

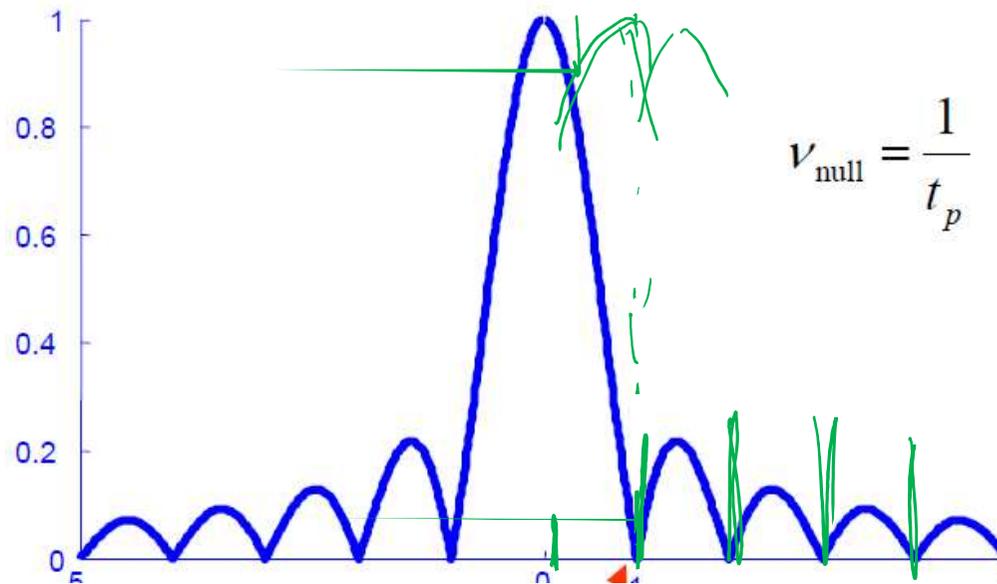
Banco di filtri adattati (I)

- Se $V_{max} > V_{null}$ un filtro adattato non basta
 serve un BANCO di FILTRI ADATTATI a diverse Doppler

- Quanti filtri ed a quali Doppler?

- In frequenza andamento sinc con larghezza $1/\tau_p$
- Quindi ne servono $2V_{max} * \tau_p$
- Posso centrarli alle frequenze k/τ_p , $k=0, \pm 1, \pm 2, \dots$

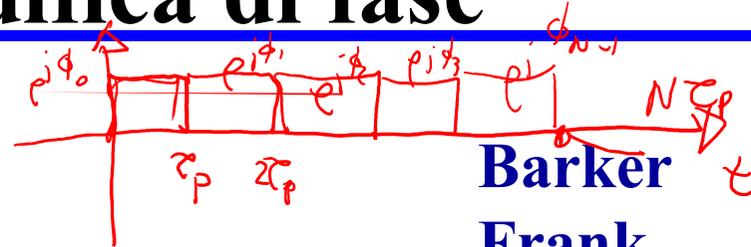
$$\frac{2V_{max}}{\frac{\lambda}{2} \frac{1}{\tau_p}} = \frac{4V_{max}\tau_p}{\lambda}$$



Forme d'onda con codifica di fase

$$s_0(t) = \frac{1}{\sqrt{N\tau_p}} \sum_{n=0}^{N-1} s_{0n}(t - n \cdot \tau_p)$$

$$s_{0n}(t) = e^{j\phi_n} \text{rect}_{\tau_p} \left(t - \frac{\tau_p}{2} \right) = \begin{cases} e^{j\phi_n}, & 0 \leq t \leq \tau_p \\ 0, & \text{altrove} \end{cases}$$



Barker

Frank

P3 e P4

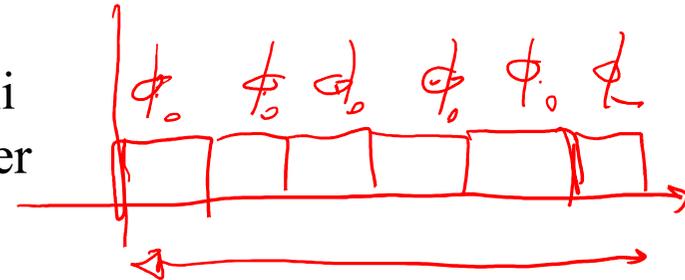
P(n,k)

- **Codici bi-fase:**

0, 180°

- facili da implementare
- permettono buon controllo dei lobi laterali
- non forte tolleranza alla frequenza Doppler

