Direct Sequence Spread Spectrum (DSSS)

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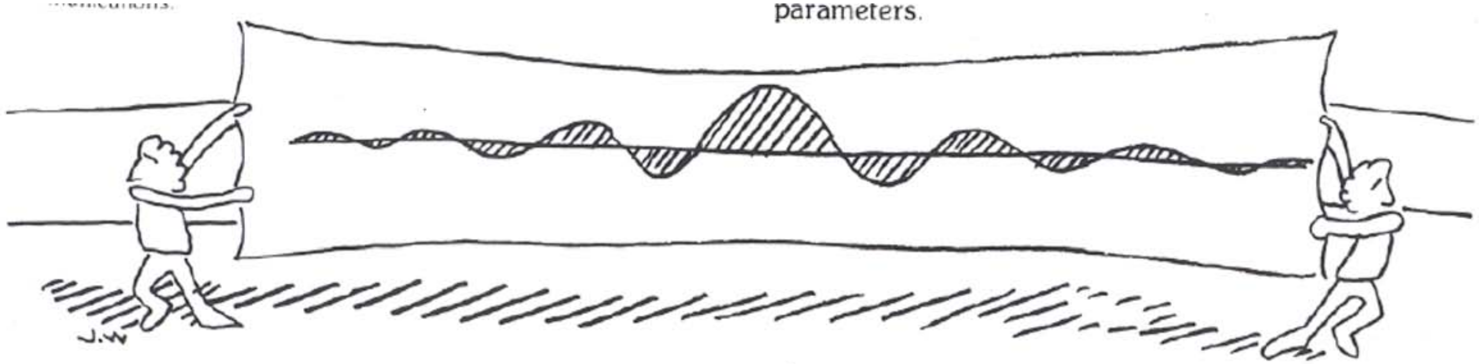
1. Basic idea of Spread Spectrum

"Spread spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery."

parameters.



May 1979 0163-6804/79/0500-0011$00.75 © 1979 IEEE 11

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Main advantages

There are many reasons for spreading the spectrum, and if done properly, a multiplicity of benefits can accrue simultaneously. Some of these are

- Antijamming
- Antiinterference
- Low probability of intercept
- Multiple user random access communications with selective addressing capability
- High resolution ranging
- Accurate universal timing.

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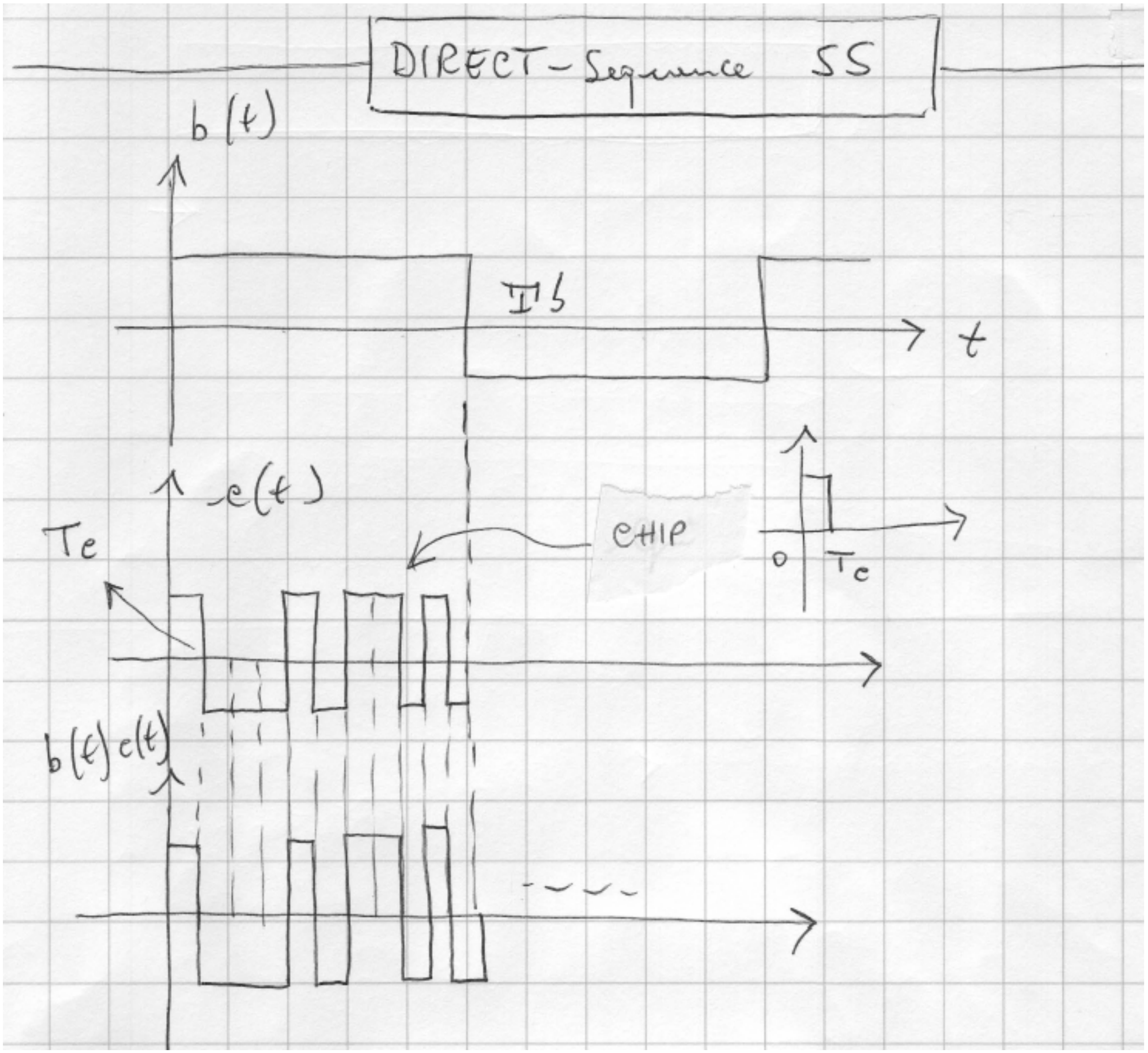

