

Sistemi di Telecomunicazioni

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*Esercitazioni al calcolatore su prestazioni di
sistemi di trasmissione numerici passa-banda*


```
ClearAll["Global`*"];
<< Graphics`Graphics`
<< Graphics`Colors`
(*<<Graphics`Legend`*)
<< Statistics`ContinuousDistributions`

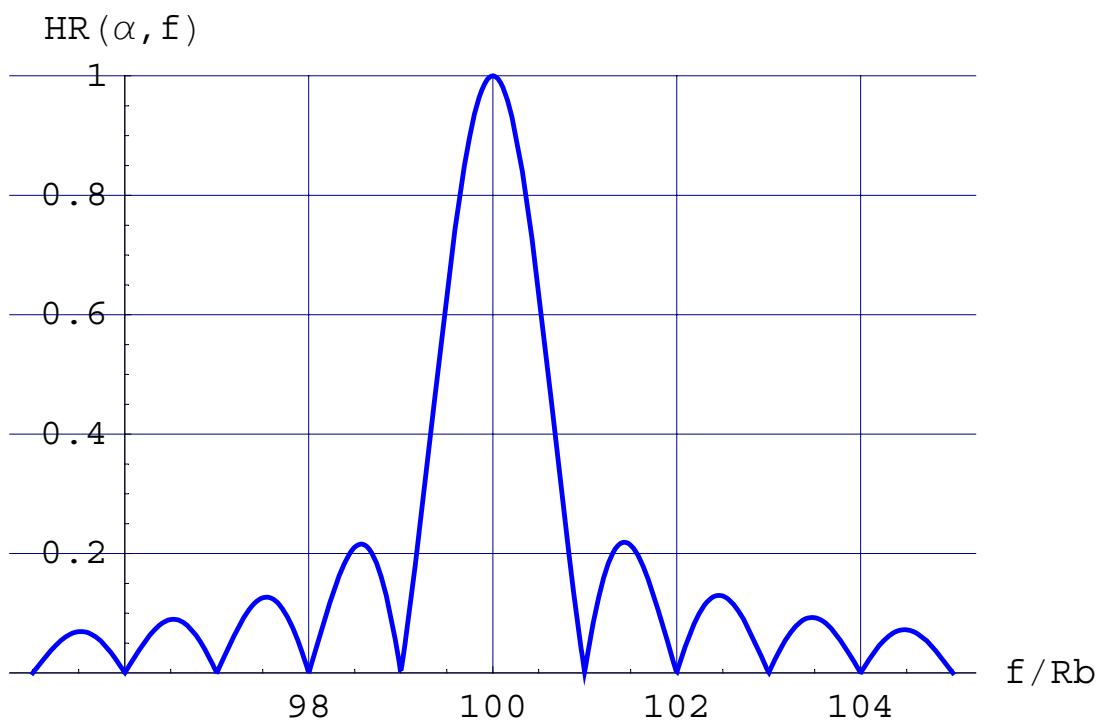
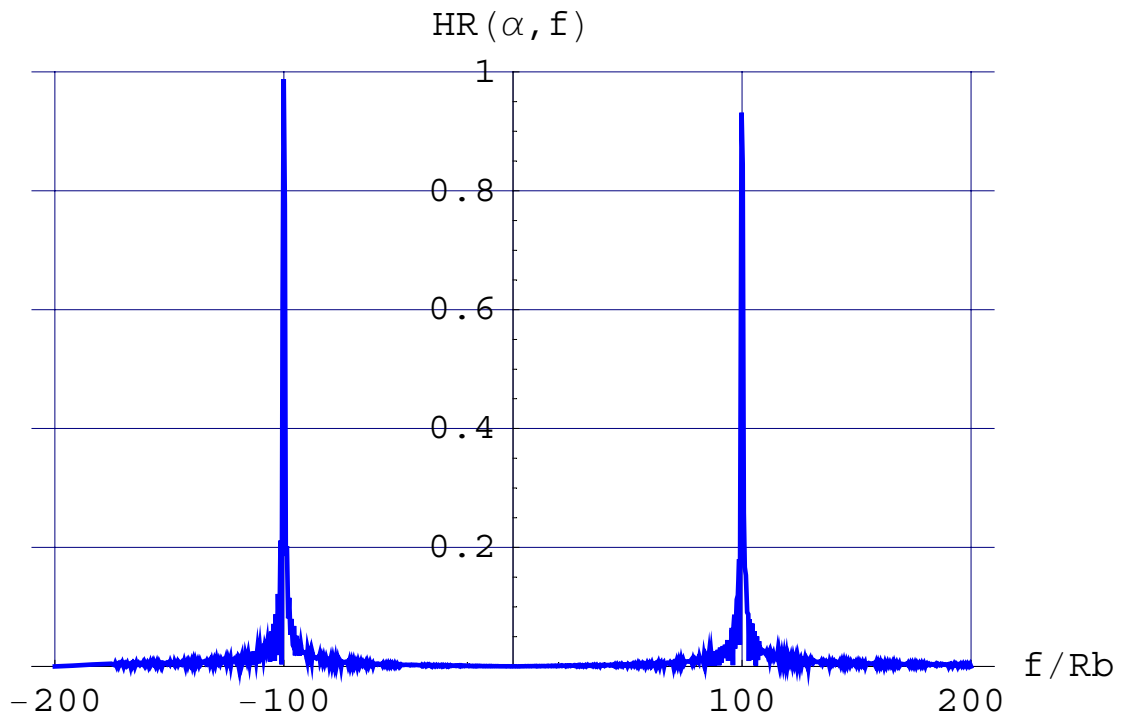
sinc[x_] := If[x == 0, 1, Sin[ $\pi x$ ] / ( $\pi x$ )]

(* BPSK su canale a banda illimitata *)
V0 := 1;
Tb := 1;
 $\varphi_0$  := 0;
f0 := 100 / Tb;
g[t_] := If[Abs[t] < 0.5 Tb, 1, 0];
x1[t_] := V0 g[t] Cos[2  $\pi$  f0 t +  $\varphi_0$ ]
x2[t_] := -V0 g[t] Cos[2  $\pi$  f0 t +  $\varphi_0$ ]

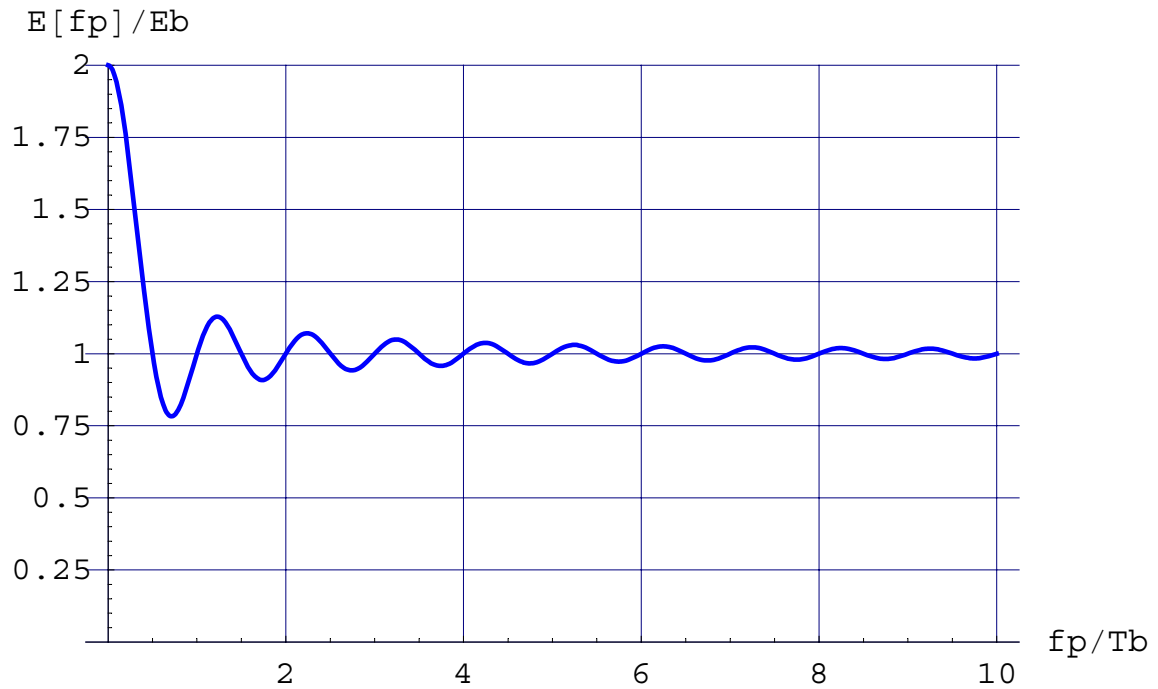
(* Filtro adattato - Matched Filter *)
G[f_] := Tb sinc[f Tb]
K := 1;
t0 := 0;
HR[f_] := K2 V0 / 2 (G[f - f0] + G[f + f0]) Exp[-i 2  $\pi$  f t0];

pHr = Plot[Abs[HR[f]], {f, -2 f0, 2 f0}, PlotStyle -> {Blue, Thickness[.005]},
  PlotRange -> {0, 1}, Frame -> False, GridLines -> Automatic,
  AxesLabel -> {"f/Rb", "HR( $\alpha$ , f)"}, TextStyle -> {FontSize -> 18}];

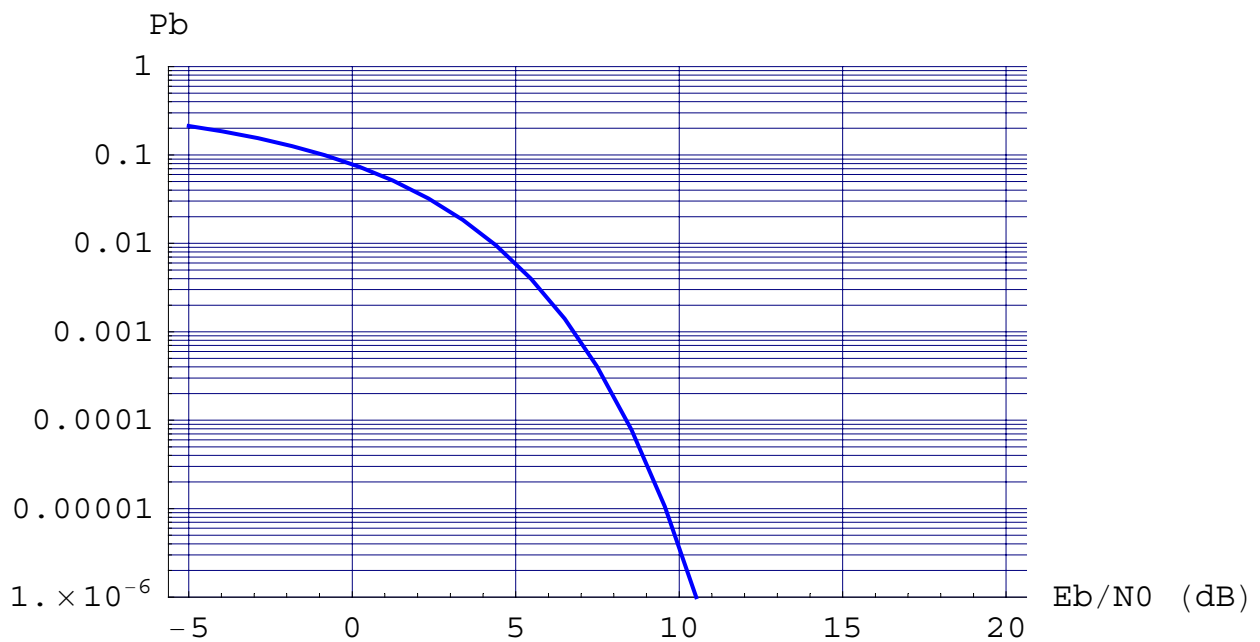
Plot[Abs[HR[f]], {f, f0 - 5 / Tb, f0 + 5 / Tb}, PlotStyle -> {Blue, Thickness[.005]},
  PlotRange -> {0, 1}, Frame -> False, GridLines -> Automatic,
  AxesLabel -> {"f/Rb", "HR( $\alpha$ , f)"}, TextStyle -> {FontSize -> 18}];
```

