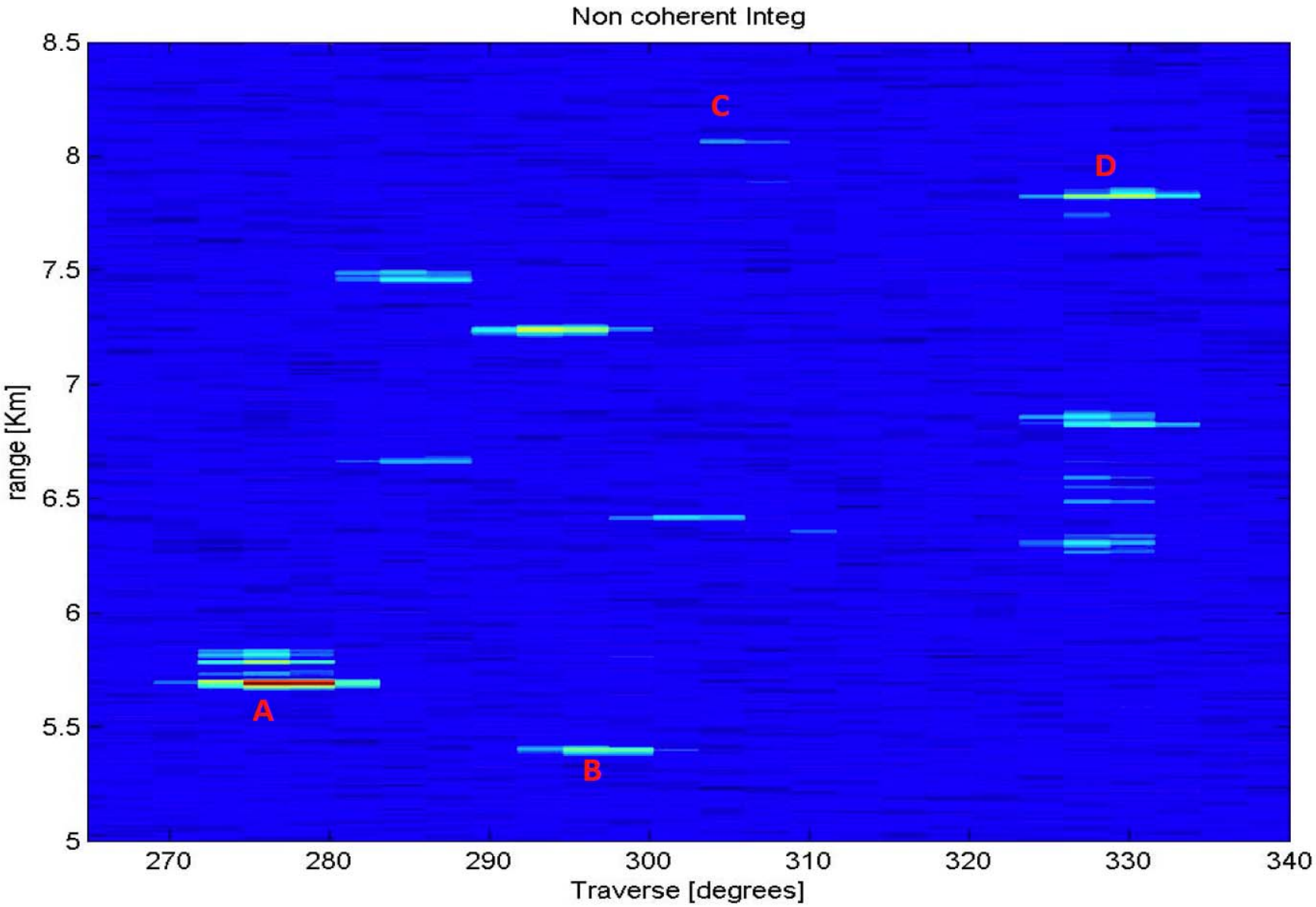


Fig. 5 Output of non-coherent processing – ships waiting to enter the port of Ashdod