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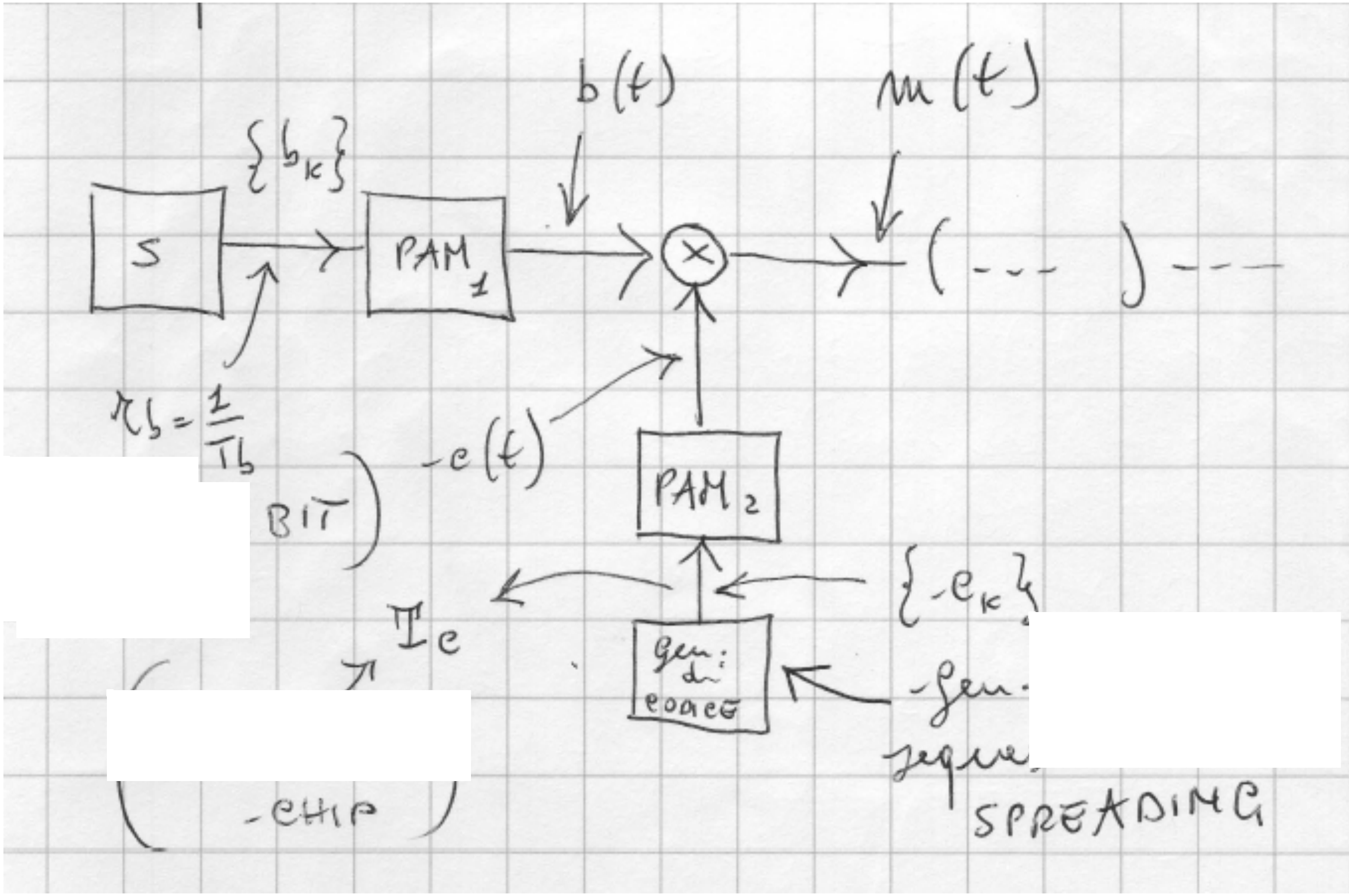
Spreading