Null¹³

```
En[fp_] :=  $\int_{-Tb/2}^{Tb/2} V0^2 (\text{Cos}[2 \pi fp t + \varphi0])^2 dt$   
Plot[En[fp] 2 / (V0^2 Tb), {fp, 0, 10}, PlotRange -> {0, 2},  
PlotStyle -> {Blue, Thickness[.005]}, Frame -> False, GridLines -> Automatic,  
AxesLabel -> {"fp/Tb", "E[fp]/Eb"}, TextStyle -> {FontSize -> 16}];
```



```
Pb[EbN0_] := 0.5 Erfc[ $\sqrt{\text{EbN0}}$ ];  
(* EbN0=Eb/N0 con N0 monolatera,  $\rho_c=\text{Eb}/\text{N0}$  *)  
PbBPSKmfEbN0 =  
  LogPlot[Pb[10^(0.1 EbN0dB)], {EbN0dB, -5, 20}, PlotRange -> {10^(-6), 1},  
    PlotStyle -> {Blue, Thickness[.005]}, Frame -> False, GridLines -> Automatic,  
    AxesLabel -> {"Eb/N0 (dB)", "Pb"}, TextStyle -> {FontSize -> 16}];
```



```

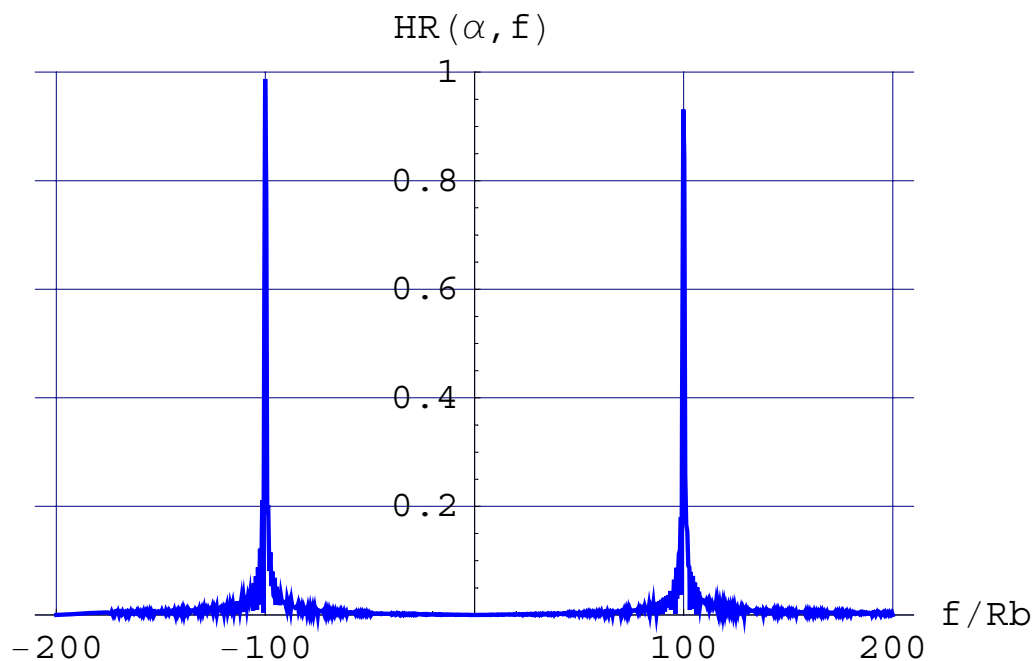
(* OOK su canale a banda illimitata *)
V0 := 1;
Tb := 1;
φ0 := 0;
f0 := 100 / Tb;
g[t_] := If[Abs[t] < 0.5 Tb, 1, 0];
x1[t_] := V0 g[t] Cos[2 π f0 t + φ0]
x2[t_] := 0

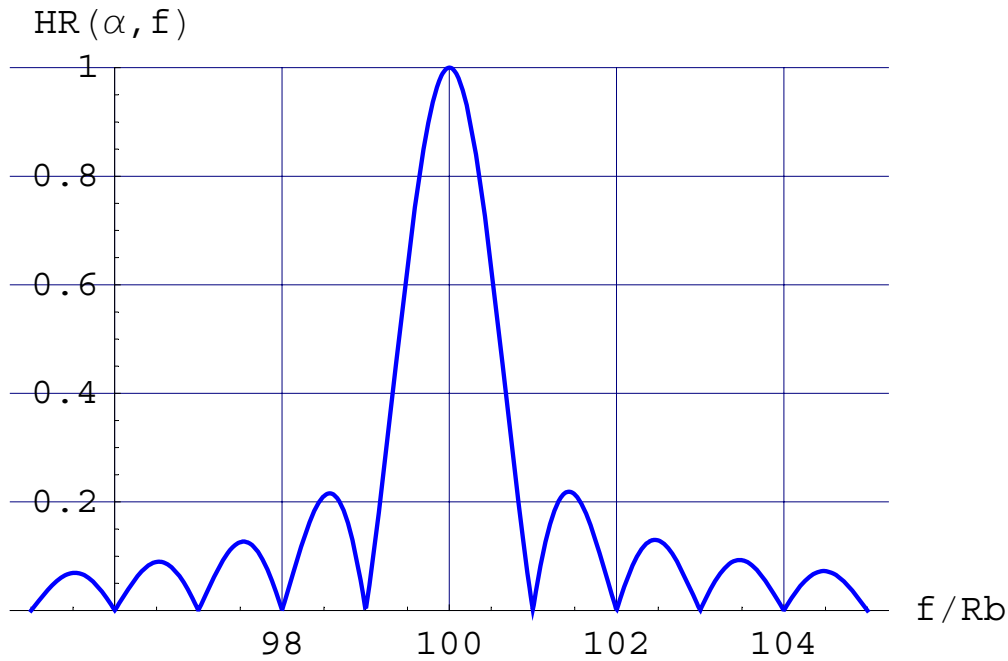
(* Filtro adattato - Matched Filter *)
G[f_] := Tb sinc[f Tb]
K := 2;
t0 := 0;
HR[f_] := K V0 / 2 (G[f - f0] + G[f + f0]) Exp[-i 2 π f t0];

pHr = Plot[Abs[HR[f]], {f, -2 f0, 2 f0}, PlotStyle → {Blue, Thickness[.005]},
  PlotRange → {0, 1}, Frame → False, GridLines → Automatic,
  AxesLabel → {"f/Rb", "HR(α, f)"}, TextStyle → {FontSize → 18}];

Plot[Abs[HR[f]], {f, f0 - 5 / Tb, f0 + 5 / Tb}, PlotStyle → {Blue, Thickness[.005]},
  PlotRange → {0, 1}, Frame → False, GridLines → Automatic,
  AxesLabel → {"f/Rb", "HR(α, f)"}, TextStyle → {FontSize → 18}];