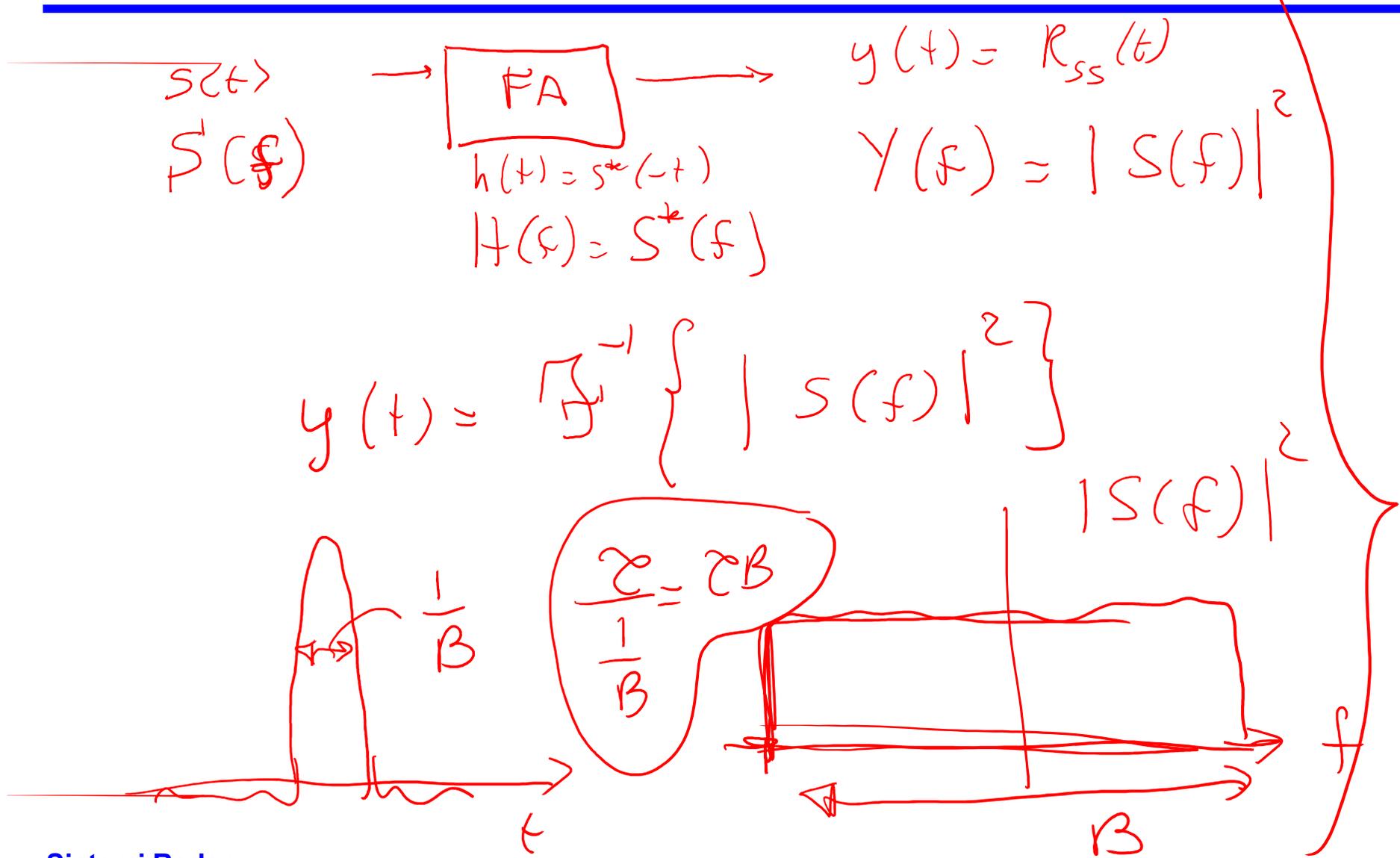
$N\tau_p$

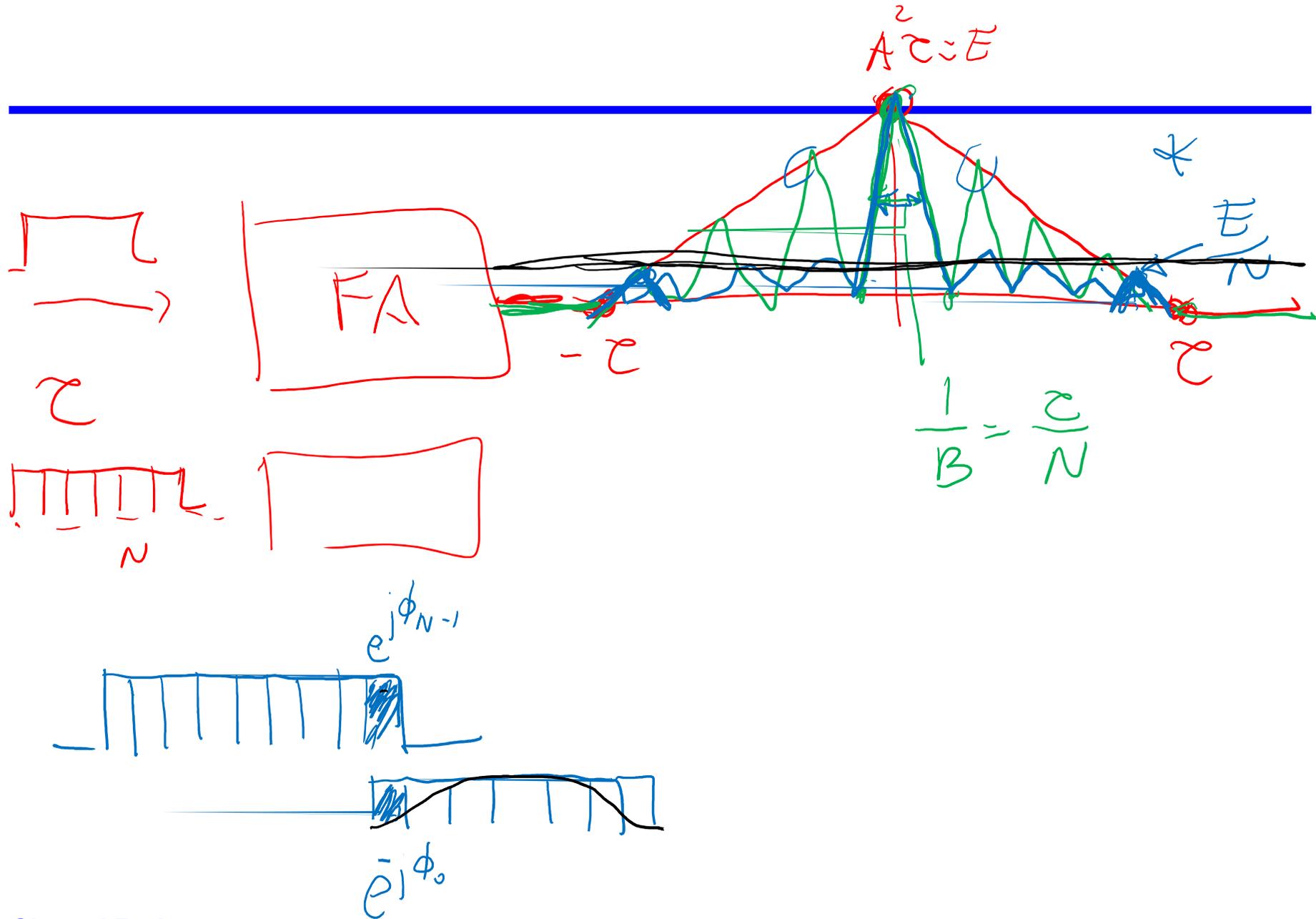


- **Codici poli-fase:**

- tendono ad avere migliore tolleranza alla frequenza Doppler
- tendono a permettere un miglior controllo dei lobi laterali

$N\tau_p$



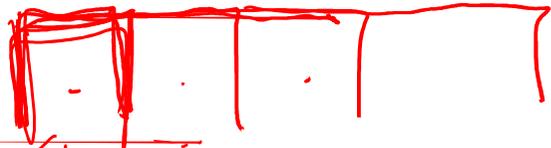
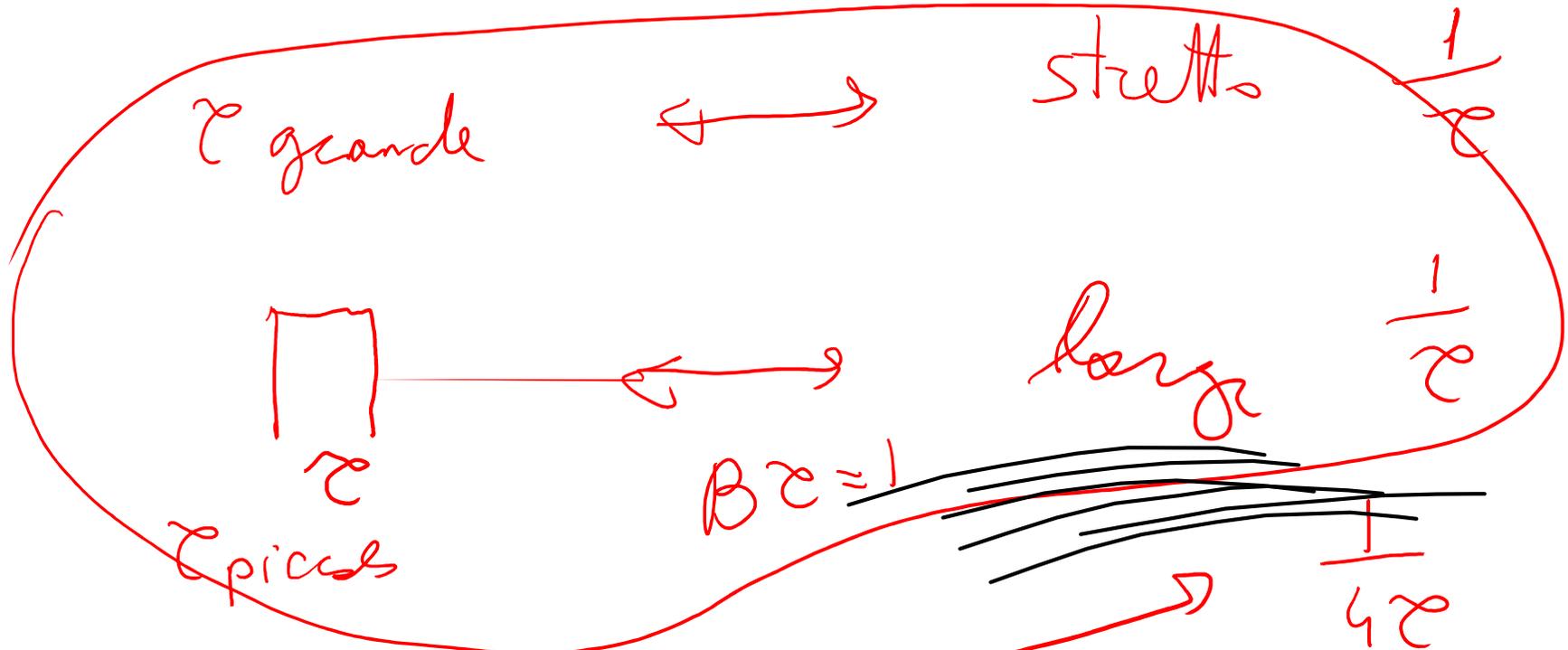


Sistemi Radar

$\Delta(t)$

$S(f)$

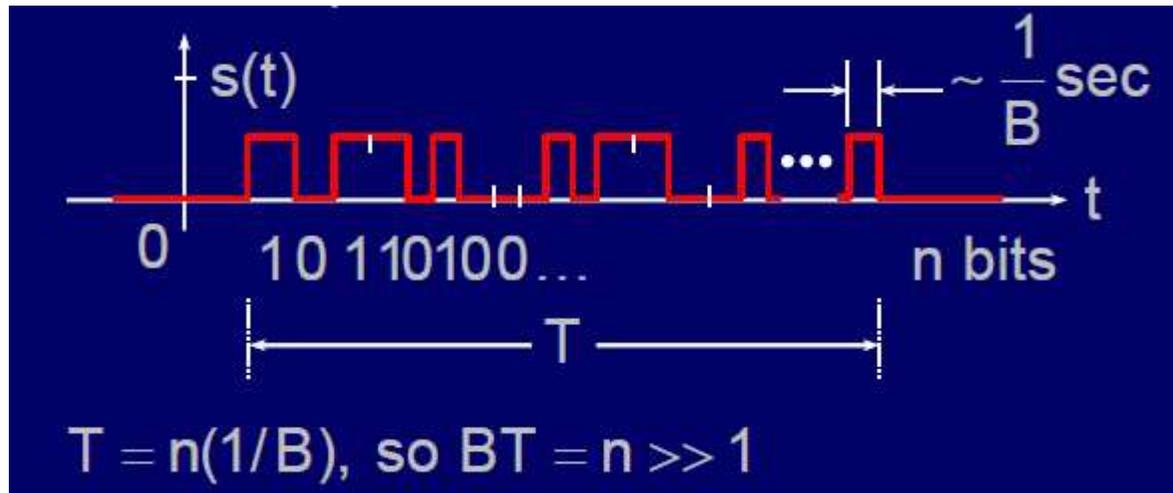
$$\text{rect}_\tau(t) \longleftrightarrow \tau \text{sinc}(\pi f \tau)$$



$$RC = N \tau \cdot \frac{1}{B} = N$$



Forme d'onda con codifica di fase



- **Se codifica di fase (0,1) \rightarrow (1,-1)**

- Rapporto di compressione = lunghezza della sequenza n
- modulo costante
- Taglio a ritardo zero