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Spreading / Despreading

* $B_T \approx \frac{1}{T_c} \gg \frac{1}{T_b}$

$\hookrightarrow$ SPREAD SPECTRUM

$m(t) = b(t) \cdot c(t) \rightarrow$ SPREADING

$m(t) \cdot c(t) \rightarrow$ DESPREADING

$\hookrightarrow m(t) \cdot c(t) \cdot c(t) = m(t)$!!!!!!

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Spreading / Despreading

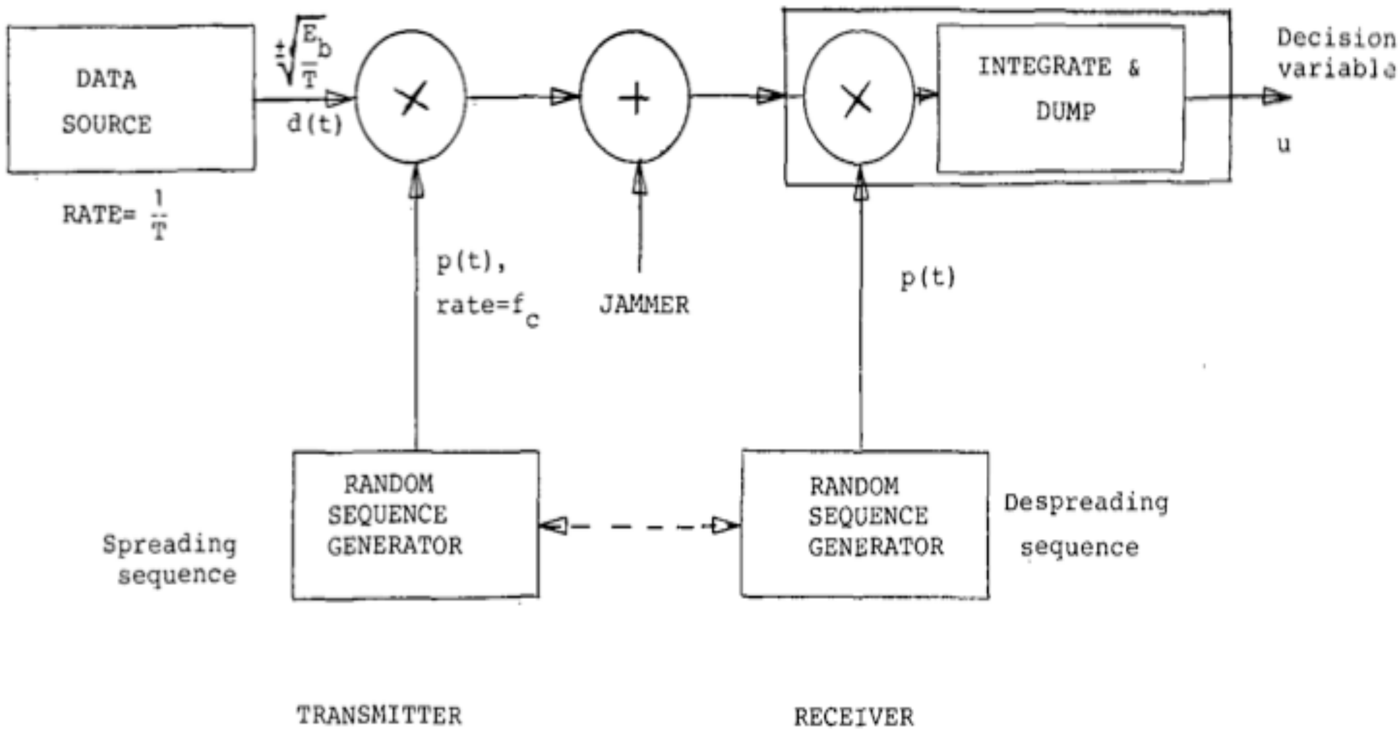

Fig. 1. Direct-sequence spread-spectrum system for transmitting a single binary digit (baseband).