```





Null¹³

```
Pb[EbN0_] := 0.5 Erfc[ $\sqrt{\text{EbN0}/2}$ ];
```

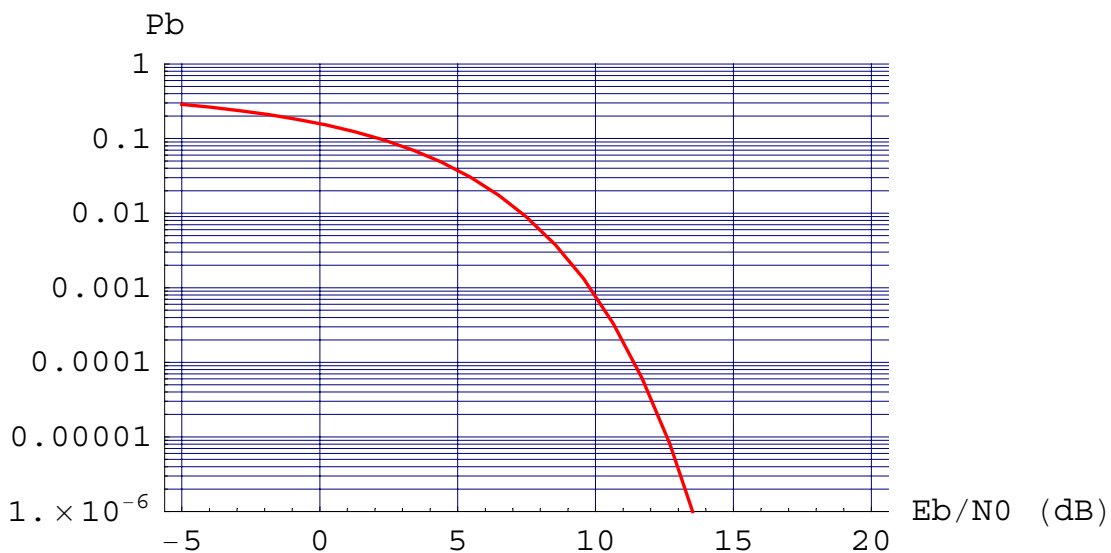
```
(* EbN0=Eb/N0 con N0 monolatera,  $\rho c = \text{Eb}/(2 N0)$ )
```

```
!!! OOK perde 3 dB rispetto BPSK in
```

```
termini di Eb/N0 mentre perde 6 dB in termini di  $\rho c$  !!! *)
```

```
PbOOKmfebn0 = LogPlot[Pb[ $10^{(0.1 \text{EbN0dB})}$ ], {EbN0dB, -5, 20}, PlotRange -> { $10^{-6}$ , 1},  
PlotStyle -> {Red, Thickness[.005]}, Frame -> False, GridLines -> Automatic,  
AxesLabel -> {"Eb/N0 (dB)", "Pb"}, TextStyle -> {FontSize -> 16}];
```