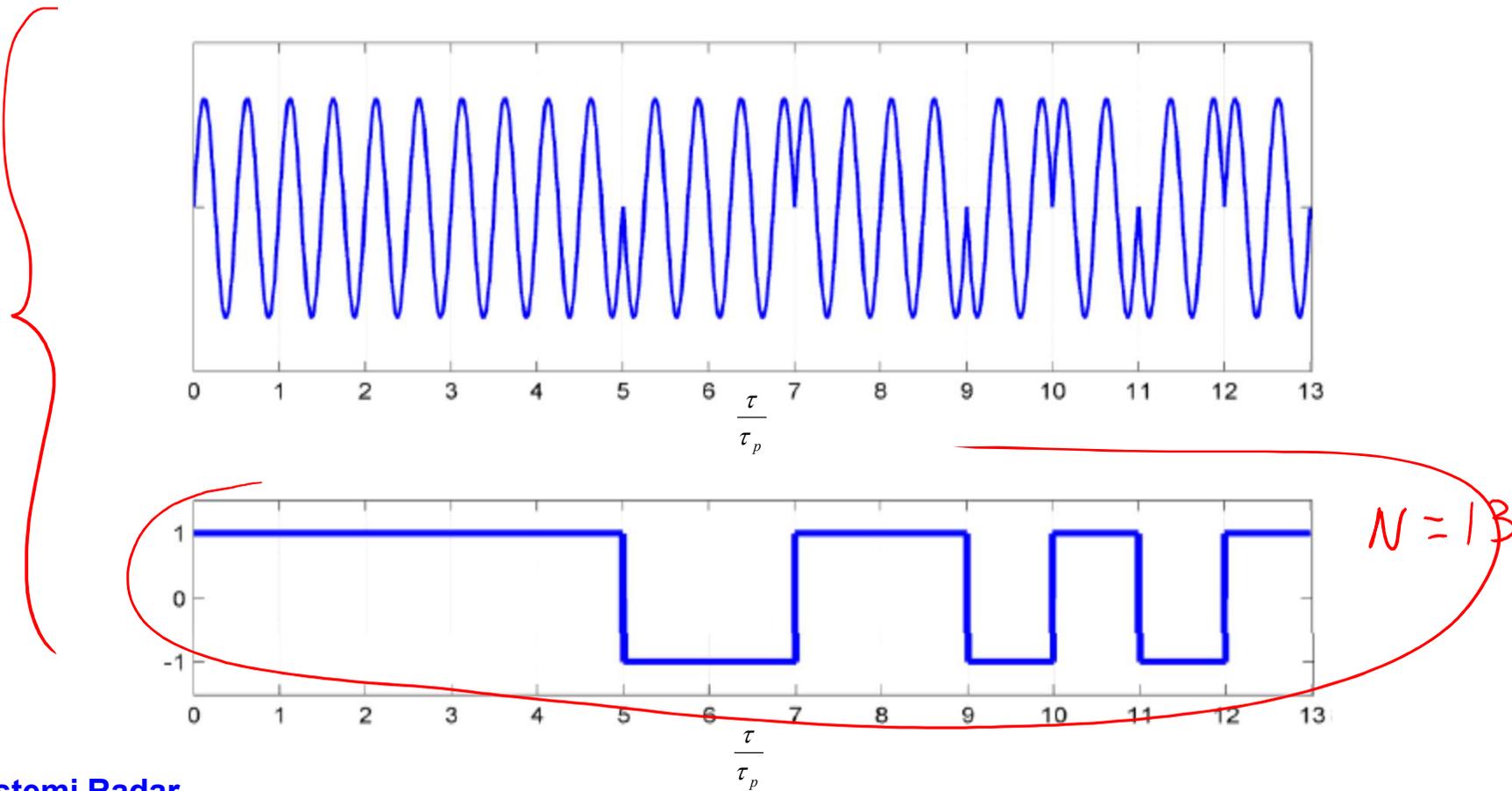
$$T = N \tau_p$$

$$|\chi(0, \nu)| = \left| \int_{-\infty}^{\infty} |s_0(t)|^2 e^{j2\pi\nu t} dt \right| = \left| \frac{1}{n\tau_p} \int_0^{n\tau_p} e^{j2\pi\nu t} dt \right| = \left| \sin c(\pi\nu n\tau_p) \right| = \left| \sin c(\pi\nu T) \right|$$

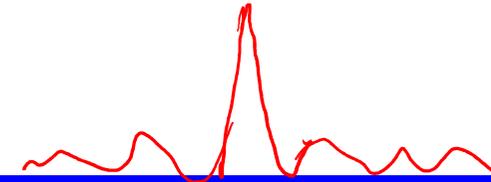
Codici Binari

- La fase della portante ad RF commuta fra due valori di fase distanti di 180°

Può essere descritta usando sequenze di +1 e -1:



Codici di Barker



Sono codici binari di lunghezza N , caratterizzati da Funzione di AutoCorrelazione (ACF) con lobi laterali in modulo $\leq 1/N$

- Esistono solo poche sequenze con queste caratteristiche:

Lunghezza N	codice	PSR (dB)	ISLR (dB)
2	+ -	6,0	3,0
2	++	6,0	3,0
3	++-	9,5	6,5
3	+ - +	9,5	6,5
4	++-+	12,0	6,0
4	+++ -	12,0	6,0
5	+++ - +	14,0	8,0
7	+++ - - + -	16,9	9,1
11	+++ - - - + - - - + -	20,8	10,8
13	+++++ - - + - - + - + -	22,3	11,5

0
→

→

Sistemi Radar

$20 \log_{10} N$

Calcolo ACF del codice di Barker da 7

Table 8.3 The Autocorrelation Sequence of a Barker Code of Length 7

$\{u_n\}$		+	+	+	-	-	+	-						
$\{u_{N-n+1}^*\}$														
-		-	-	-	+	+	-	+						
+			+	+	+	-	-	+	-					
-				-	-	-	+	+	-	+				
-					-	-	-	+	+	-	+			
+						+	+	+	-	-	+	-		
+							+	+	+	-	-	+	-	
+								+	+	+	-	-	+	-
Output sequence		-1	0	-1	0	-1	0	+7	0	-1	0	-1	0	-1

Da N. Levanon, "Radar Principles"

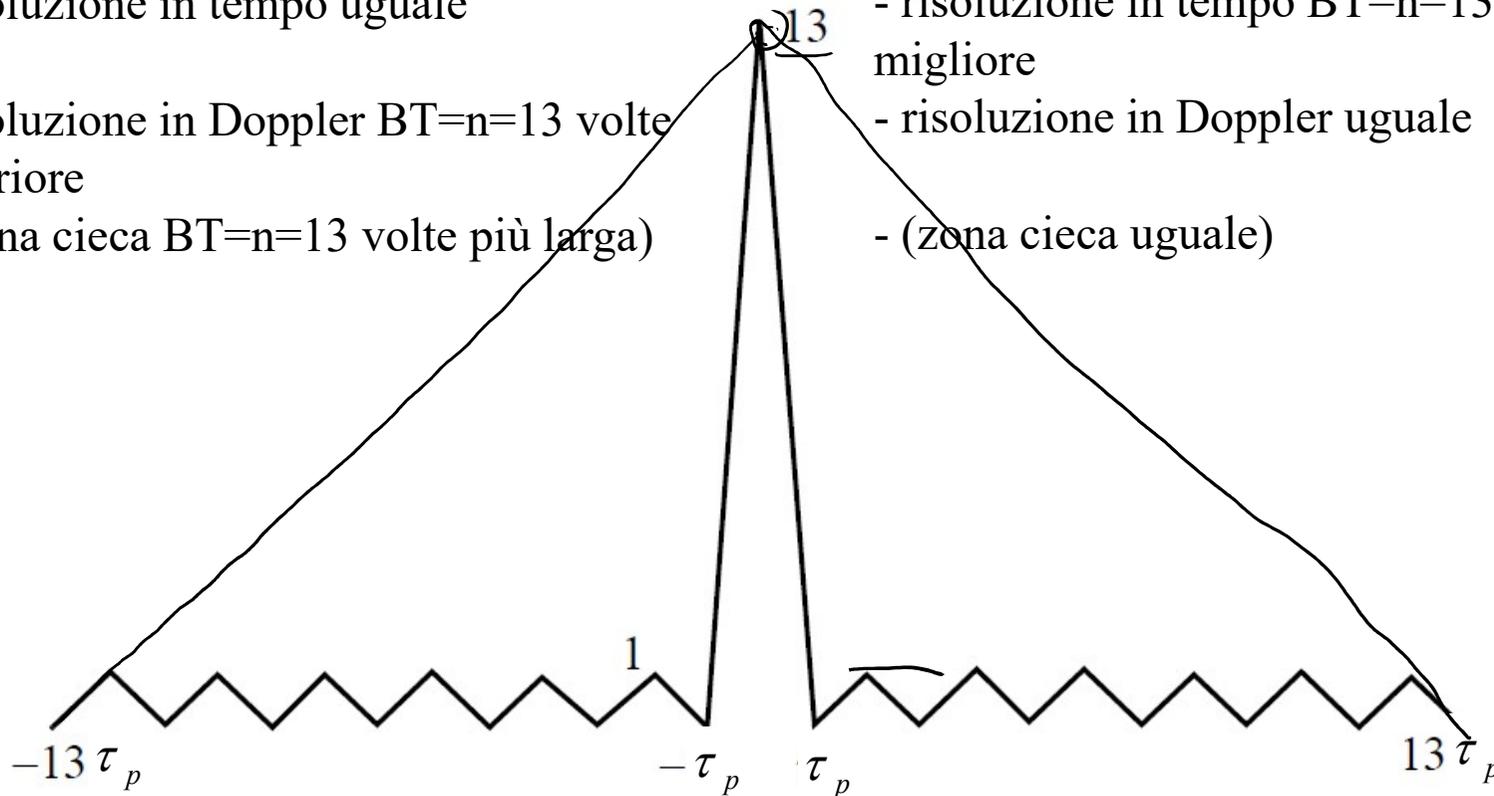
ACF del codice di Barker da 13

Rispetto ad impulso non modulato τ_p :