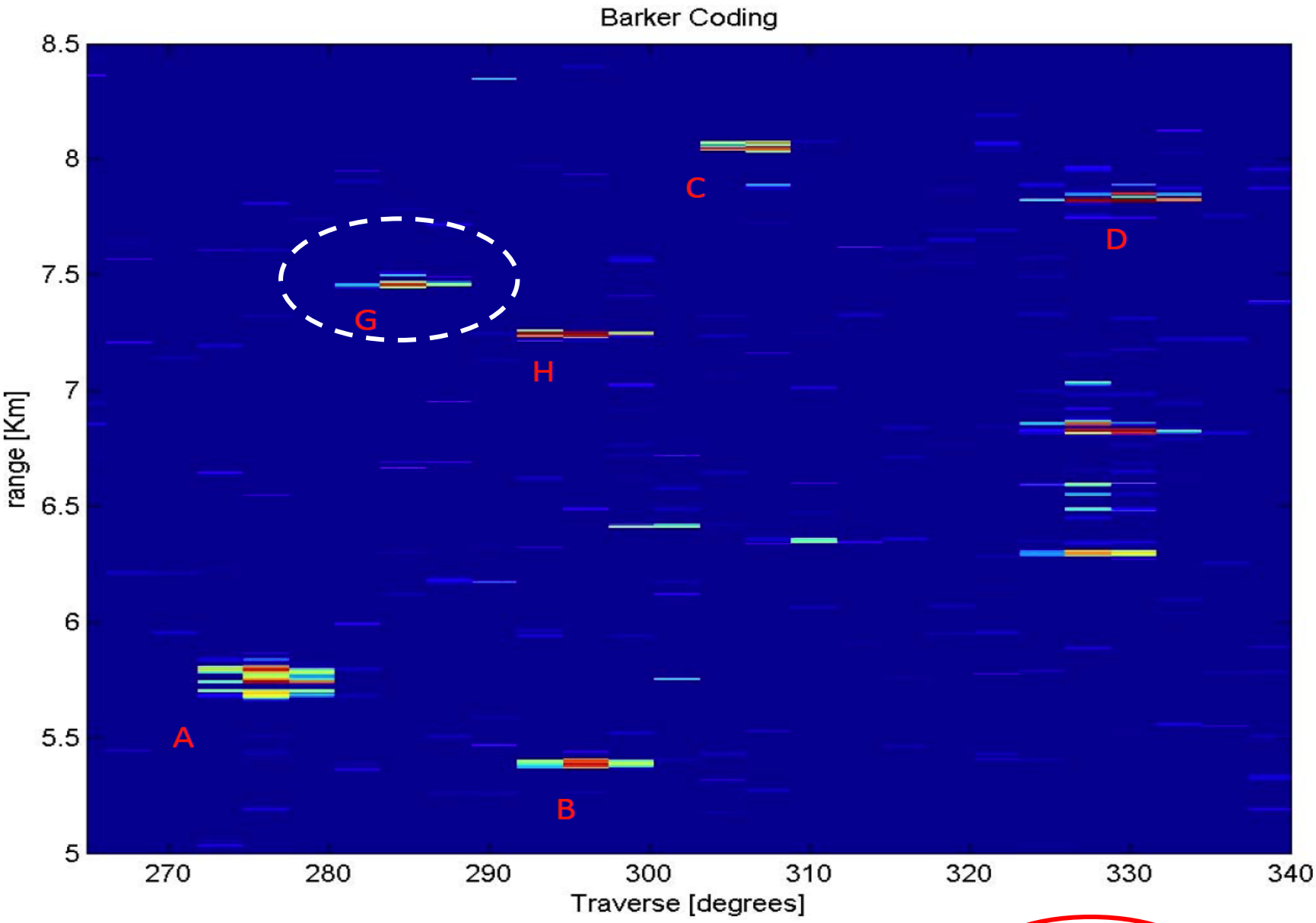


Fig. 8 Output of Barker processing – same scene as in Fig. 5 (PRF = 6250)