Null

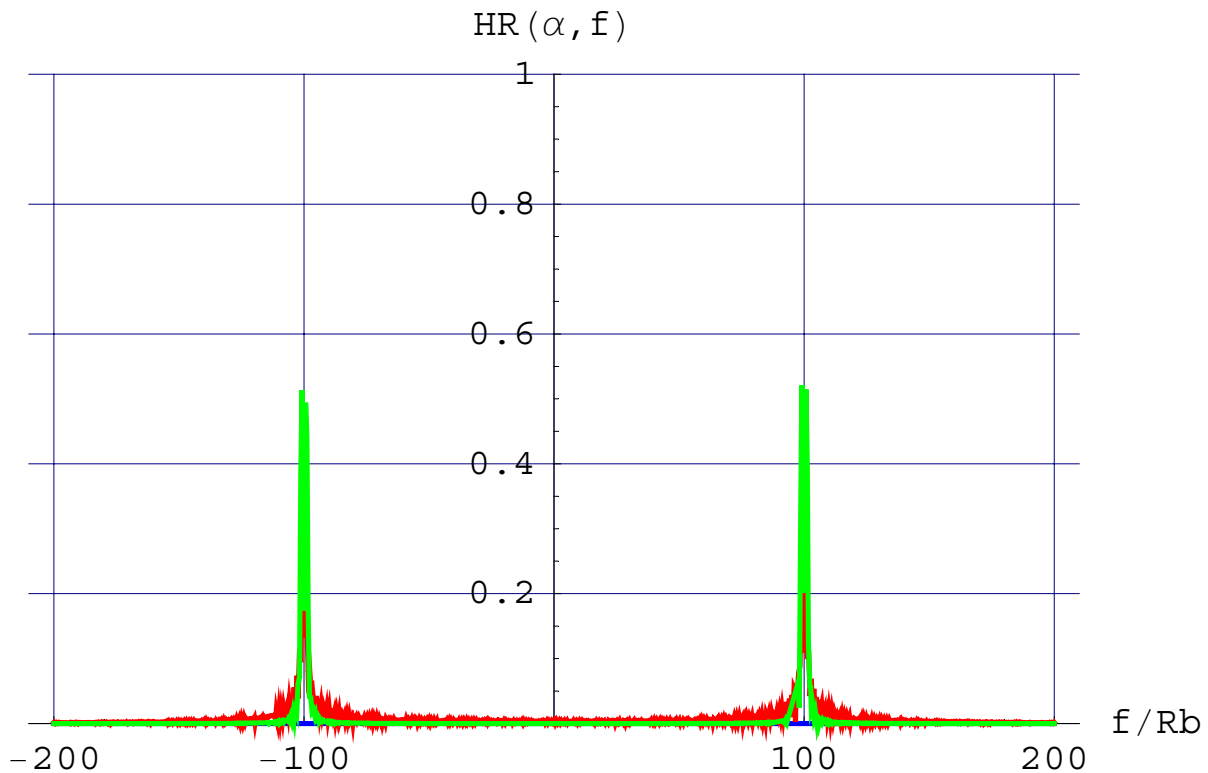


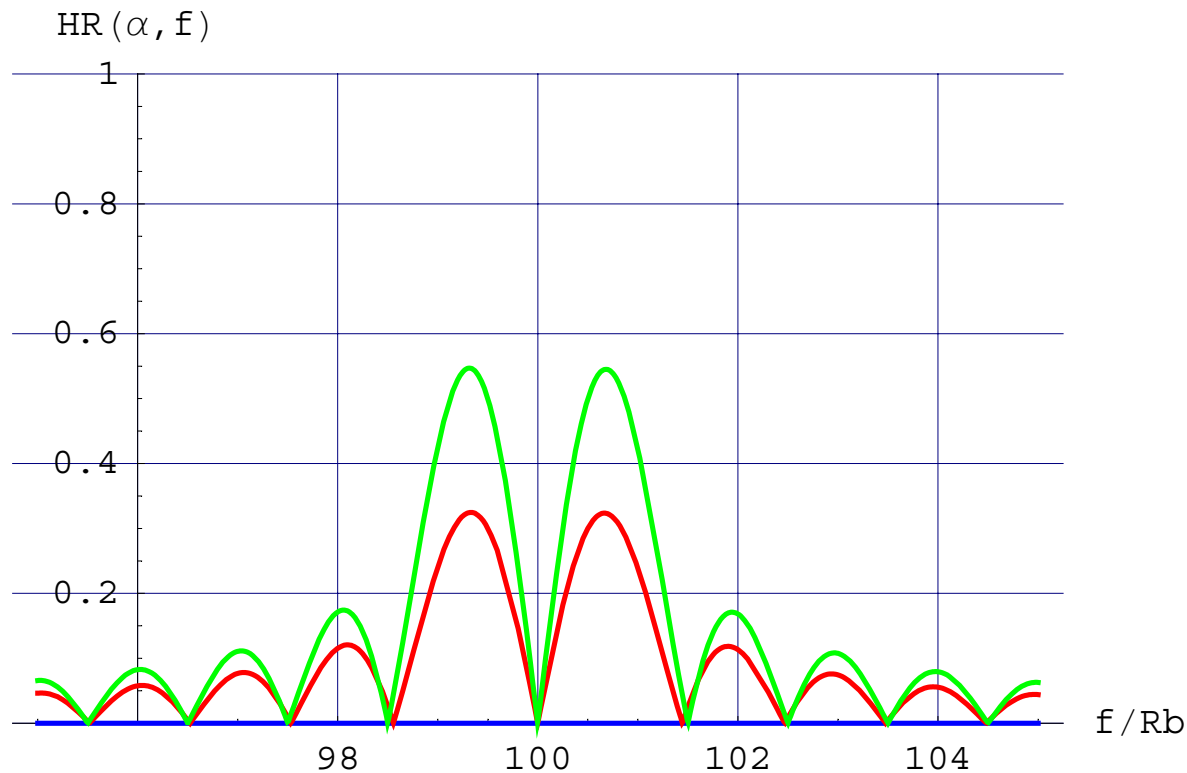
```
(* BFSK su canale a banda illimitata *)
V0 := 1;
Tb := 1;
φ0 := 0;
f0 := 100 / Tb;
g[t_] := If[Abs[t] < 0.5 Tb, 1, 0];
x1[t_, Δf_] := V0 g[t] Cos[2 π (f0 + Δf) t + φ0]
x2[t_, Δf_] := V0 g[t] Cos[2 π (f0 - Δf) t + φ0]

(* Filtro adattato - Matched Filter *)
G[f_] := Tb sinc[f Tb]
K := 1;
t0 := 0;
HR[f_, Δf_] := K V0 / 2
  (G[f - (f0 + Δf)] + G[f + (f0 + Δf)] - G[f - (f0 - Δf)] - G[f + (f0 - Δf)]) Exp[-i 2 π f t0];

pHrbfskΔf = Plot[{Abs[HR[f, 0]], Abs[HR[f, 0.25 / Tb]], Abs[HR[f, 1 / Tb]]},
  {f, -2 f0, 2 f0}, PlotStyle →
  {{Blue, Thickness[.005]}, {Red, Thickness[.005]}, {Green, Thickness[.005]}},
  PlotRange → {0, 1}, Frame → False, GridLines → Automatic,
  AxesLabel → {"f/Rb", "HR(α, f)", TextStyle → {FontSize → 18}}];

Plot[{Abs[HR[f, 0]], Abs[HR[f, 0.25 / Tb]], Abs[HR[f, 0.5 / Tb]]},
  {f, f0 - 5 / Tb, f0 + 5 / Tb}, PlotStyle →
  {{Blue, Thickness[.005]}, {Red, Thickness[.005]}, {Green, Thickness[.005]}},
  PlotRange → {0, 1}, Frame → False, GridLines → Automatic,
  AxesLabel → {"f/Rb", "HR(α, f)", TextStyle → {FontSize → 18}}];
```