- Energia trasmessa $BT=n=13$ volte superiore
- risoluzione in tempo uguale
- risoluzione in Doppler $BT=n=13$ volte superiore
- (zona cieca $BT=n=13$ volte più larga)

Rispetto ad impulso non modulato $T=n\tau_p$:

- Energia trasmessa uguale
- risoluzione in tempo $BT=n=13$ volte migliore
- risoluzione in Doppler uguale
- (zona cieca uguale)

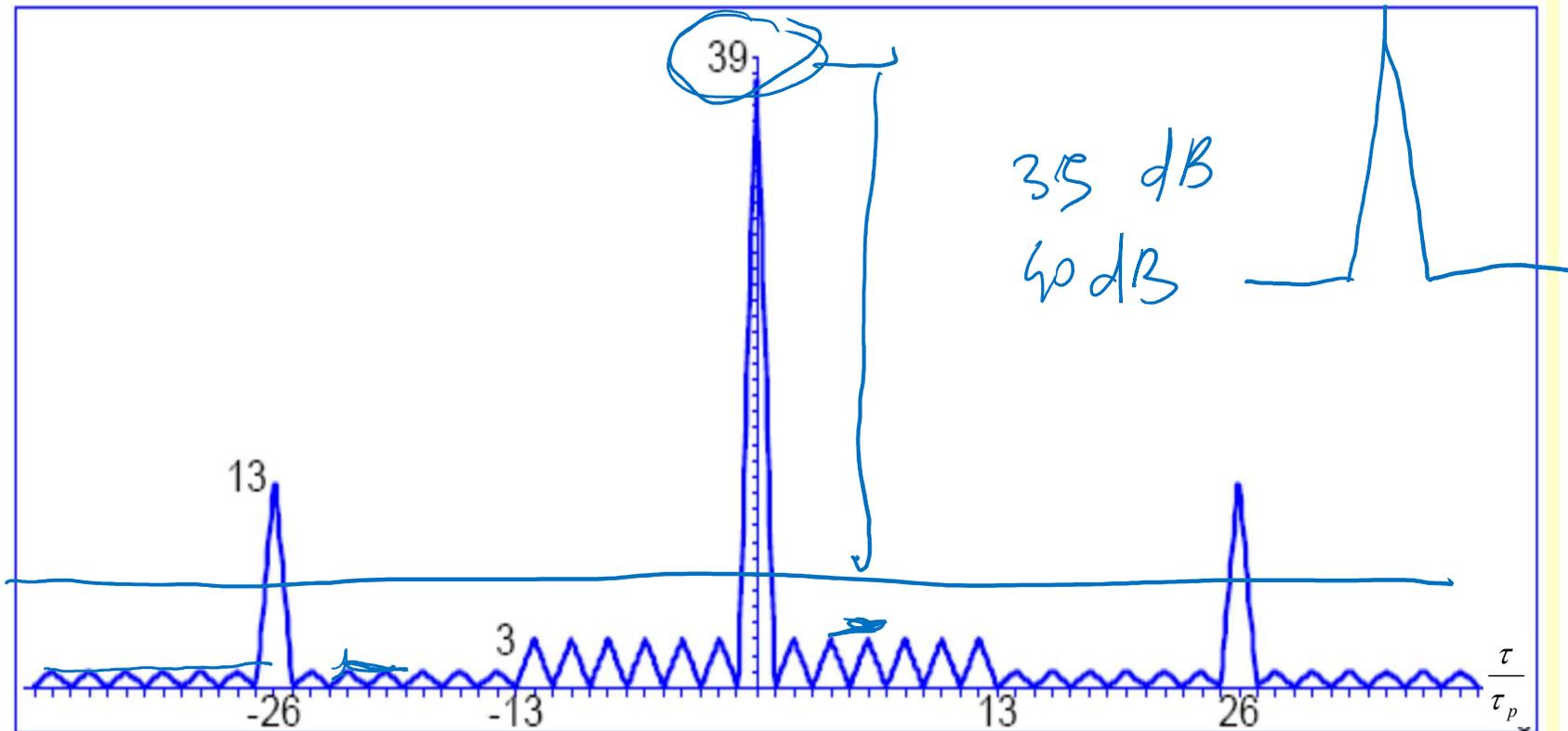


Sistemi Radar

Codici di Barker innestati

- Si possono innestare codici di barker fra loro:
- Esempio di ACF per combinazione di Barker 13 con Baker 3

11111-1-111-11-11 11111-1-111-11-11 -1-1-1-1-111-1-11-11-1



Codici di Barker Polifase

- Usare valori di fase generici (non binari) può portare a lobi più bassi e sequenze lunghe
- Il lobo laterale più lontano dal picco vale sempre 1 (sia per codici binary che polifase)
- Le sequenze polifase con PSLR massimo (escluso il lobo laterale esterno) sono chiamate **sequenze di barker generalizzate** o **sequenze di Barker Polifase**

Codici di Barker Polifase

- **Caso 1:** valori di fase pari alla radice k -esima dell'unità
(es: $k=2$ codici di Barker, $k=6$ sextic Barker codes).
- **Caso 2:** senza restrizione sui valori di fase quantizzati utilizzabili
(sequenze note per valori di $M \leq 36$)

Codici di Barker Polifase (I)

Espressione in forma normalizzata:

i primi due elementi di ogni codice valgono 0 e non sono riportati in tabella.

M	Peak sidelobe	Phase values [°]
4	0.5	104 313
5	0.77	73 225.3 90.6
6	1	58.2 175.9 354.1 234.2
7	0.522	106.4 93 316.7 60.5 270.7
8	0.662	72.1 28.6 294.3 151.7 251.2 63.3
9	0.430	38.7 41.5 270.2 215.1 40.5 160.7 334.3
10	0.832	60.2 132.1 142.8 18.3 10.7 230.8 22.9 242.9
11	0.892	34.1 259 266.5 327.9 158.4 13.7 22.7 221.5 94.5
12	0.908	104.8 163 170.9 344.3 241 185.5 282.2 147.6 209 78.7
13	0.721	115.8 114.8 248.4 213.4 123.1 154.9 140.2 12.7 149.6 303.5 121.6
14	0.968	66.8 133.5 202.2 100.4 37.5 235.8 167.2 86 168.7 33.5 143.1 13.3
15	0.805	17.8 5.5 5.4 142.4 212 298.1 123.9 91.6 1.3 206 314.2 156.5 23.9
16	0.933	26.5 38.5 97.3 49.4 305.8 286.5 197 65.7 241.3 137.5 319.1 47.9 178.5 303
17	0.733	5.3 18.5 278.4 307.6 67.3 149 207.5 70.6 301.2 282.8 137.3 6.5 120.5 327.9 186
18		(?)
19	0.980	53.3 24.7 90 79.2 232.5 8 331.4 99 240 318.4 159.8 307.8 161.3 137.1 31.8 338.2 217
20	0.979	99.1 125.8 233.1 251.4 133.9 144 354.8 304.5 192.1 302.5 219.5 161.7 283.8 145.4 250.2 106.1 228.4 107

Codici di Barker Polifase (II)