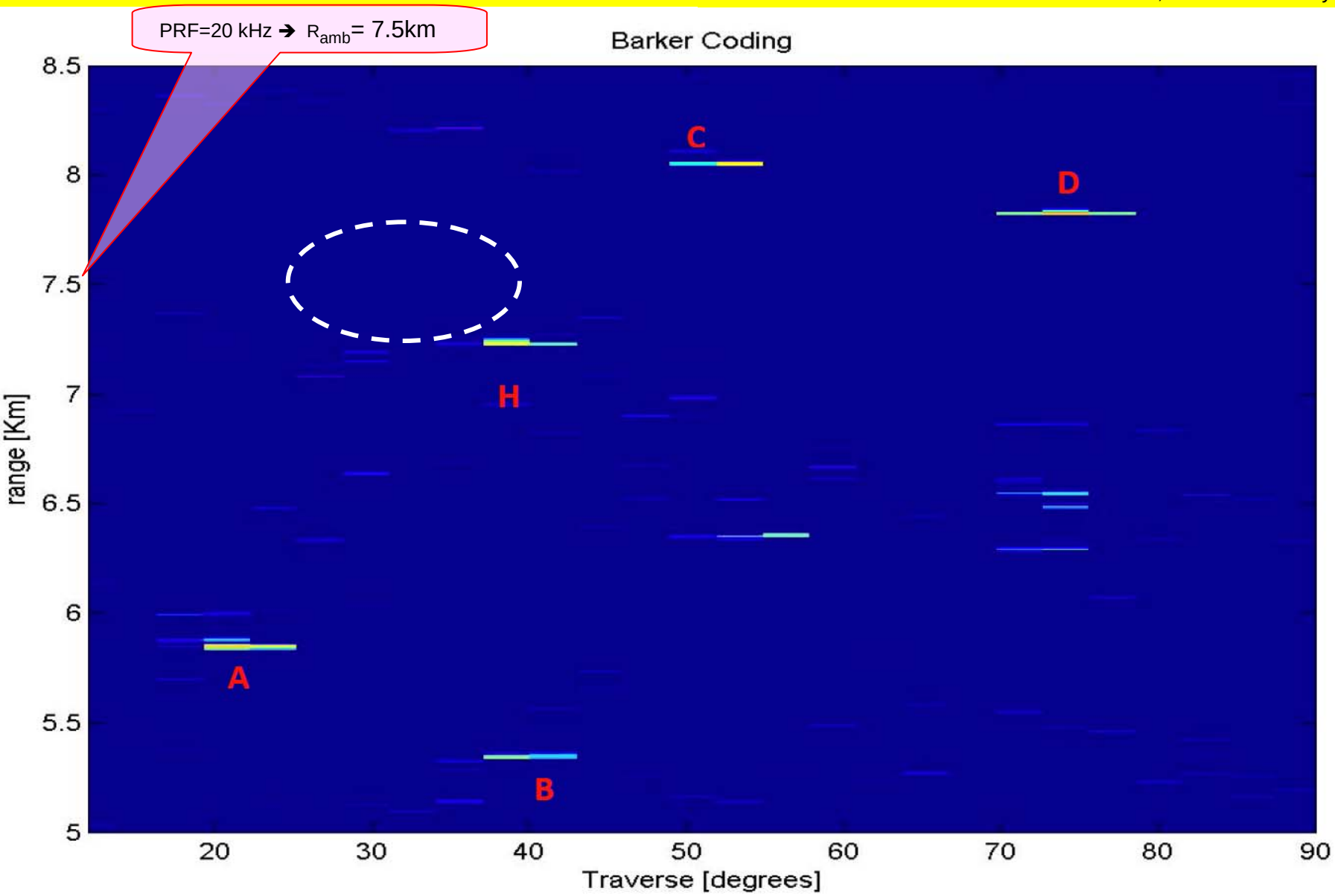
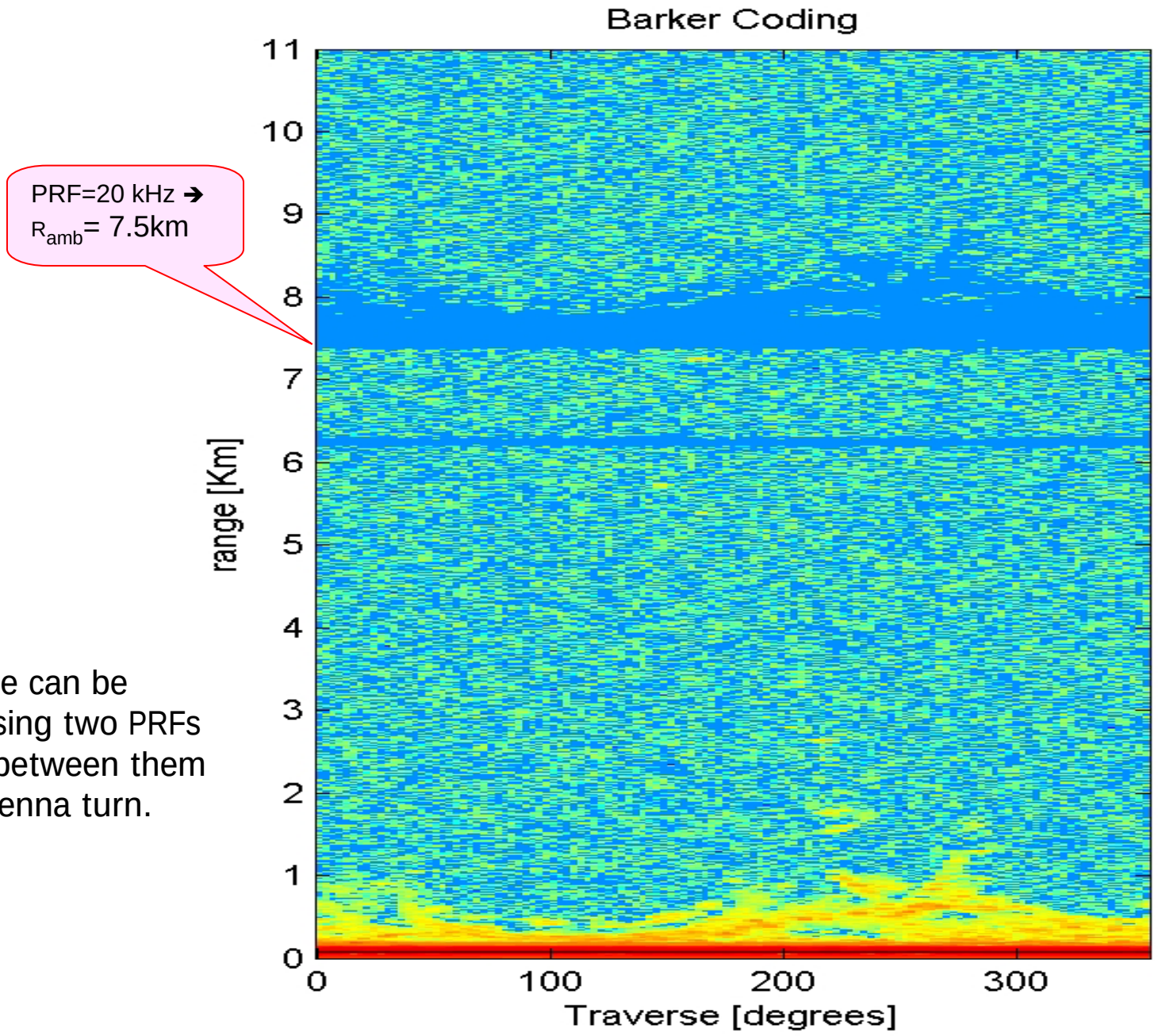


Fig. 9 Output of Barker processing – same scene as in Fig. 5 (PRF = 20000)



The “hole” issue can be mitigated by using two PRFs and switching between them once every antenna turn.