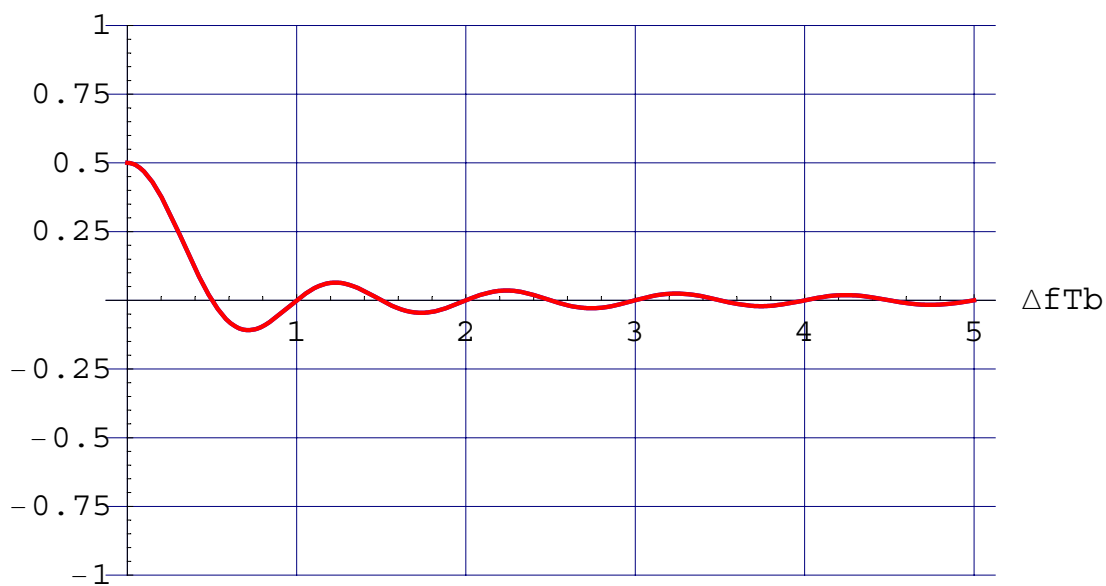




```

E12[Δf_] := ∫-Tb/2Tb/2 V0^2 (Cos[2 π (f0 + Δf) t + φ0] Cos[2 π (f0 - Δf) t + φ0]) dt
Plot[ {E12[Δf], V0^2 Tb/2 sinc[2 Δf Tb]}, {Δf, 0, 5/Tb}, PlotRange → {-1, 1},
PlotStyle → {{Blue, Thickness[.005]}, {Red, Thickness[.005]}},
Frame → False, GridLines → Automatic,
AxesLabel → {"ΔfTb", "E12[Δf], E12approx"}, TextStyle → {FontSize → 16}];
    
```

