Projects in Wireless Communication
Synchronization

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Lund, Fall 2024

Synchronization

Major problem: We dont know where the signal starts!

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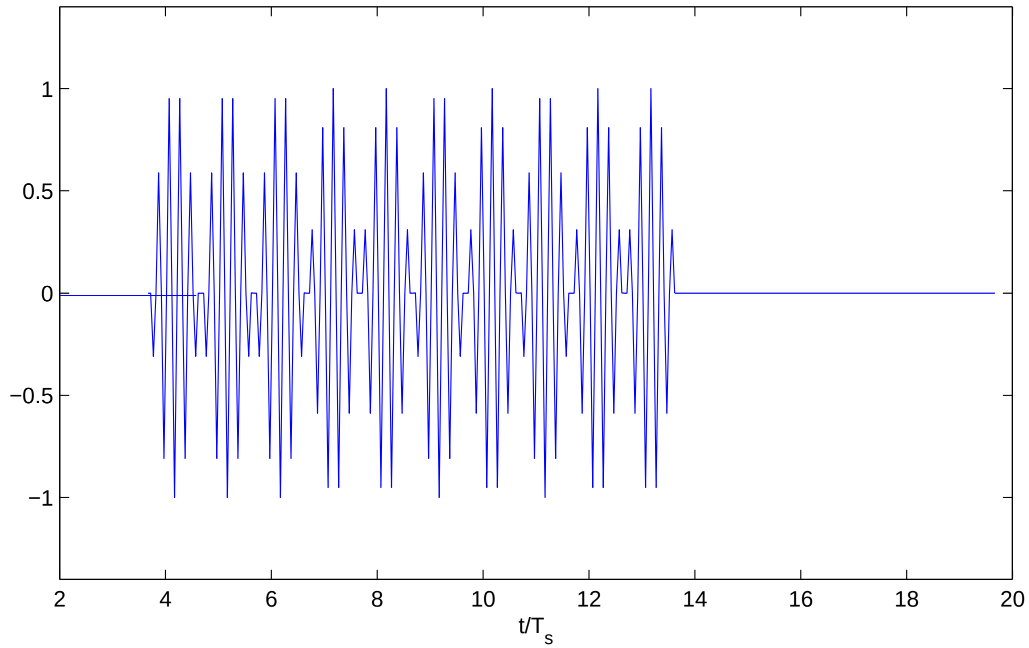

If there is no noise, its easy....

Synchronization

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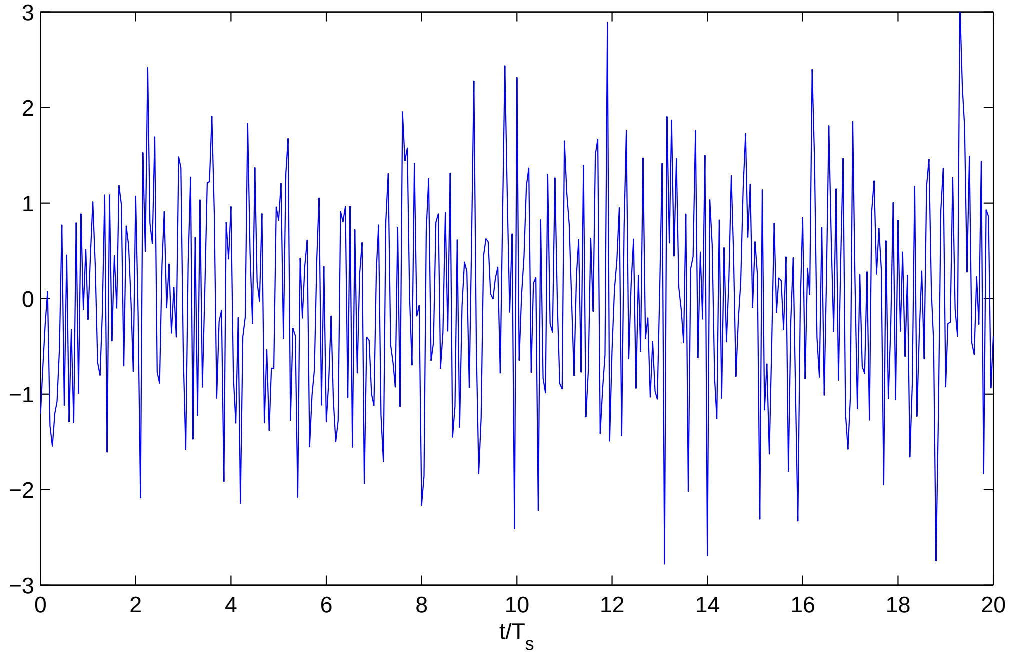

How about this one?