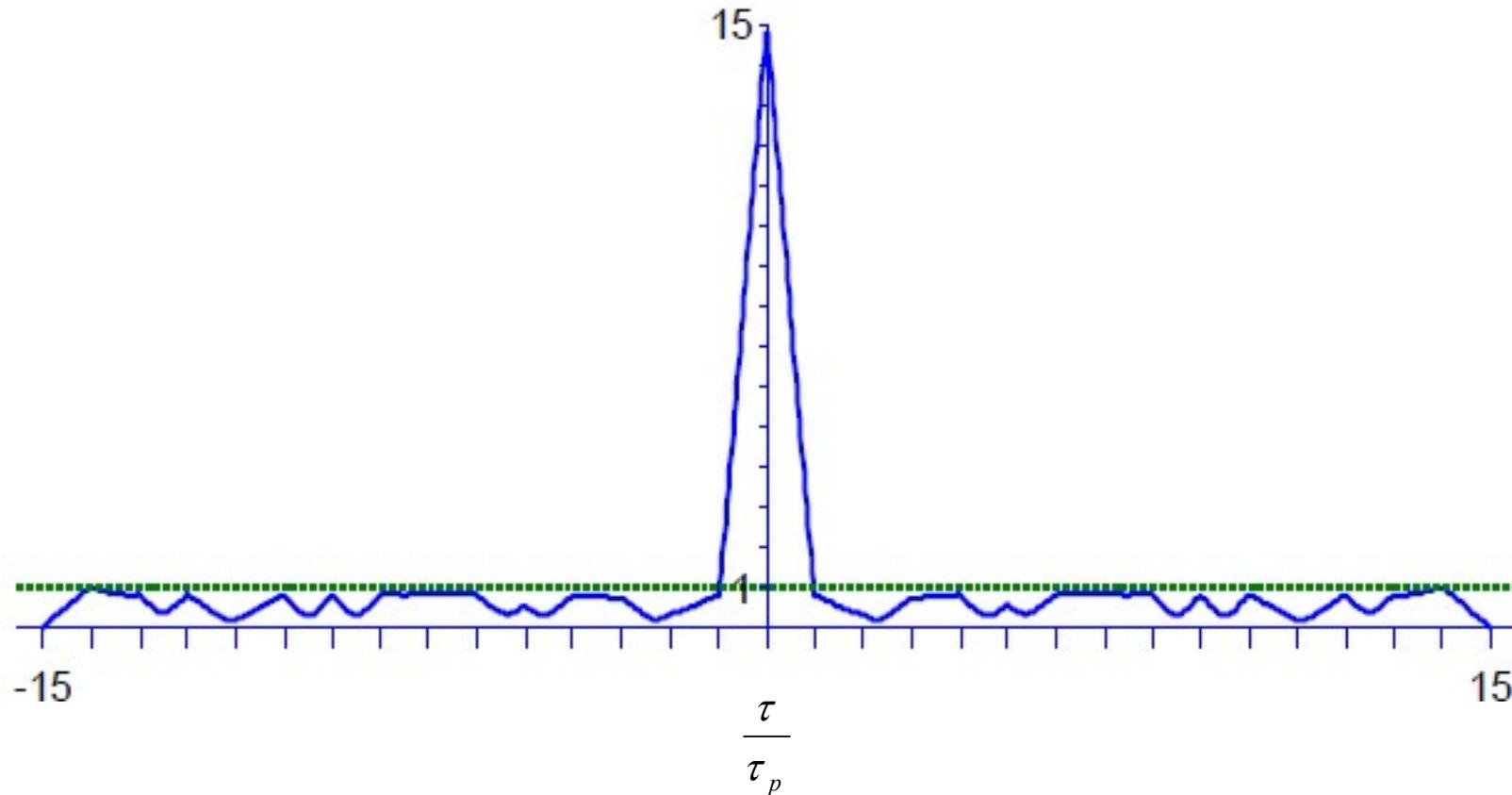
Espressione in forma normalizzata:

i primi due elementi di ogni codice valgono 0 e non sono riportati in tabella.

22	0.995	23.8 53.7 82.1 74.5 349.3 265 314 247.2 147.2 74.6 285.7 160.2 335.4 78.5 317.2 148.4 248.6 344.3 87.8 208.7
23	0.912	7.4 276 286.4 253.9 256.7 351.7 58.4 60.2 226.3 353.1 100.5 168.6 41 208.5 347.8 219.2 125.9 349.7 315.3 182.1 56.3
24	0.997	5 316.4 257.1 216.5 202.4 319 311.1 356.9 296.8 111.2 36.1 280.8 136.9 10.1 115.7 259.2 134.3 268.0 28.0 142.3 208.4 333.8
25	0.936	81.9 65 316.3 273.1 326.3 339.8 62.7 18.8 270.5 198 98.8 126.6 206.5 350.7 105.9 270.8 295.4 162.3 334.2 155.5 339.8 147.7 4.4
26	0.879	51.3 117.1 138.2 265.4 267 175.4 117.8 260.2 200 136.1 154.2 179 75.8 341 187.4 307 194.4 92.5 190.2 17.2 110 250.3 38.7 199.7
27	0.985	10.6 21.9 28.7 324.7 308.4 280.6 118.4 99.2 112.2 284.5 200.6 313.8 116.3 326.7 184.8 53.4 8.8 193.9 97.1 240.9 335.3 103 228.6 332 93
28	0.950	46.9 84.3 166.3 145.7 199.8 105.1 116.6 58.7 109.7 325.9 24.3 189.9 21.4 196.2 58.8 326.5 129.2 259 306.7 123.5 111.2 312.7 298.5 173.8 97.9 327.8
29	0.871	6.9 318.2 239.9 264.7 239.2 160.4 301.5 327.5 18.7 319.7 84.9 108.6 224.1 6.3 31.4 184 167.8 89.9 325.2 227.5 145.4 329.9 91.6 263.7 94 252.9 59.6
30	0.998	33.1 34.6 33.7 11.9 300.1 281.5 26.5 54.2 155.6 211.9 231.6 134.4 76 317.7 275.8 67.6 299 184.6 72.6 153.8 6.6 262.6 94.1 242.8 359.1 149.7 306.4 71.5
31	0.935	28.4 117.7 165.1 236.5 308.7 305 236.5 216.4 327.4 279.5 211.3 247.2 192 95.4 17 273 52.8 331.1 224 303.7 147.2 21.7 245.6 29.3 145.5 297.1 62.4 190.8 7.8
32	0.996	13.5 16.5 90.5 110 95 60.5 333 307 289 281.5 85.5 164 248.5 335 171.5 76 64 221.5 298 110 37 272.5 179.5 19.5 179 288 82.5 292 133 329.5
33	0.990	143 153.5 339 332.5 180.5 133.5 19 108.5 166 216.5 225.5 227.5 318.5 238.5 184.5 226 141.5 113.5 75 36 185.5 327 226.5 108.5 302.5 116.5 273 350 188 356.5 164.5
34	0.997	11 1 307 245 200 184 231 293 300 348 45 227 247 57 335 1 127 249 68 91 315 221 57 116 238 58 287 127 273 127 5 216
35	0.999	93.2 65.4 166.4 132.4 344.1 279.4 337.6 301.3 197.6 56.2 36.8 9.2 325.8 334.3 24.4 157.8 291.1 301.1 148.4 112.9 141.3 296.6 128.7 125.4 341.4 129.9 244.6 73.8 321.5 157.6 300.7 107.5 254.4
36	0.969	82 118 228 228 58 60 154 108 20 234 212 262 236 196 220 116 12 226 178 122 126 76 266 114 256 108 320 100 266 30 124 246 60 186

Sistemi Radar

ACF del codice di Barker Polifase con M=15



Codici binari con PSL massimo (I)

M	PSL	Sample code
6	2	110100
8	2	10010111
9	2	011010111
10	2	0101100111
12	2	100101110111
14	2	01010010000011
15	2	001100000101011
16	2	0110100001110111
17	2	00111011101001011
18	2	011001000011110101
19	2	1011011101110001111
20	2	01010001100000011011
21	2	101101011101110000011
22	3	0011100110110101011111
23	3	01110001111110101001001
24	3	011001001010111111100011
25	2	1001001010100000011100111
26	3	10001110000000101011011001
27	3	010010110111011101110000111
28	2	1000111100010001000100101101
29	3	10110010010101000000011100111
30	3	100011000101010010010000001111
31	3	0101010010010011000110000001111
32	3	00000001111001011010101011001100
33	3	01100110010101010010110000111111
34	3	1100110011111111100001101001010101
35	3	00000000111100101101010101100110011
36	3	001100110001010010100000100000111110

$\frac{1}{N}$
 $\frac{2}{N}$
 $\frac{3}{N}$

G. Coxson &
 J Russo,
 IEEE Trans
 on AES
 Jan 2005

Sistemi Radar

Codici binari con PSL massimo (II)

3/48

37	3	0010101110100001001110110111110011110
38	3	00000000111100001101001010101001100110
39	3	001001100110101000010111110111100111100
40	3	0010001000100011110111000011101001011010
41	3	000111000111010100101001000000001101100100
42	3	000100010001000111101110000111010010110100
43	3	0000000010110110010101011001100111000011100
44	3	0000111111011001110110010110010101011010111
45	3	00010101011110000110011000110110110111110110
46	3	00001111000000110011110111101101100101010110
47	3	000011010011101001111110100001010001100110001000
48	3	00010101011010110110000111100110010011111110011
49	4	0000100101010101111101100011110011110010001101111
50	4	00001001011000011000111010101111000010011001101111
51	3	000111000111111100010001100100010010101001001011
52	4	0000100101000101101011100000111100110010010001101111
53	4	0000100110010101010100111111100011010010110001101111
54	4	000010011001101010001010000001010010110011110001101111
55	4	0000100110000100110101010100001111000110010010001101111
56	4	00001001100110111010101011001011010001111011110001101111
57	4	000010010011010001010100011101101011000100011110001101111
58	4	0000100011110011100101010001011100100111101101011001101111
59	4	00001001001110100111000000100101000101000011101110001101111
60	4	000010101011100011011111000011001001011100110010010100101111
61	4	0000001011011010001001100010011000111100111101010001101010000
62	4	00000000101101011001100110001101001100101100000111010001010000
63	4	000010011001111010110100010010001110001011001010111110001101111
64	4	010000001001000010100010111010011110011000110010001101111000010
65	4	000000010110111100000010110000110110011011110011100101010001010000
66	4	000000011010011011010001010100011100111001111100010010101101000010
67	4	0100000010100000110110010011010101100011110100100001001110011000010
68	4	00000000100111100100100111100011011001100010101010001110101001010000
69	4	000100110111111011011000010011010100000111010000100011000111000010101
70	4	0110100001001100111011010011100011000010010011111011011101010101111110