E12[Δf], E12approx

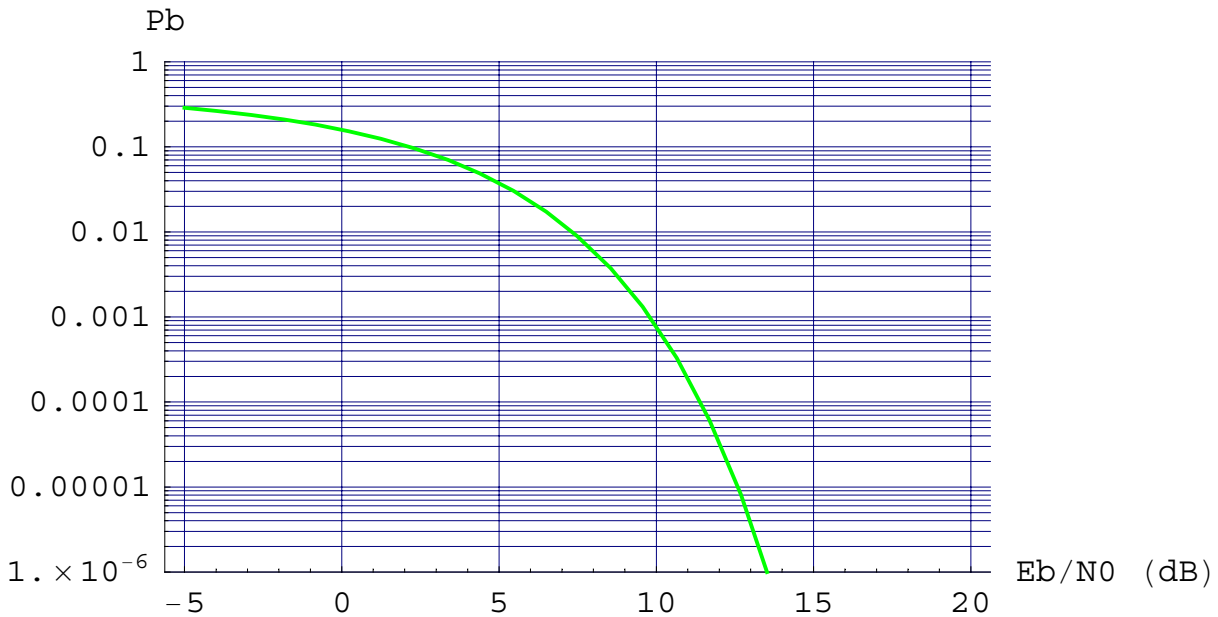


(* **Minimo Δf che rende $x_1(t)$ e $x_2(t)$ ortogonali è $\Delta f=Rb/2$ ***)

```

Pb[EbN0_, ΔfTb_] := 0.5 Erfc[√EbN0 / 2 (1 - sinc[2 ΔfTb])];
(* EbN0=Eb/N0 con N0 monolatera, ρc=Eb/N0
   !!! BFSK ortog. perde 3 dB
   rispetto BPSK in termini sia di Eb/N0 che di ρc !!! *)
PbBFSKortmfebn0 = LogPlot[Pb[10^(0.1 EbN0dB), 0.5], {EbN0dB, -5, 20},
  PlotRange → {10^(-6), 1}, PlotStyle → {Green, Thickness[.005]},
  Frame → False, GridLines → Automatic,
  AxesLabel → {"Eb/N0 (dB)", "Pb"}, TextStyle → {FontSize → 16}];
Null

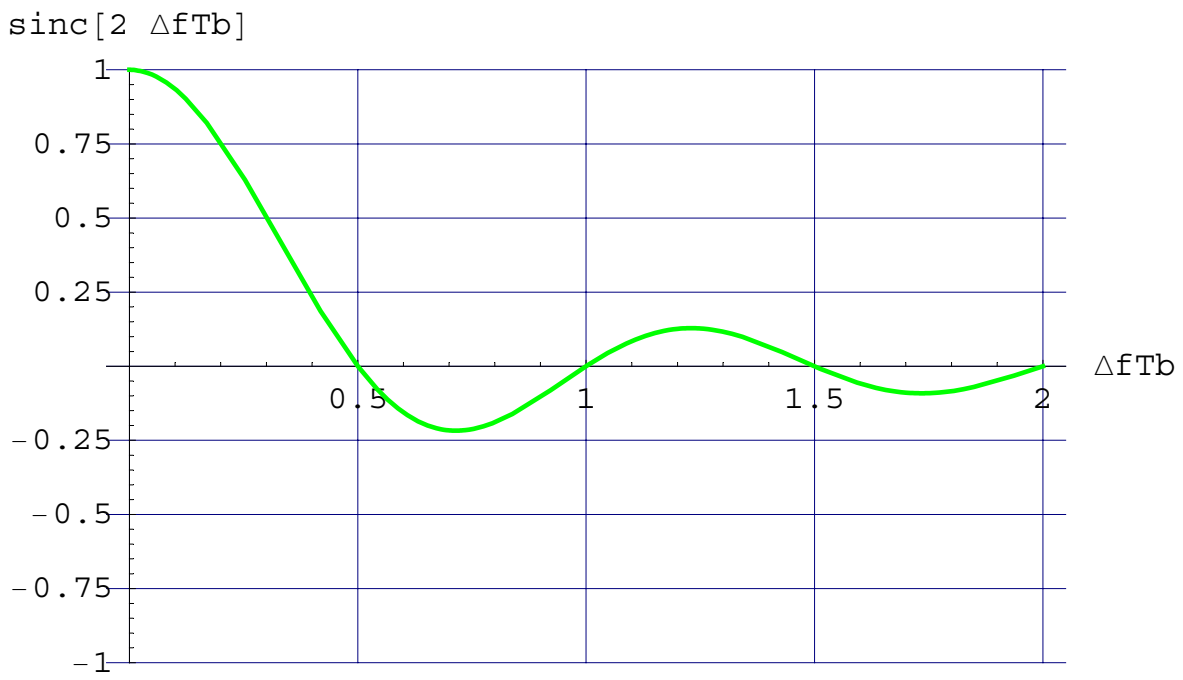
```



```

(* Ricerca Δf che ottimizza Pb => minimizza sinc[2 ΔfTb] *)
Plot[sinc[2 ΔfTb], {ΔfTb, 0, 2}, PlotRange → {-1, 1},
  PlotStyle → {Green, Thickness[.005]}, Frame → False, GridLines → Automatic,
  AxesLabel → {"ΔfTb", "sinc[2 ΔfTb]"}, TextStyle → {FontSize → 16}];
TableForm[Table[{ΔfTb, sinc[2 ΔfTb]}, {ΔfTb, 0.5, 1., 0.01}]]
1.43 0.25

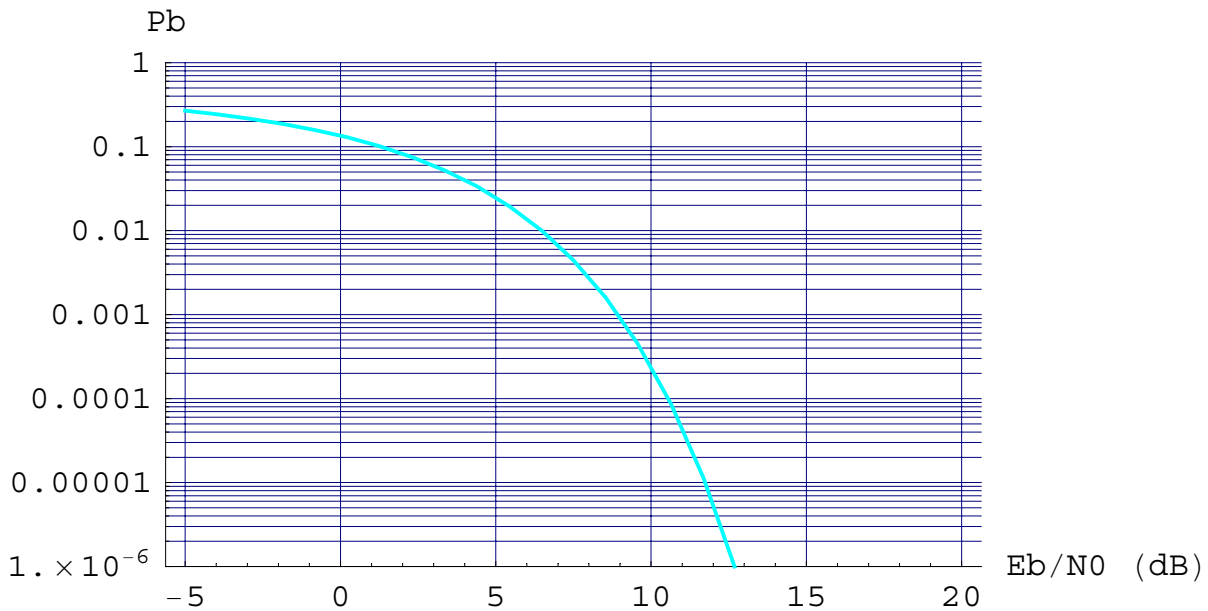
```