Synchronization

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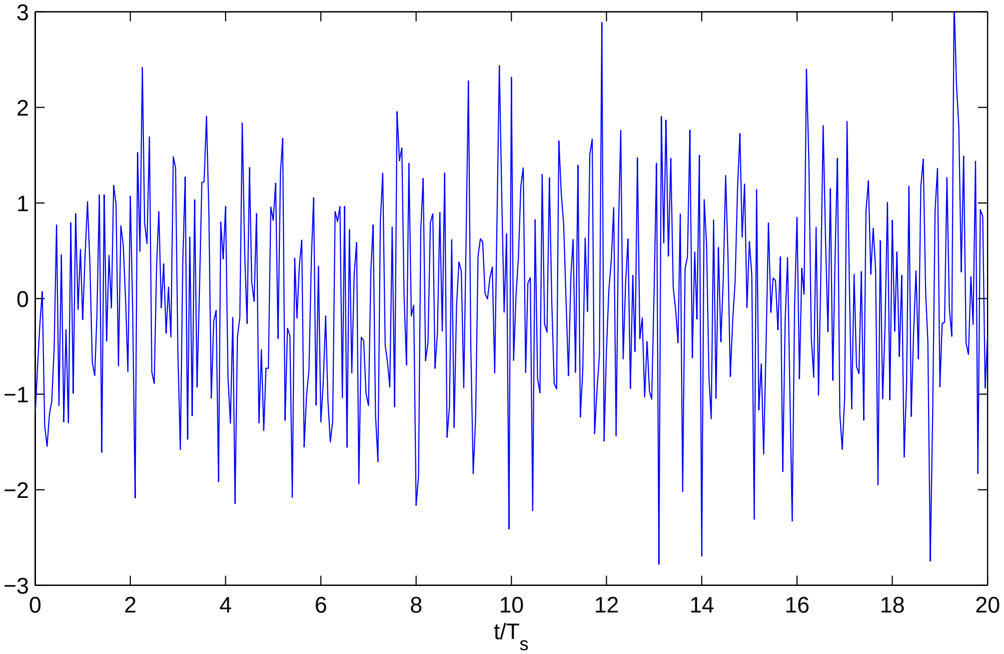

How about this one?
The signal starts at $t/T_s = 6.5$ and ends at $t/T_s = 16.5$. $E_b/N_0 = 10$ dB.

Synchronization

- In general, syncronization is a difficult subject
- Requires solid background in statistical signal processing and control theory
- Phase-locked-loops (PLL) are essential
- We will only make use of simple techniques....

Synchronization

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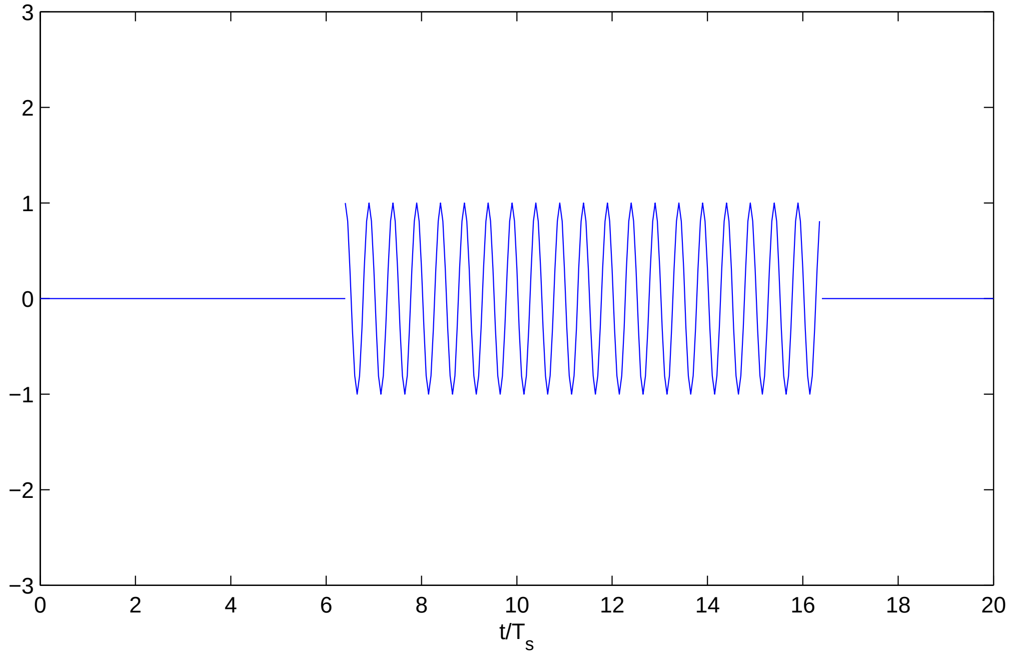