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Bandwidth and Processing Gain (G)

$$m(t) = b(t)\cdot c(t)$$

$$b(t) = \sum_k b_k \, \underbrace{\mathrm{rect}\left(\frac{t - T_b/2 - kT_b}{T_b}\right)}_{g_b(t)}$$

$$c(t) = \sum_i c_i \, \underbrace{\mathrm{rect}\left(\frac{t - T_c/2 - kT_c}{T_c}\right)}_{g_c(t)} \rightarrow$$ PAM rett. con $T_{s_2} = T_c$

$\boxed{T_c \ll T_b}$ $\leftarrow$ IMP. $\rightsquigarrow$ $B_T \simeq 1/T_c = G\cdot\frac{1}{T_b}$

$$g_b(t)\cdot g_c(t) \rightarrow G_b(f) * G_c(f)$$

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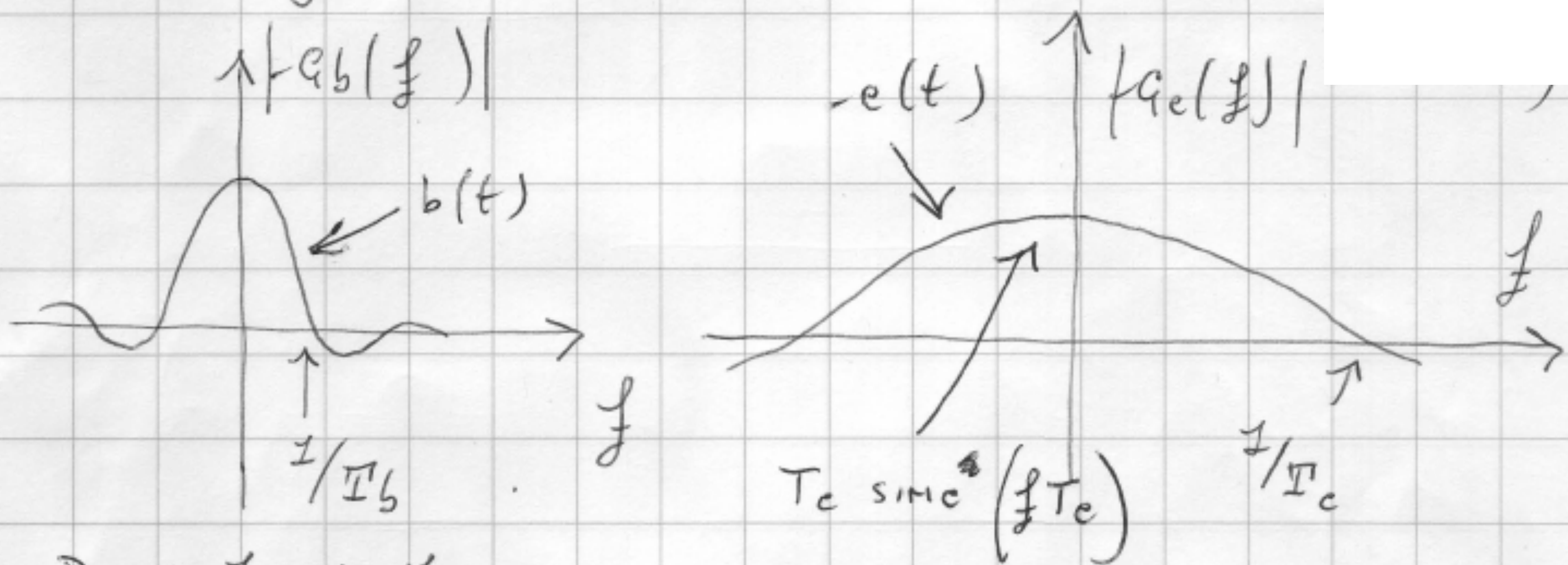
Spectrum

$$g_b(t) \cdot g_c(t) \rightarrow G_b(f) * G_c(f)$$



$$* \quad B_T \approx \frac{1}{T_c} \gg \frac{1}{T_b}$$

↳ SPREAD SPECTRUM

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Spectrum (spreaded …)