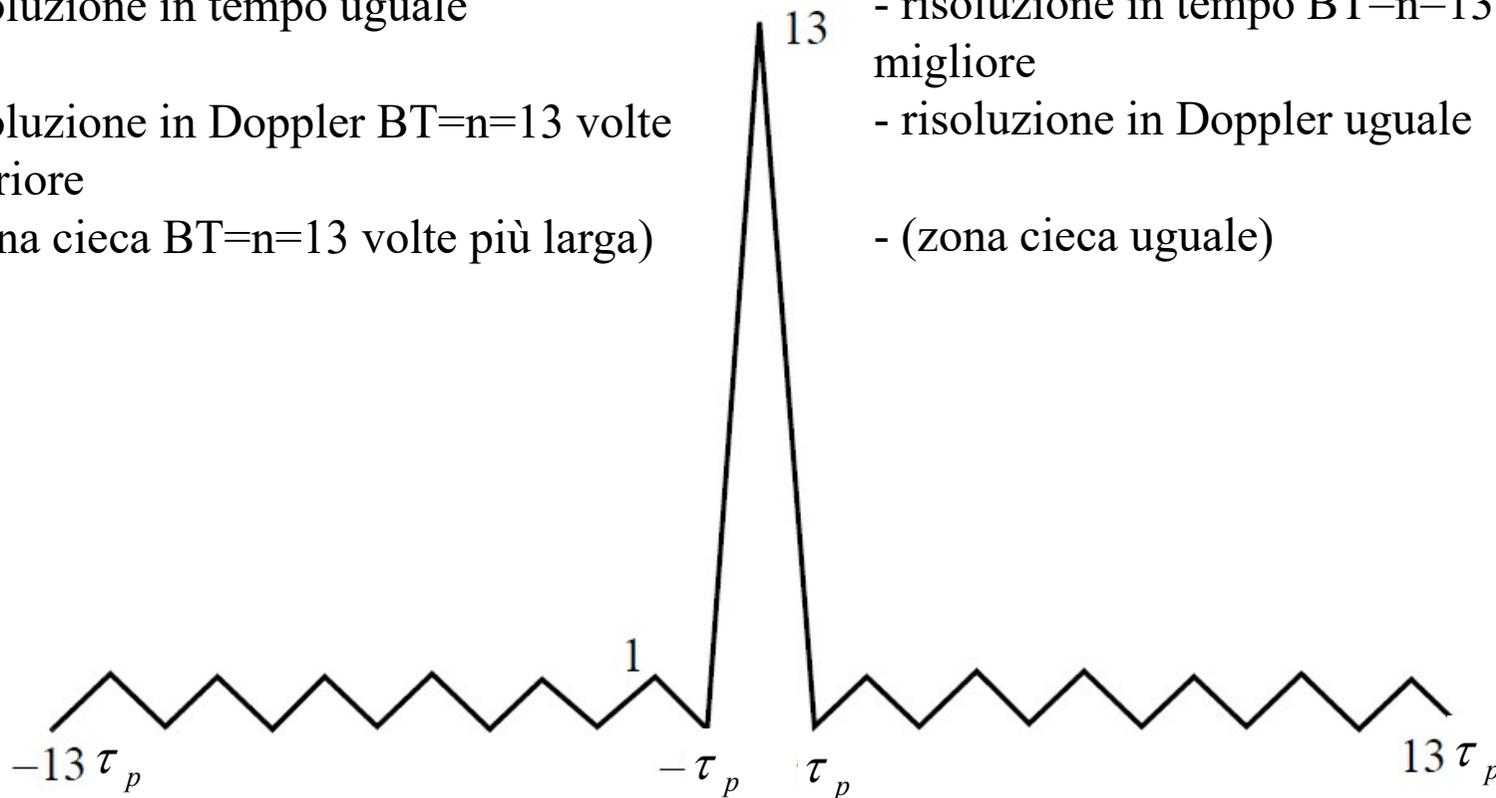
ACF del codice di Barker da 13

Rispetto ad impulso non modulato τ_p :

- Energia trasmessa $BT=n=13$ volte superiore
- risoluzione in tempo uguale
- risoluzione in Doppler $BT=n=13$ volte superiore
- (zona cieca $BT=n=13$ volte più larga)

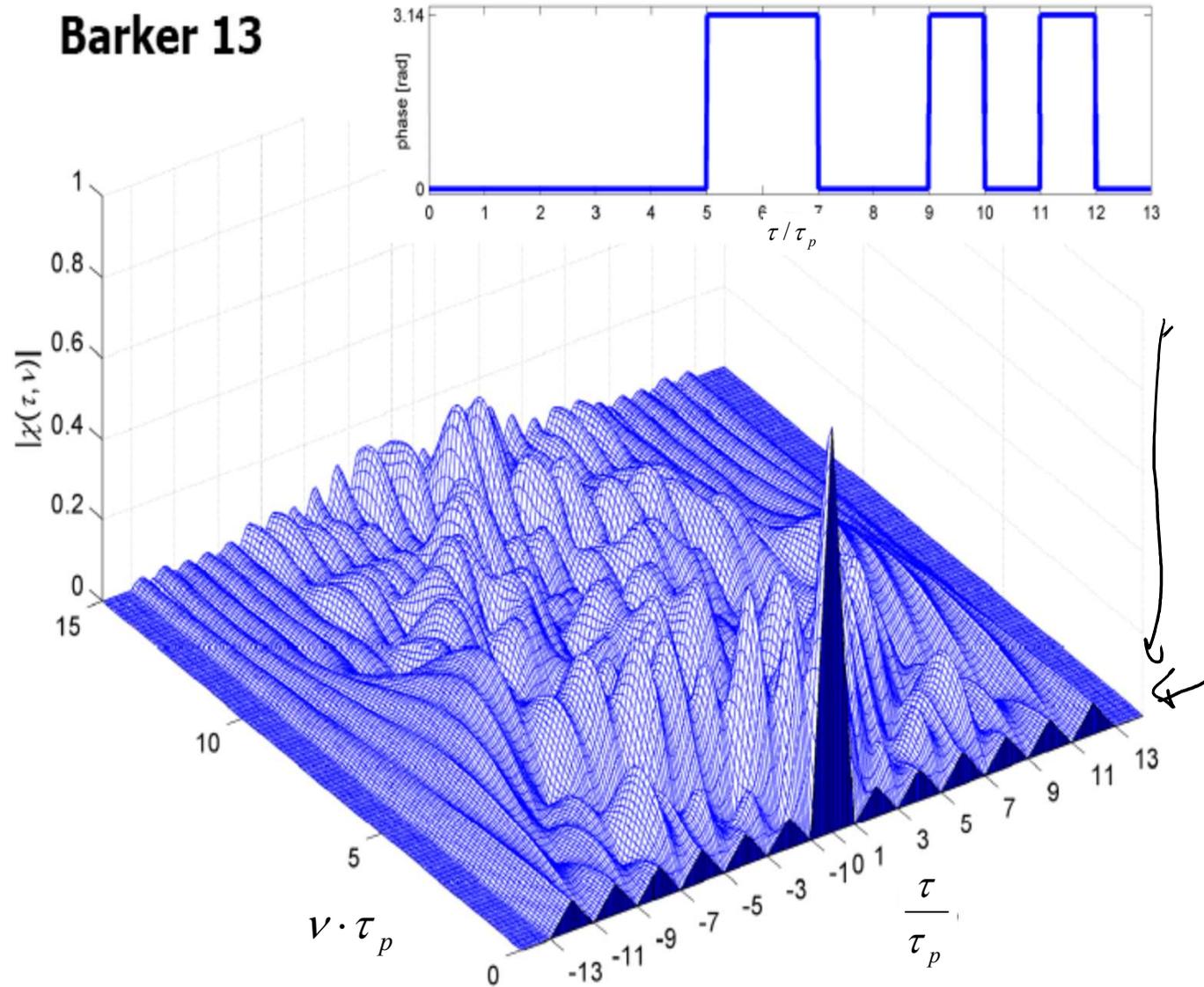
Rispetto ad impulso non modulato $T=n\tau_p$:

- Energia trasmessa uguale
- risoluzione in tempo $BT=n=13$ volte migliore
- risoluzione in Doppler uguale
- (zona cieca uguale)