The transmitted signal (in-phase component) contains a cosine

Synchronization

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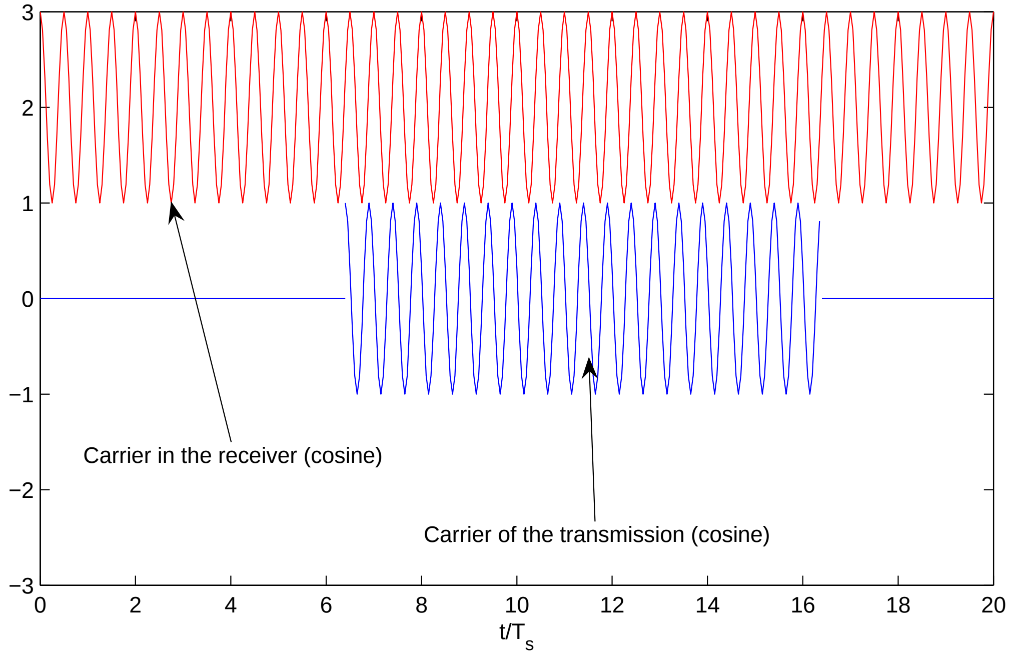
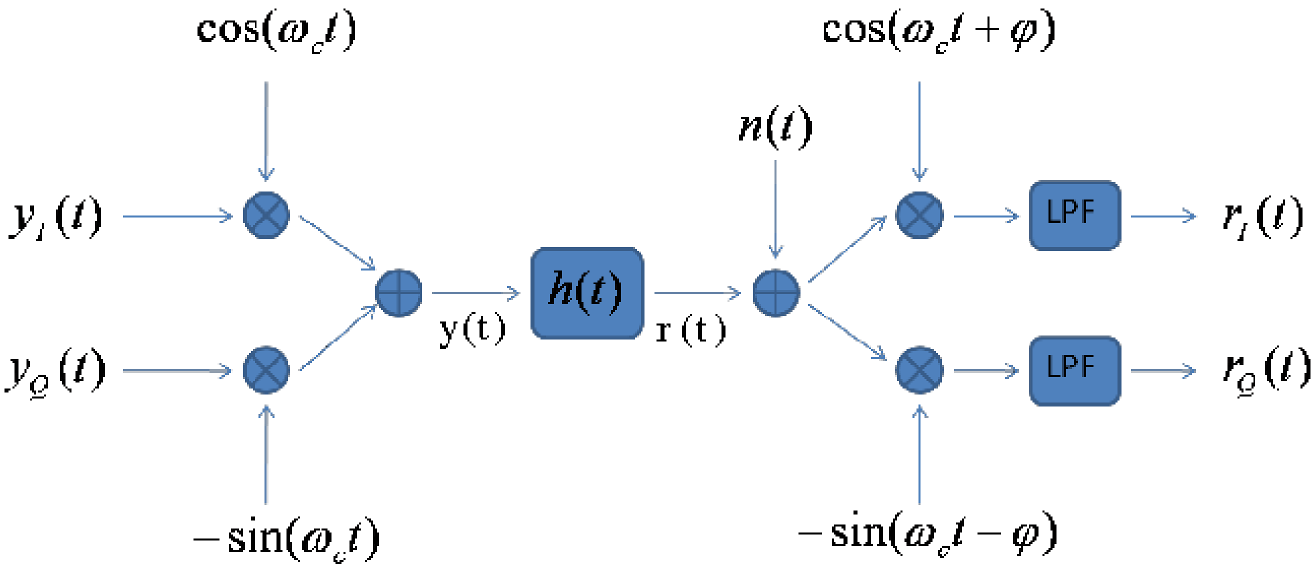


The transmitted signal (in-phase component) contains a cosine
If we dont know the exact starting position of the signal, the cosine of the reciever and the cosine of the transmission will be out of phase

Synchronization

The situation can be represented as below.



Synchronization

Major problem: We dont know where the signal starts!

We derived on the last lecture, that if the transmitted complex symbol is a, the the received symbol will be $a \exp(-i\phi)$. Hence, it is crucial that the receiver can estimate ϕ so that it can compensated.

Synchronization

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We derived on the last lecture, that if the transmitted complex symbol is a, the the received symbol will be $a\exp(-i\phi)$. Hence, it is crucial that the receiver can estimate ϕ so that it can compensated.

Moreover, we dont know where the sampling unit (after the matched filter) should sample the signal

Synchronization

We have that the transmitted signal is based on the pulse shape $p(t)$, and the channel is $h(t)$.

A matched filter should be mathced to the receive pulse $v(t) = p(t) \star h(t)$. But, this is not possible in cases where the receiver does not know $h(t)$.