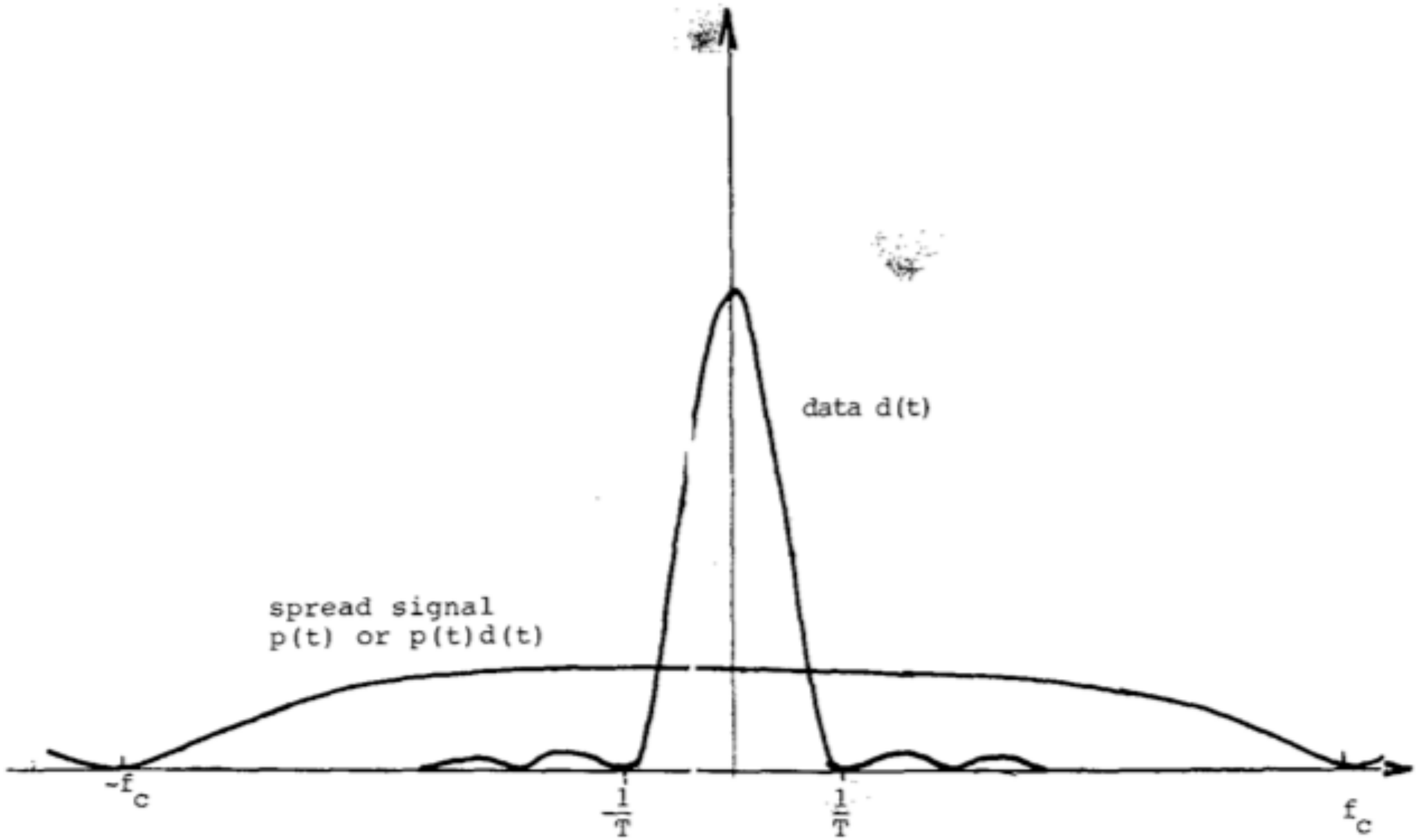

Fig. 3. Power spectrum of data and of spread signal.