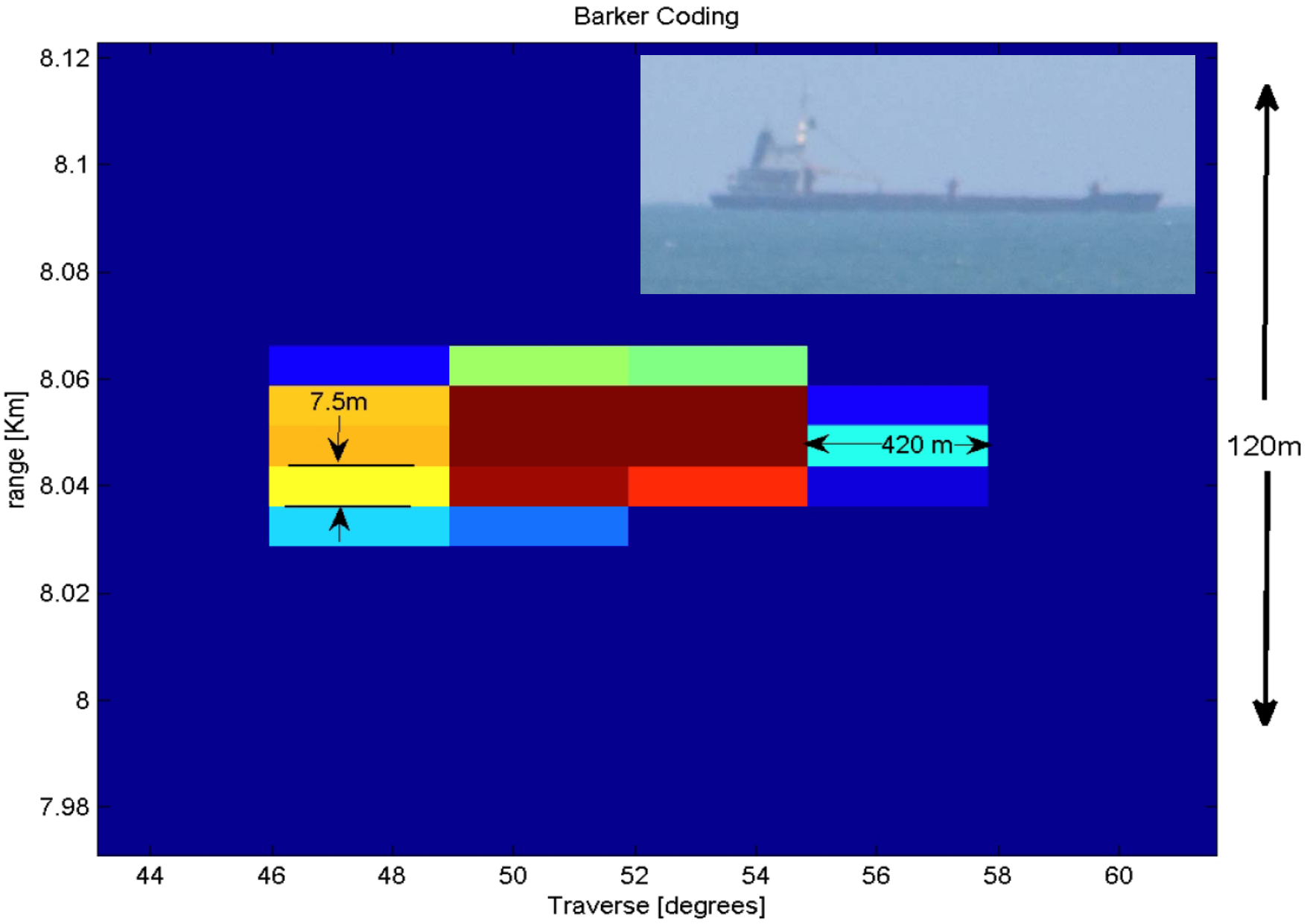


Fig. 12 Zoom on Target C

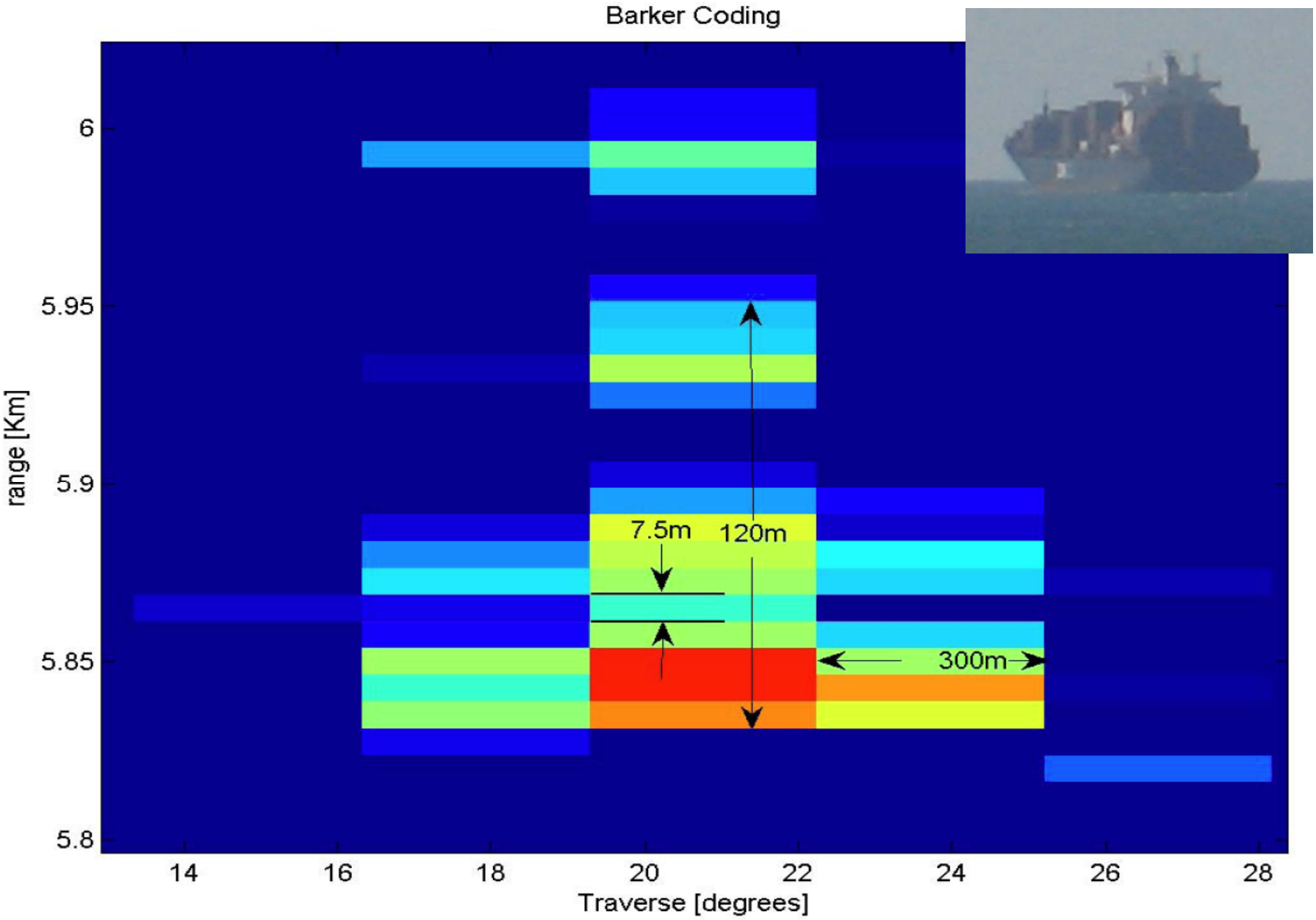