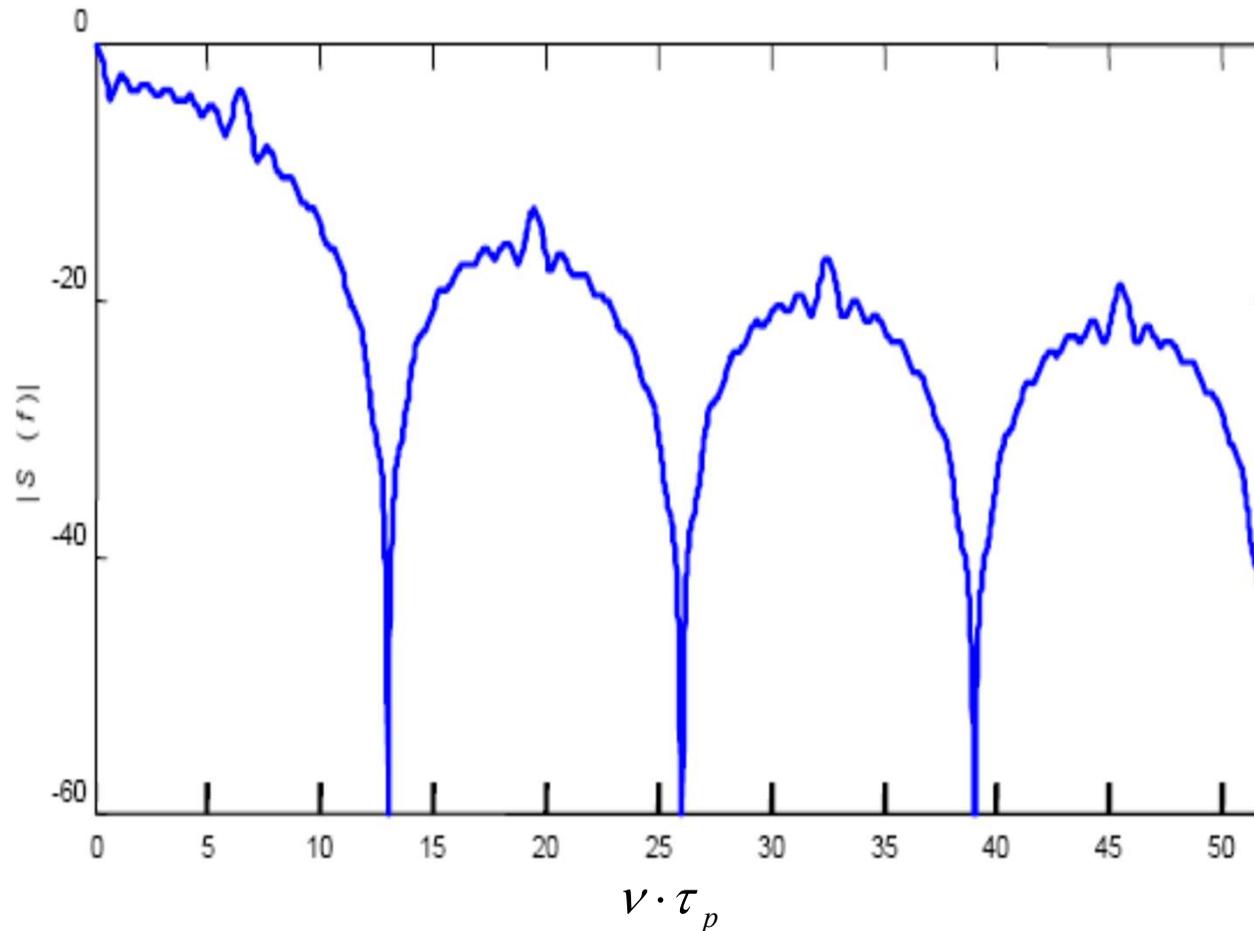
Sistemi Radar

Funzione di Ambiguità del Barker da 13 (I)



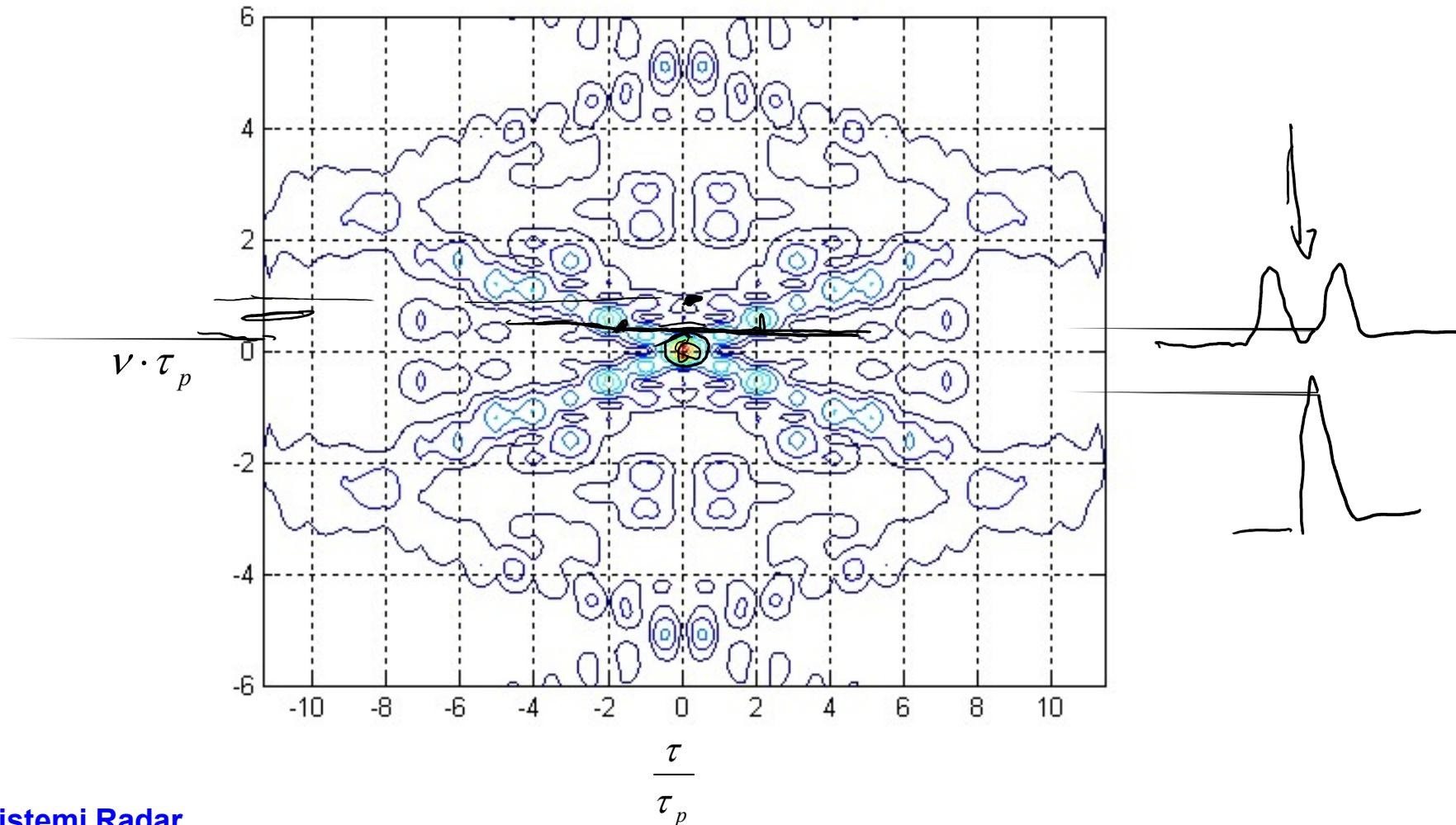
Funzione di Ambiguità del Barker da 13 (II)

- Sezione a ritardo nullo della funzione di ambiguità



Funzione di Ambiguità del Barker da 13 (III)