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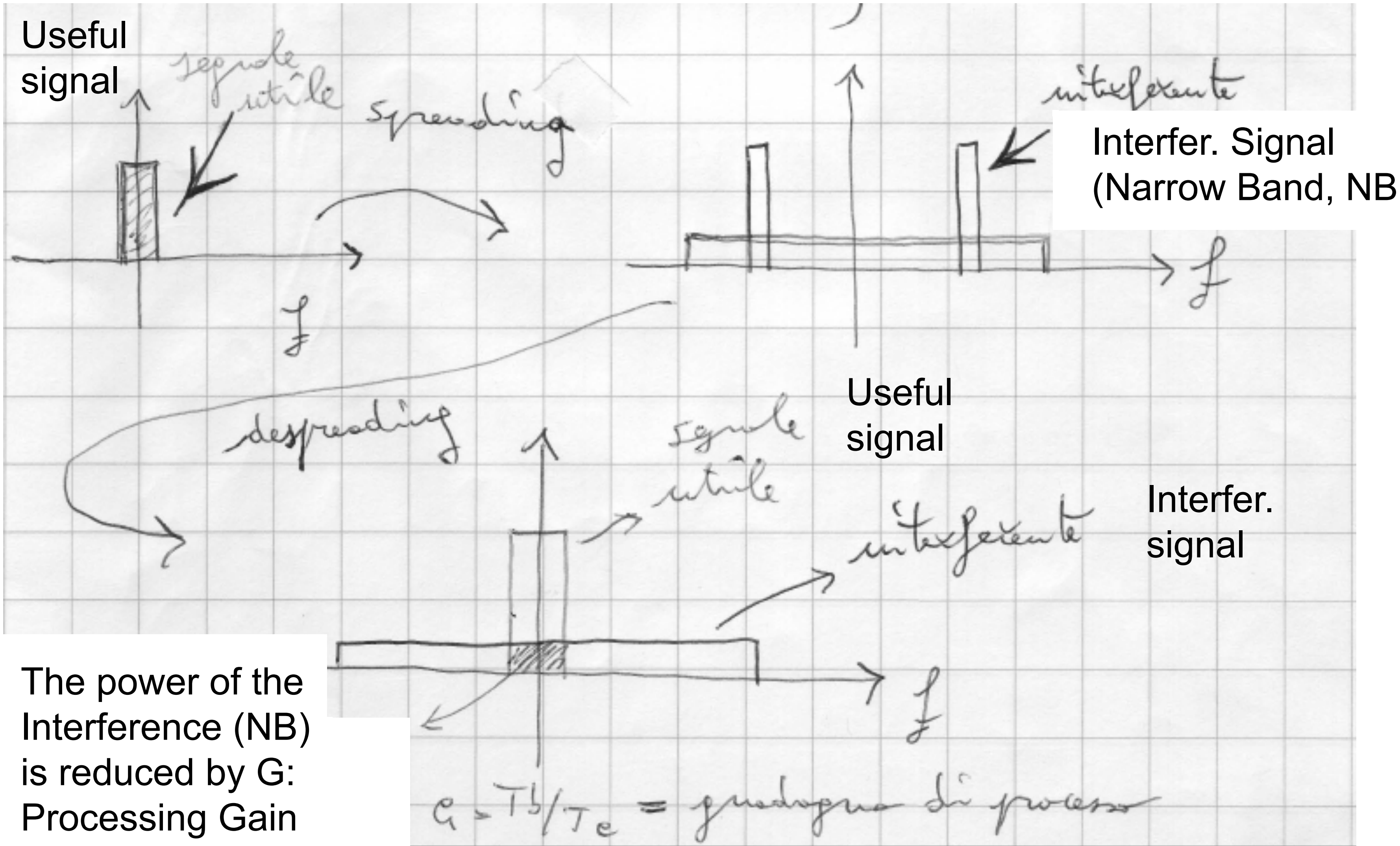
Processing Gain (G=Tb/Tc)



The power of the Interference (NB) is reduced by G: Processing Gain

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Robustness to Narrow-Band Jamming

The spreading of the jammer signal and despreading of the desired signal operation is conceptually illustrated in Figure 9.