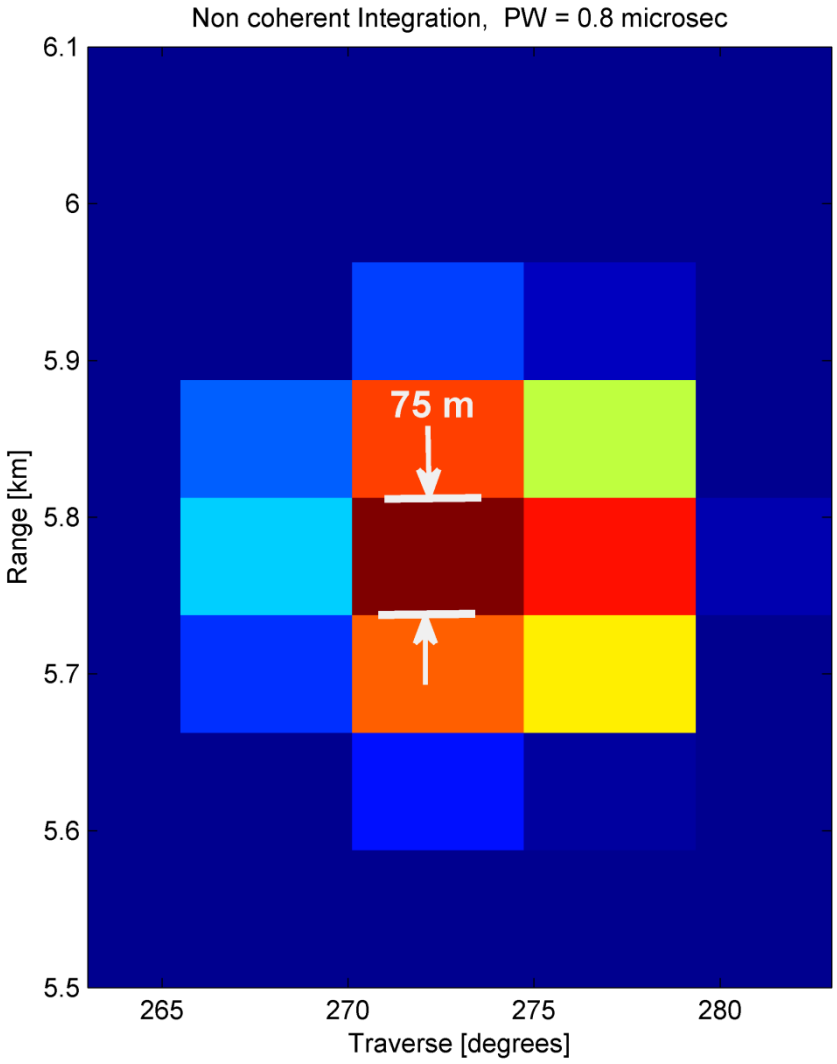
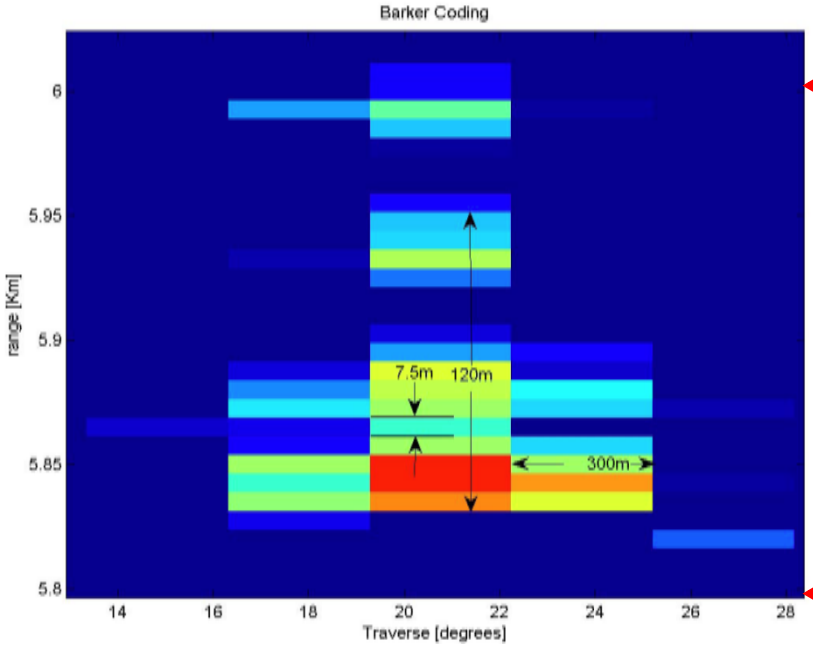