Not knowing ϵ is severe and will be analyzed next.

Synchronization

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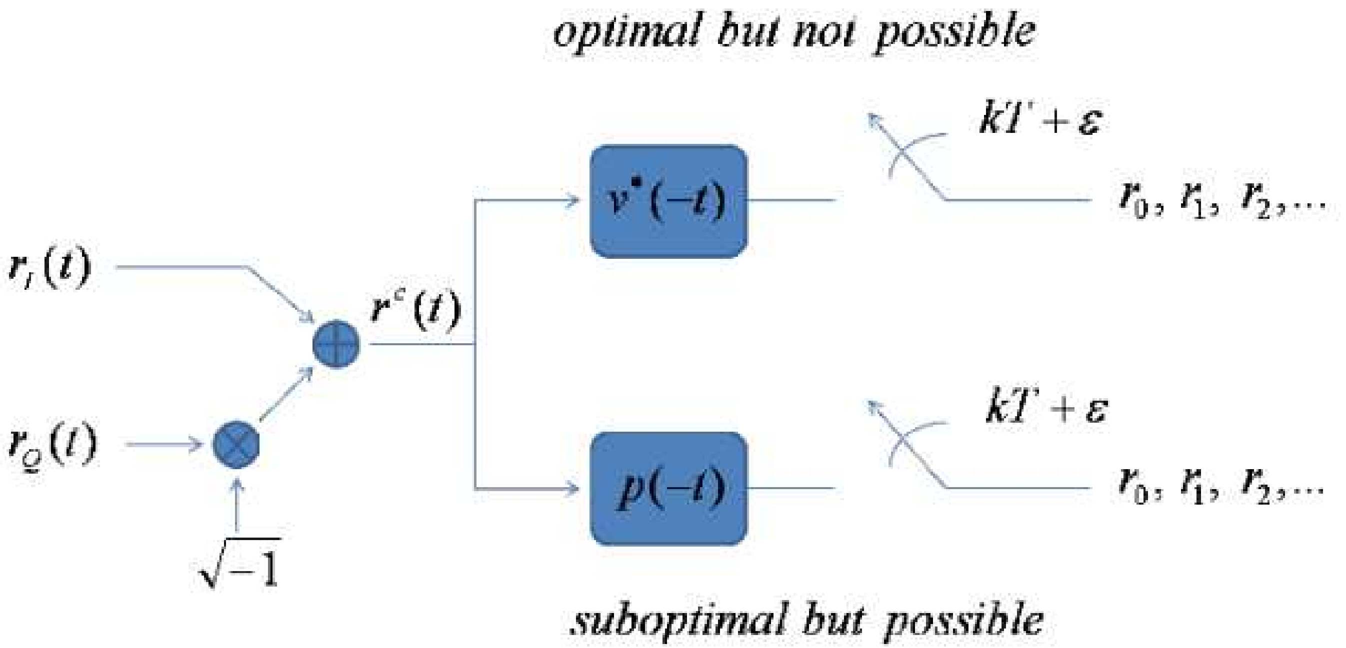