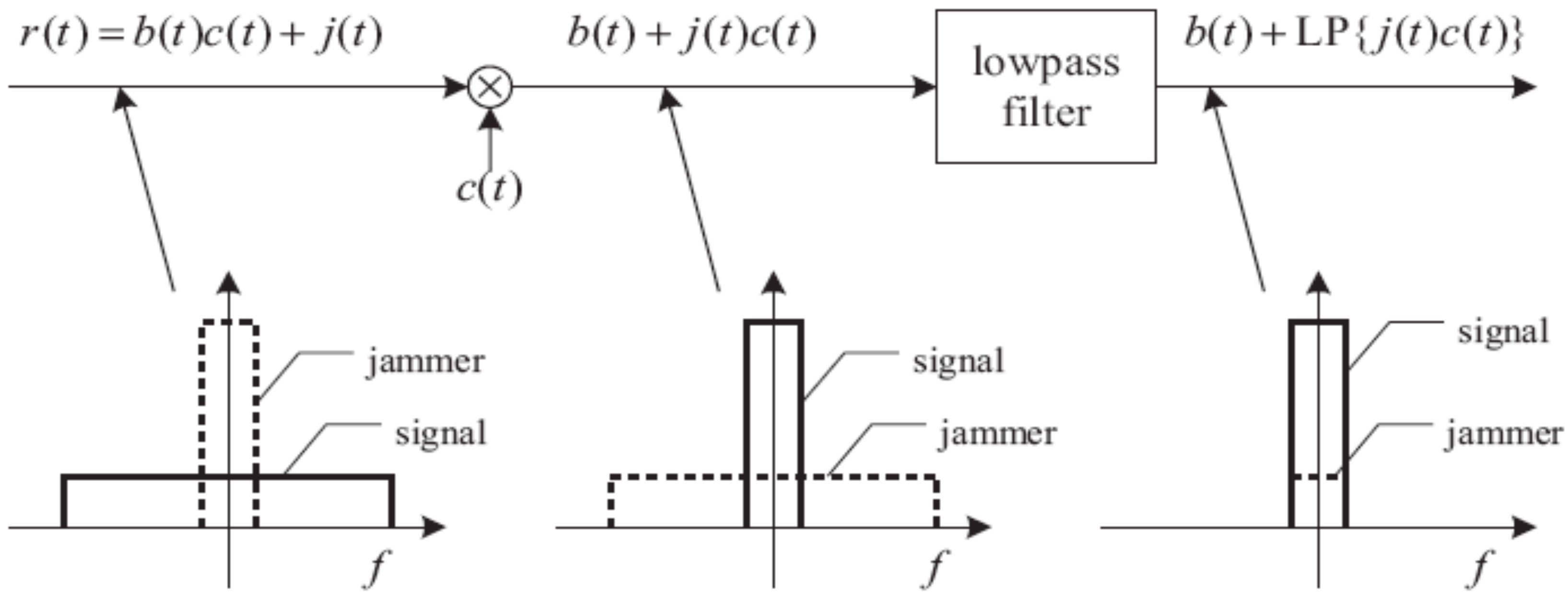
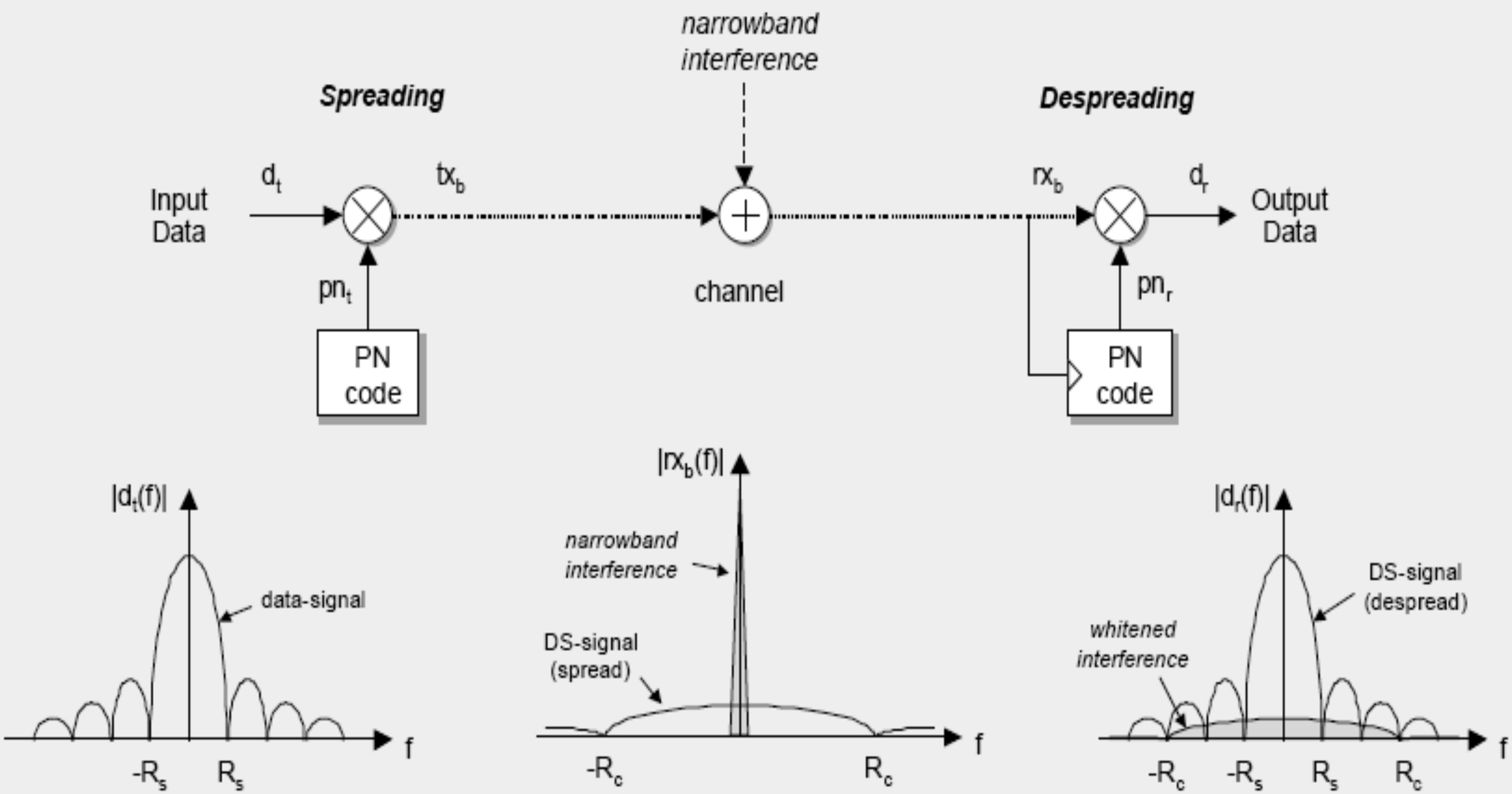