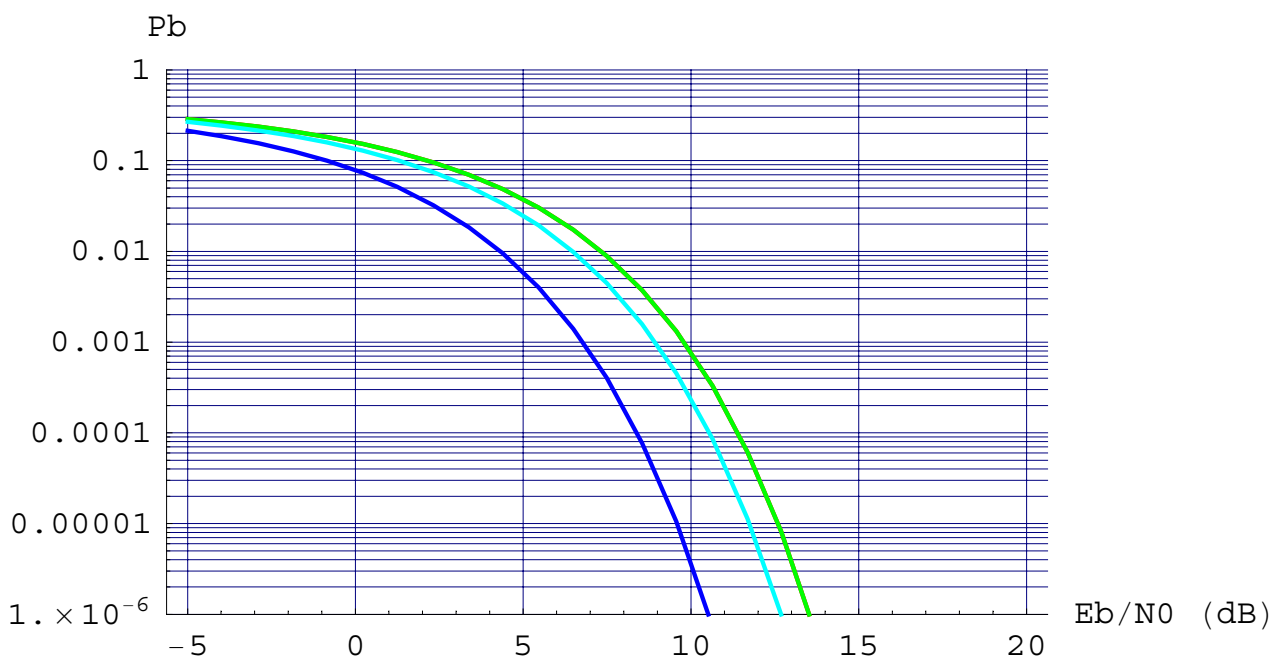
0.5	3.89804×10^{-17}
0.51	-0.0195949
0.52	-0.0383604
0.53	-0.0562692
0.54	-0.0732967
0.55	-0.0894211
0.56	-0.104623
0.57	-0.118886
0.58	-0.132196
0.59	-0.144541
0.6	-0.155915
0.61	-0.16631
0.62	-0.175724
0.63	-0.184157
0.64	-0.191611
0.65	-0.198091
0.66	-0.203604
0.67	-0.208162
0.68	-0.211776
0.69	-0.214462
0.7	-0.216236
0.71	-0.217119
0.72	-0.217133
0.73	-0.216301
0.74	-0.21465
0.75	-0.212207
0.76	-0.209001
0.77	-0.205065
0.78	-0.200431
0.79	-0.195133
0.8	-0.189207
0.81	-0.18269
0.82	-0.175619
0.83	-0.168034
0.84	-0.159975
0.85	-0.151481
0.86	-0.142594
0.87	-0.133355
0.88	-0.123806
0.89	-0.113988
0.9	-0.103943
0.91	-0.0937137
0.92	-0.0833407
0.93	-0.0728655
0.94	-0.0623286
0.95	-0.0517701
0.96	-0.0412294
0.97	-0.030745
0.98	-0.0203545
0.99	-0.0100944
1.	-3.89804×10^{-17}

0.3575

```
PbBFSKoptmfebn0 =
  LogPlot[Pb[10^(0.1 EbN0dB), 0.72], {EbN0dB, -5, 20}, PlotRange -> {10^(-6), 1},
    PlotStyle -> {Cyan, Thickness[.005]}, Frame -> False, GridLines -> Automatic,
    AxesLabel -> {"Eb/N0 (dB)", "Pb"}, TextStyle -> {FontSize -> 16}];
```

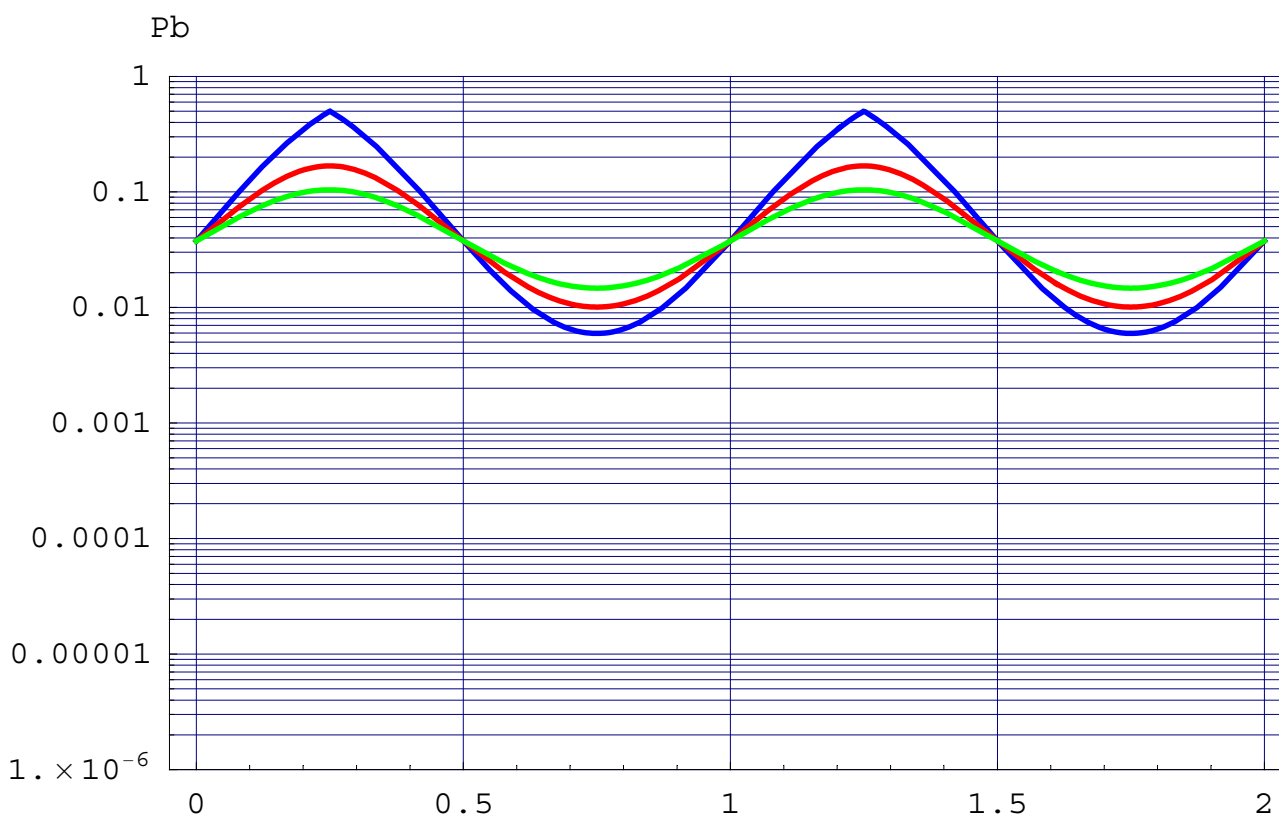


```
Show[PbBPSKmfefbn0, PbOOKmfefbn0, PbBFSKortmfefbn0, PbBFSKoptmfefbn0];
(* verso Eb/N0 OOK=BFSKortog *)
```