Synchronization

The phase mismatch and non-optimal sampling instance yields a channel model

$$r[k] = \alpha \mathrm{e}^{i\phi} a[k] + n[k]$$

Phase mismatch gives ϕ and sampling mismatch gives α

ϕ can be estimated from a pilot symbol p. Let

$$a[1] = p = 1 + i = \sqrt{2}\mathrm{e}^{i\pi/4}$$

then

$$\hat{\phi} = \mathrm{angle}\{r[1]\} - \frac{\pi}{4}$$

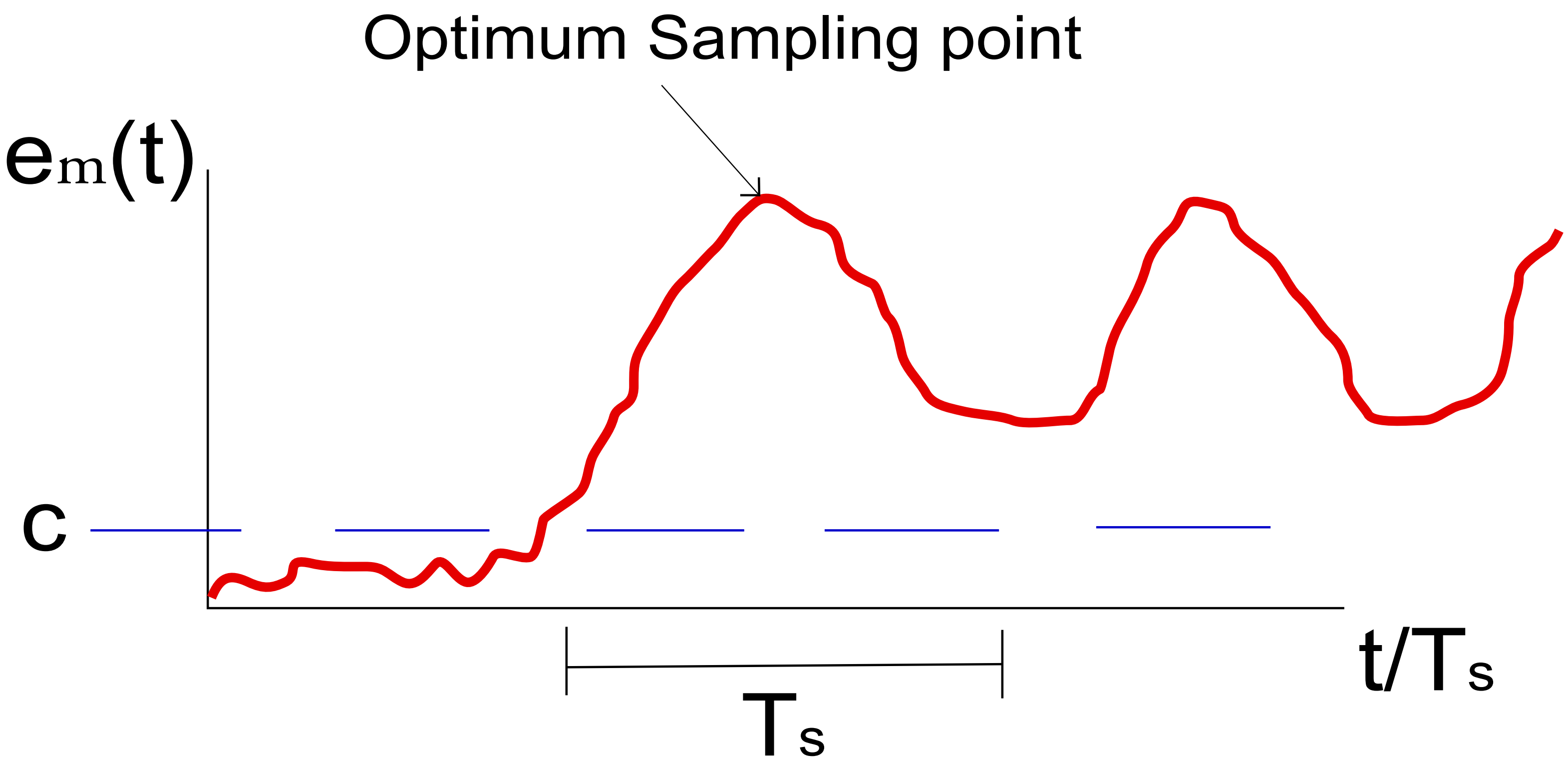
Synchronization

Estimation of ϵ is solved by selecting the sampling instance such that α is maximized. Recall the receiver structure