Fig. 11 Zoom on Target A

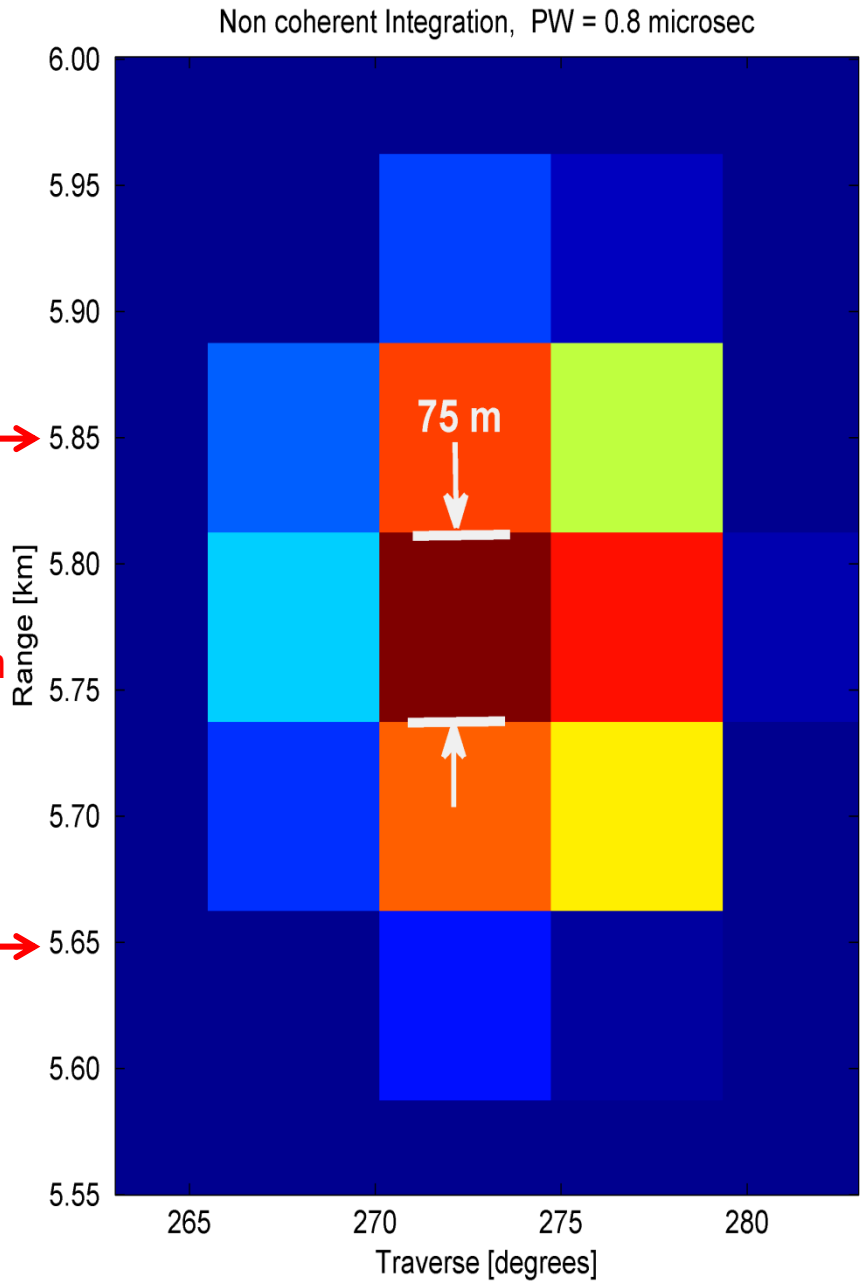


Target **A**, PW = **0.8** μs, PRF = 625 Hz



PW = 0.08 microsec

200m



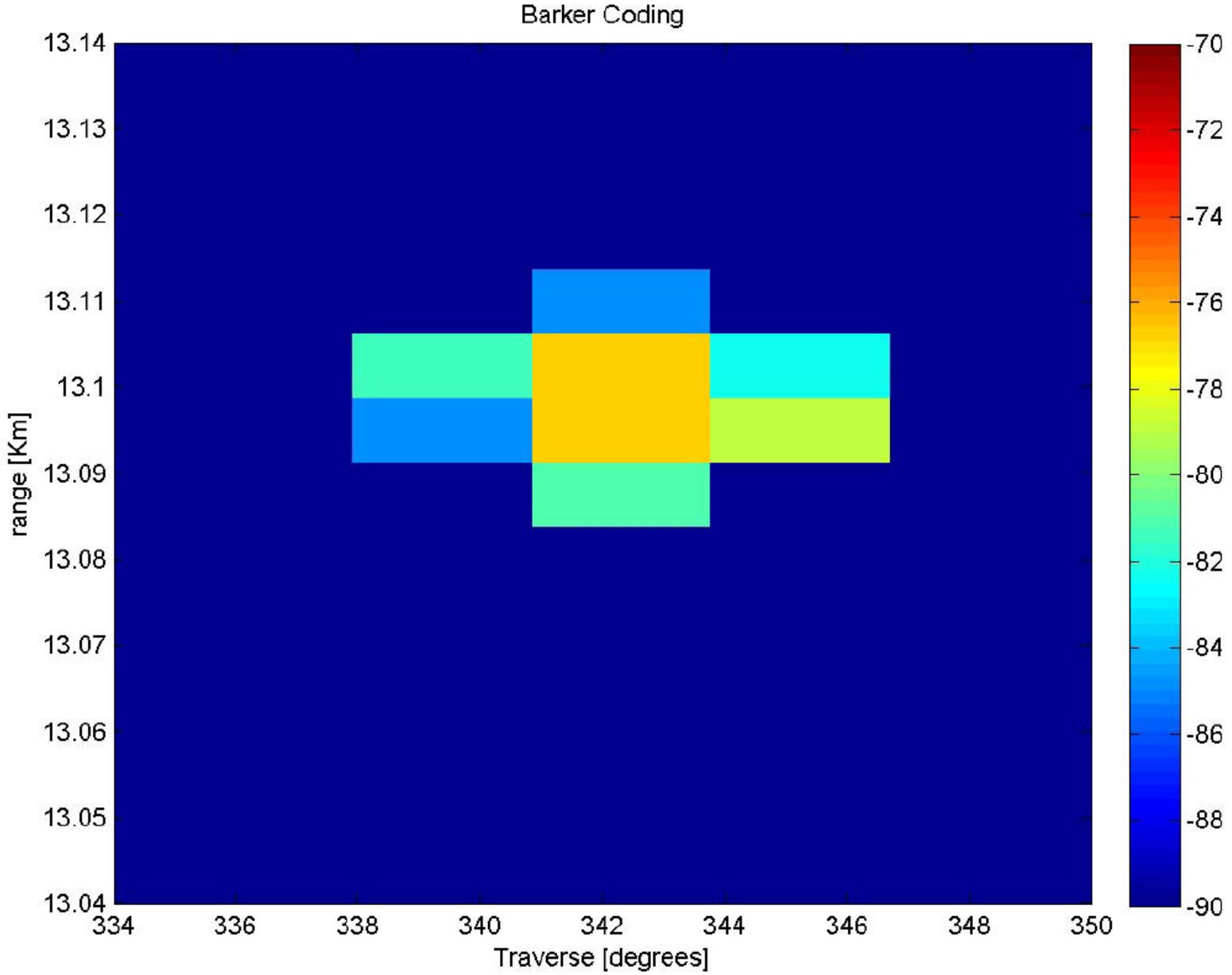


Fig. 16. Ship target at 13km (Barker processing, PRF=12.5kHz).