- Sezioni a livello costante



Sistemi Radar

Mismatched filter per il Barker 13

$-20 \log_{10}(13) = -22.28 \text{ dB}$

Mismatched filter for Barker 13

fmincon.m

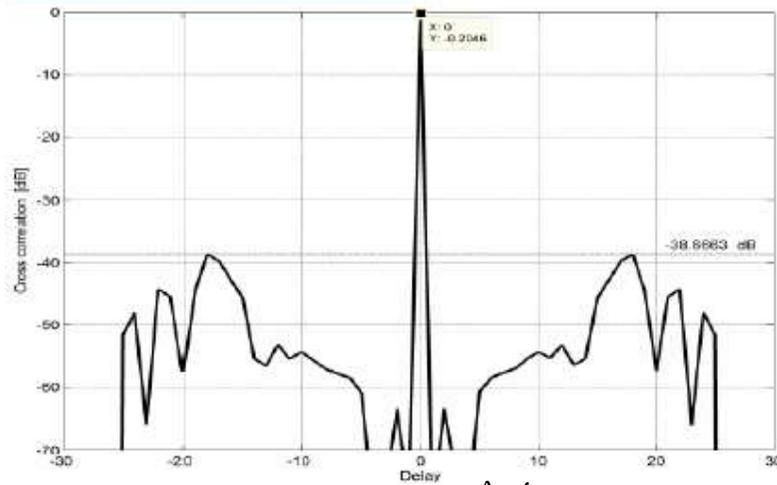


Fig. 1 Output of mismatched min ISL filter with $M = 39$, for a Barker 13 signal

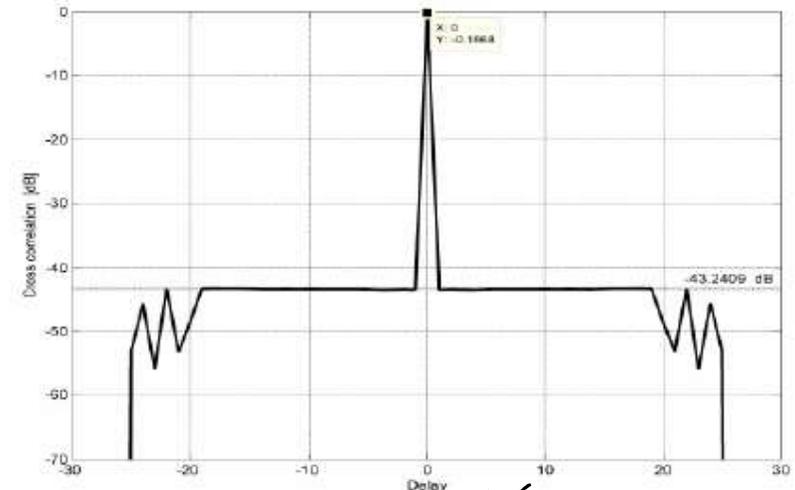
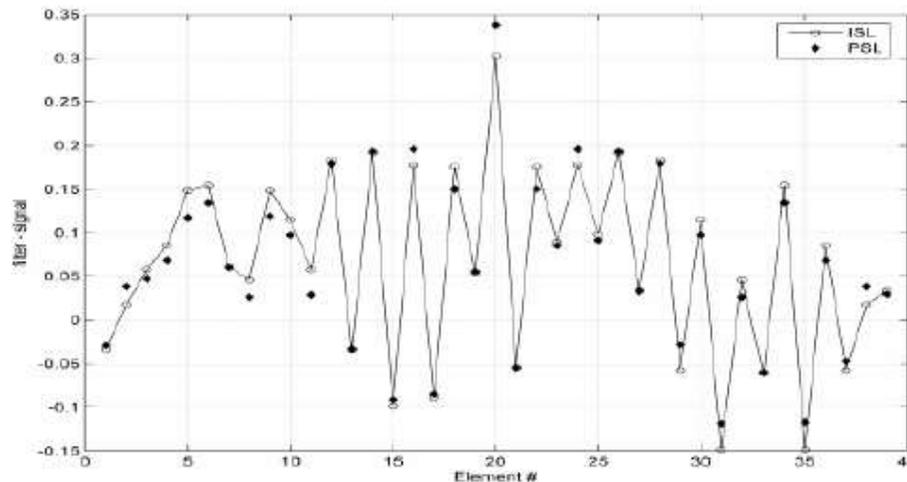


Fig. 2 Output of mismatched min PSL filter with $M = 39$, for a Barker 13 signal



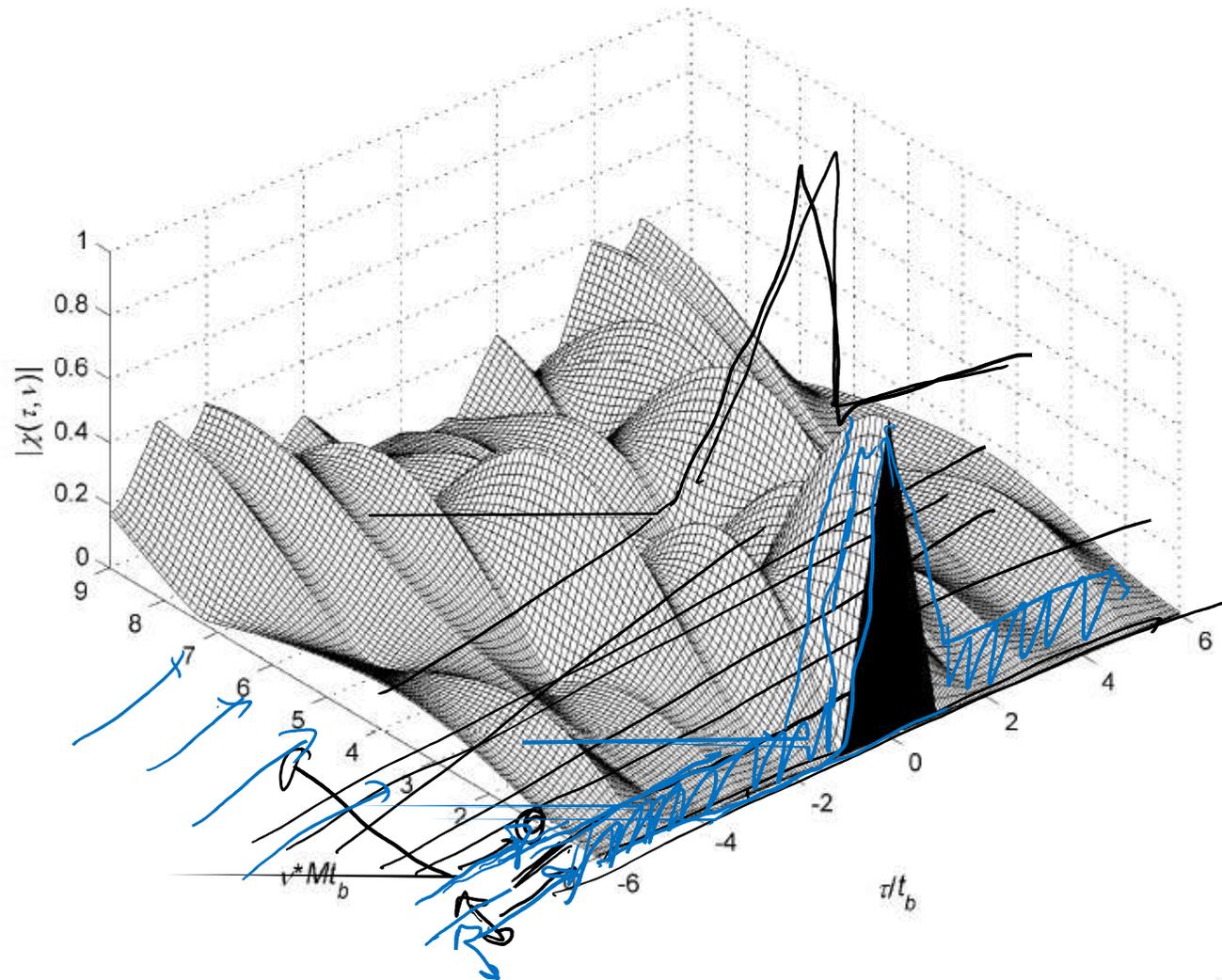
Deviation of mismatched filter elements from Barker 13 signal values (The signal occupies elements 14 to 26)

N. Levanon : "Cross-correlation of long binary signals with longer mismatched filters", *IEE Proc. - Radar, Sonar and Navigation*, 152 (6), 372-382, 2005

Mismatched filter per il Barker 13

Signal	Reference
0	-0.0293
0	0.0383
0	0.0471
0	0.0684
0	0.1171
0	0.1343
0	0.0603
0	0.0262
0	0.1188
0	0.0972
0	0.0285
0	0.1789
0	-0.0330
-1	-0.8068
-1	-1.0913
-1	-0.8040
-1	-1.0850
-1	-0.8501
1	1.0554
1	1.3379
-1	-1.0554
-1	-0.8501
1	1.0850
-1	-0.8041
1	1.0914
-1	-0.8069
0	0.0331
0	0.1789
0	-0.0285
0	0.0971
0	-0.1188
0	0.0262
0	-0.0603
0	0.1343
0	-0.1171
0	0.0684
0	-0.0471
0	0.0383
0	0.0292

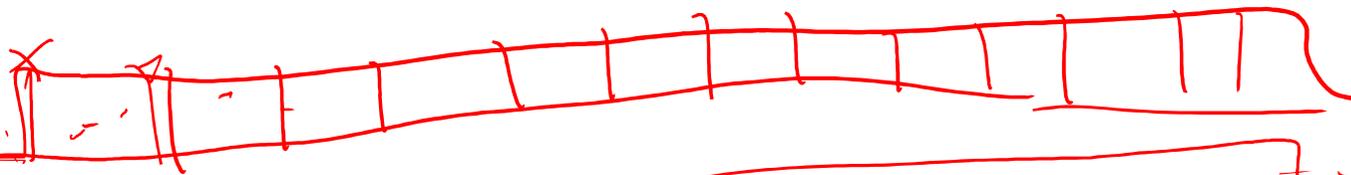
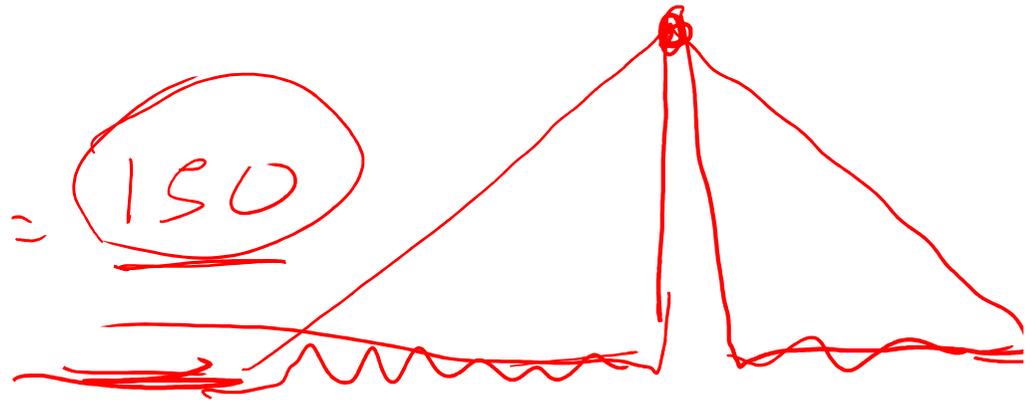
Mismatched (min PSL) filter for Barker 13



$$400 \mu s \rightarrow r_{ic} \leq \frac{400 \mu s}{2} = \underline{60 \text{ Km}}$$

400 m

$$RC = \frac{\overset{3}{\cancel{60'000}}}{\underset{2}{\cancel{400}}} = \frac{300}{2} = \underline{150}$$



10^8

Sistemi Radar