Synchronization

$$e_m(t) = \sqrt{m_I^2(t) + m_Q^2(t)}$$

c is a threshold, easiest to find by trial and error

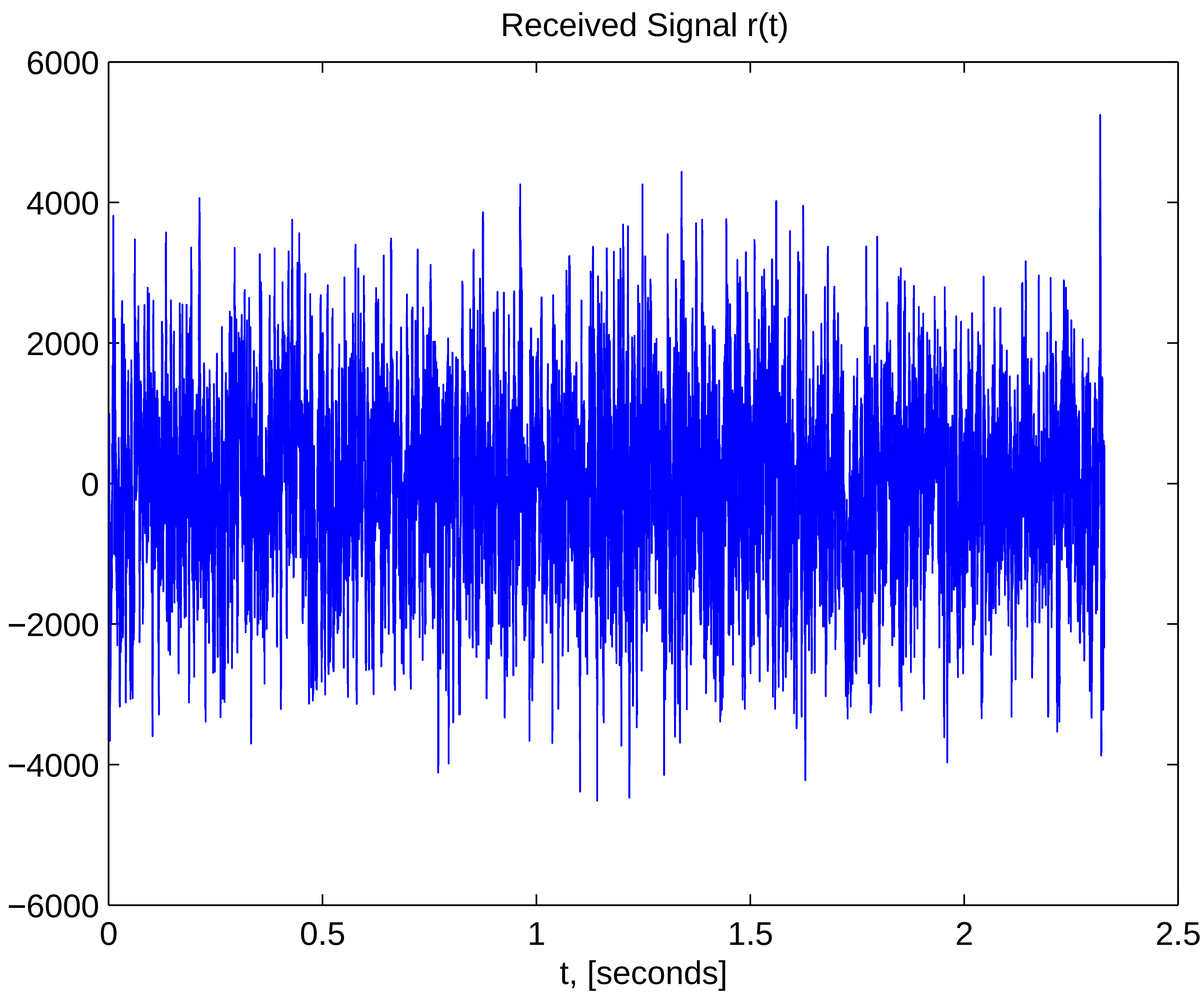


Example

Example

The transmission starts and ends with pilots $2 + 2i$

Example


Received Signal r(t)
6000
4000
2000
0
−2000
−4000
−6000
0
0.5
1
1.5
2
2.5
t, [seconds]

Example

Construct $m_I(t)$ and $m_Q(t)$ as

$$m_I(t) = r(t)\cos(2\pi f_c t) \star p(t)$$

and

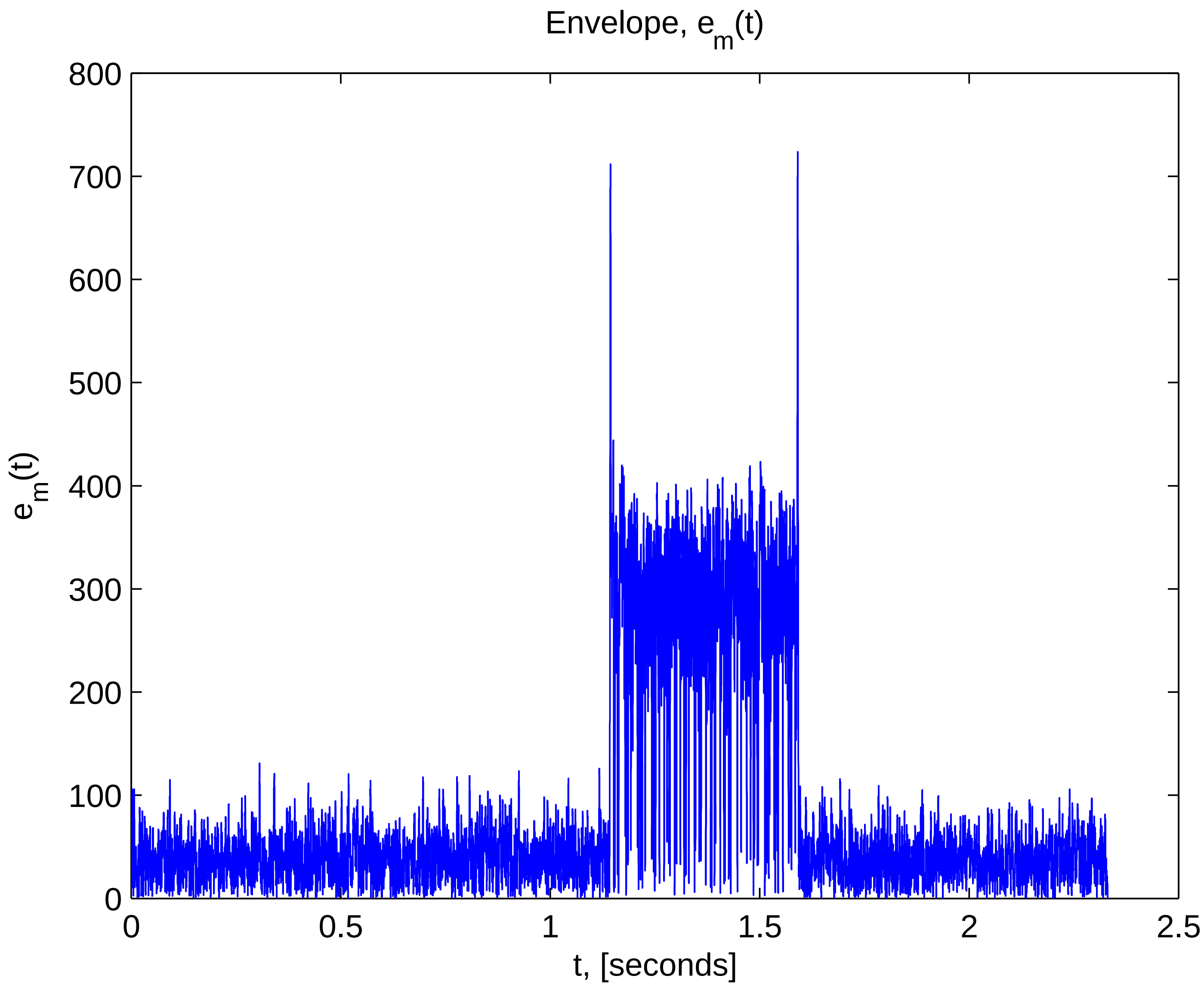
$$m_Q(t) = -r(t)\sin(2\pi f_c t) \star p(t)$$