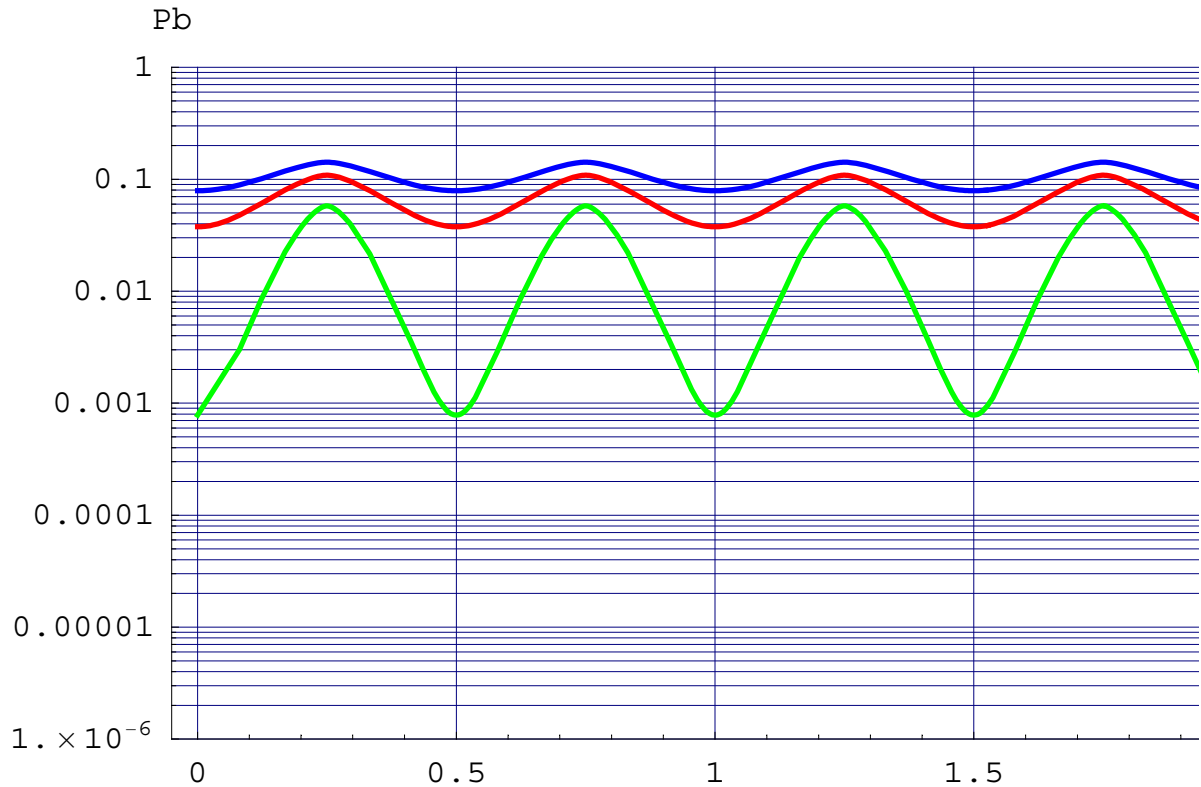
(* Caso di differenza di fase iniziale $\Delta\varphi$ generica *)

```
Pb[EbN0_, ΔfTb_, Δφ_] :=
  0.5 Erfc[√EbN0 / 2 (1 - 0.5 (Sin[2 π ΔfTb + Δφ] + Sin[2 π ΔfTb - Δφ]))];
SNRdB := 5;
PbBFSKΔfΔφ = LogPlot[{Pb[10^(0.1 SNRdB), ΔfTb, 0],
  Pb[10^(0.1 SNRdB), ΔfTb, N[π/4]], Pb[10^(0.1 SNRdB), ΔfTb, N[π/3]]},
{ΔfTb, 0, 2}, PlotRange → {10^(-6), 1}, PlotStyle →
  {{Blue, Thickness[.005]}, {Red, Thickness[.005]}, {Green, Thickness[.005]}},
Frame → False, GridLines → Automatic, AxesLabel → {"ΔfTb", "Pb"},
TextStyle → {FontSize → 16}]
```



- Graphics -

```
(* cerco la Pb media rispetto Δφ unif. distrib. da -π a π *)
Pbmed[EbN0_, ΔfTb_] :=
  N[ ∫-ππ 0.5 / (2 π) Erfc[ √(EbN0 / 2 (1 - 0.5 (Sin[2 π ΔfTb + Δφ] + Sin[2 π ΔfTb - Δφ])) ) ] dΔφ ];
PbmedBFSKΔf = LogPlot[{Pbmed[10^(0.13), ΔfTb], Pbmed[10^(0.15), ΔfTb],
  Pbmed[10^(0.110), ΔfTb]}, {ΔfTb, 0, 2}, PlotRange → {10^(-6), 1}, PlotStyle →
  {{Blue, Thickness[.005]}, {Red, Thickness[.005]}, {Green, Thickness[.005]}},
  Frame → False, GridLines → Automatic, AxesLabel → {"ΔfTb", "Pb"},
  TextStyle → {FontSize → 16}]
```



- Graphics -

(* posso cercare il ΔfTb che minimizza Pb al variare di Δφ..... *)