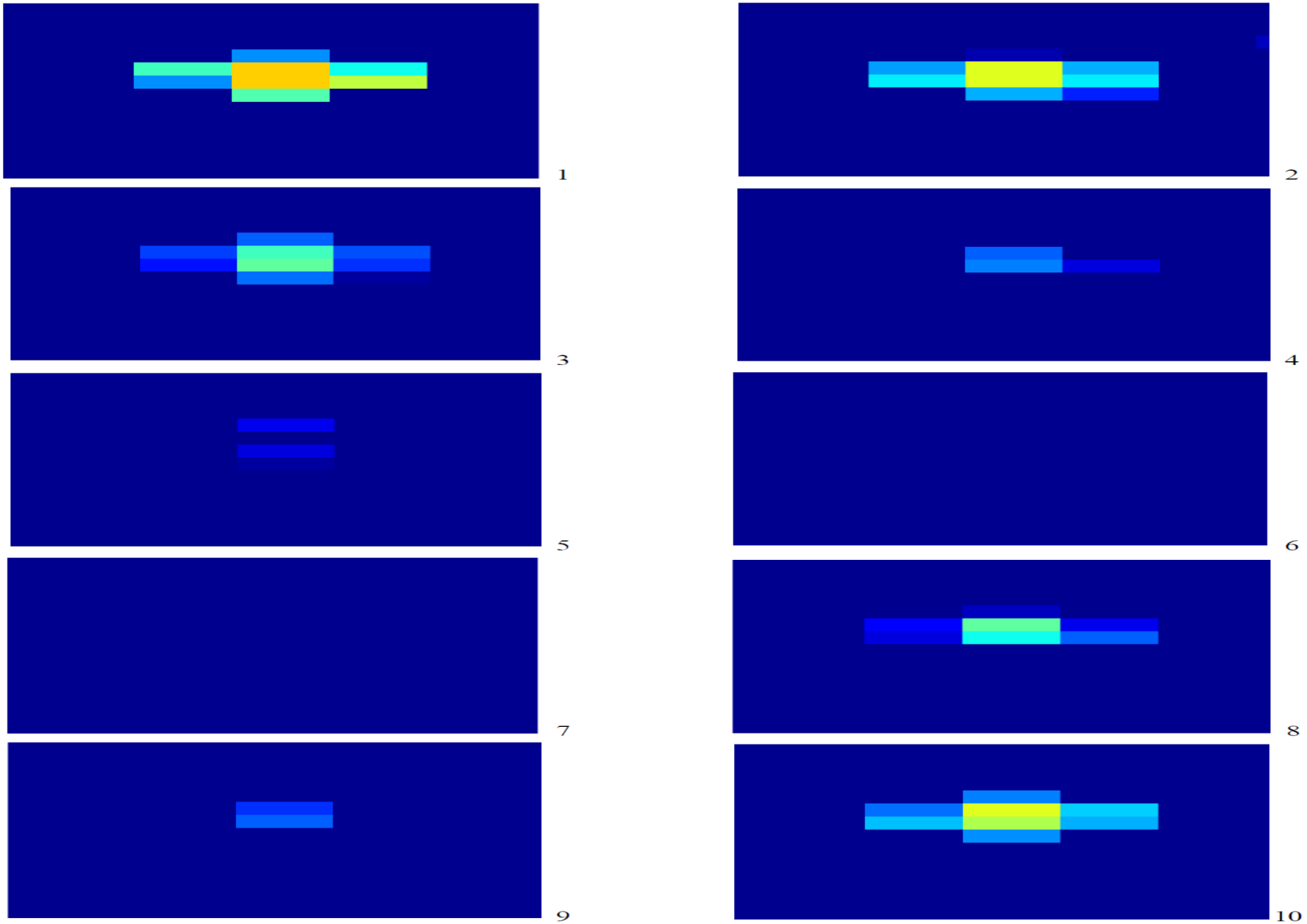


Fig. 17 Ten consecutive antenna scans of a ship target at 13.1km (PRF = 12.5kHz, Braker coded processing).

Integration	N detections out of 10 scans. N=
Non-coherent	10
Barker	8
Coherent	0

When using coherent integration, the target at 13 km was not detected even once in 10 consecutive antenna scans **???**

CONCLUSIONS

•Periodic pulse position coding is effective in extending the unambiguous range.

•This allows operating at all ranges in a "**short pulse high PRF**" mode.

•The penalty of delay response "hole" at the PRI can be mitigated by switching PRIs once per antenna turn. (Not tested yet.)

•Short pulse provides improved resolution of ship targets (including revealing the ship's aspect.)

•Short pulse is expected to reduce clutter illumination area, hence clutter reflection. (Not tested in our trials because of the calm sea.)

•Coherent detection reduces near sea clutter.

•Coherent detection hurts detection of distant ship targets (unexplained yet).

Thank you !