Then generate

$$e_m(t) = \sqrt{m_I^2(t) + m_Q^2(t)}$$

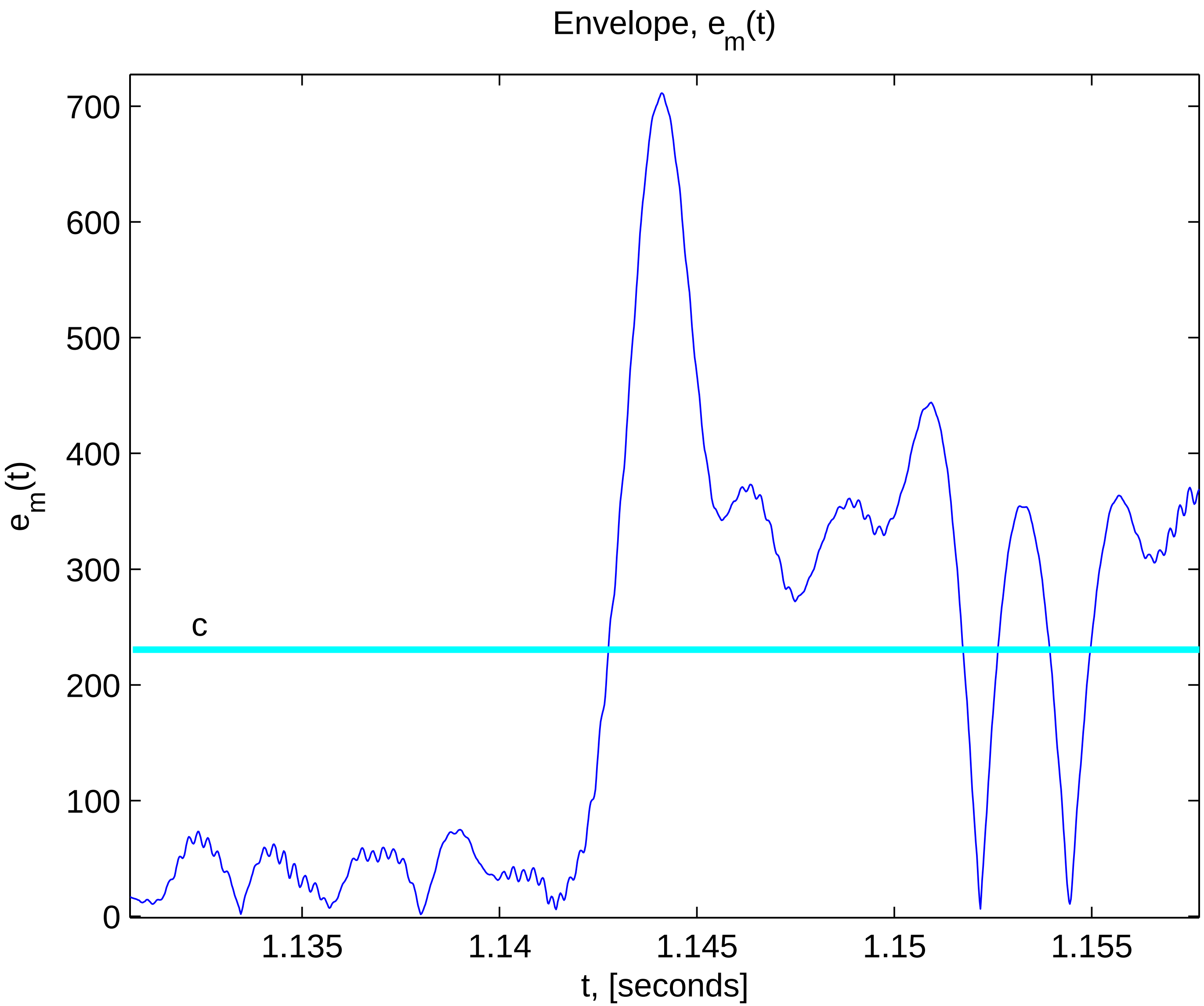
Plot

Example



Envelope, $e_m(t)$
800
700
600
500
400
300
200
100
0
$e_m(t)$
0
0.5
1
1.5
2
2.5
t, [seconds]

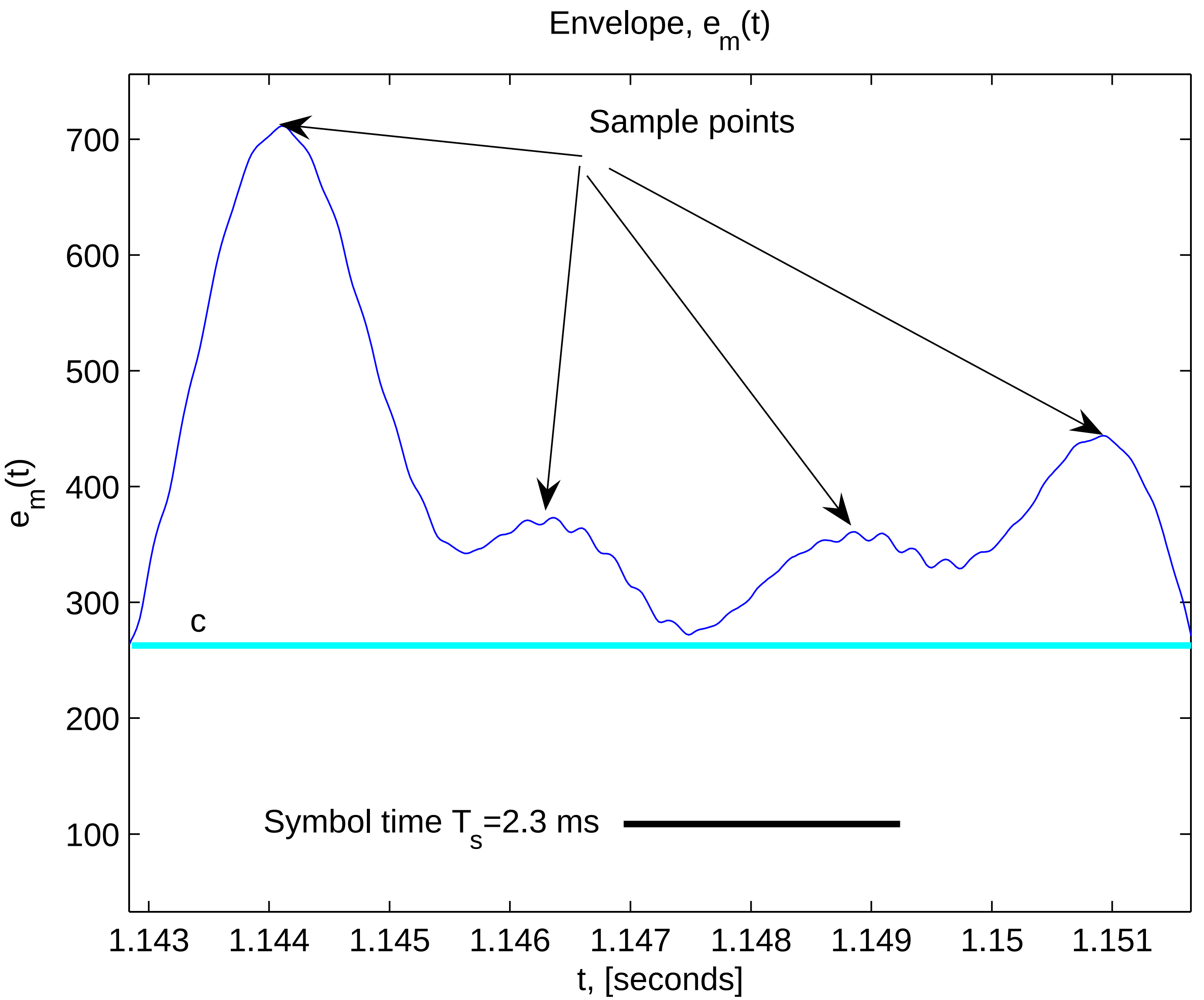
Example


Envelope, $e_m(t)$
700
600
500
400
300
200
100
0
$e_m(t)$
c
1.135
1.14
1.145
1.15
1.155
t, [seconds]

Example

Optimal sampling point is at $T_{\text{Sample}} = 1.144$ seconds.

Example


Envelope, e_m(t)
Sample points
700
600
500
400
300
200
100
e_m(t)
c
Symbol time T_s=2.3 ms
1.143
1.144
1.145
1.146
1.147
1.148
1.149
1.15
1.151
t, [seconds]

Example

Sample at $T_{\text{Sample}} + kT_s$:

$$r[k] = m_I(T_{\text{Sample}} + kT_s) + i m_Q(T_{\text{Sample}} + kT_s)$$

We get

$$r[k] = 4.38 - 5.60i \;\; 3.16 + 1.97i \;\; 2.79 + 2.16i \;\; 3.55 + 2.66i \;\; -2.73 - 2.25i....$$

Consequently

$$\alpha \exp(i\phi) = r[0]/(2+2i) = -0.30 - 2.49i$$

$$r[1]/\alpha \exp(i\phi) = -0.93 + 1.15i \;\text{ and }\; r[2]/\alpha \exp(i\phi) = -0.9899 + 0.9982i$$

So

$$\hat{a}[1] = -1 + i \;\text{ and }\; \hat{a}[2] = -1 + i$$