Figure 9: Despreading operation in the presence of narrowband jamming. The plots show the power spectral densities at various points in the despreading circuit

4.1 Narrowband interference



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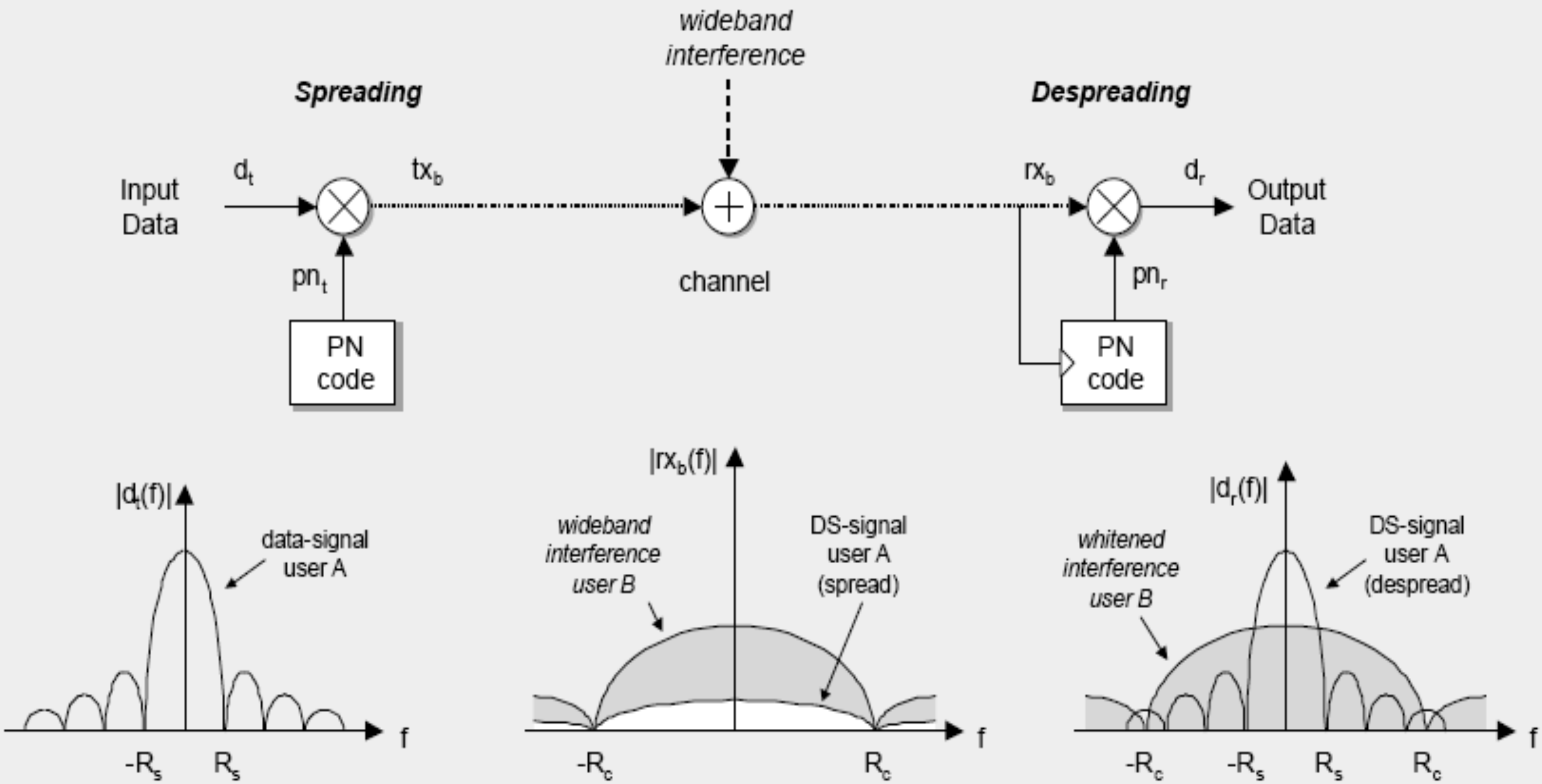
4.2 Wideband interference



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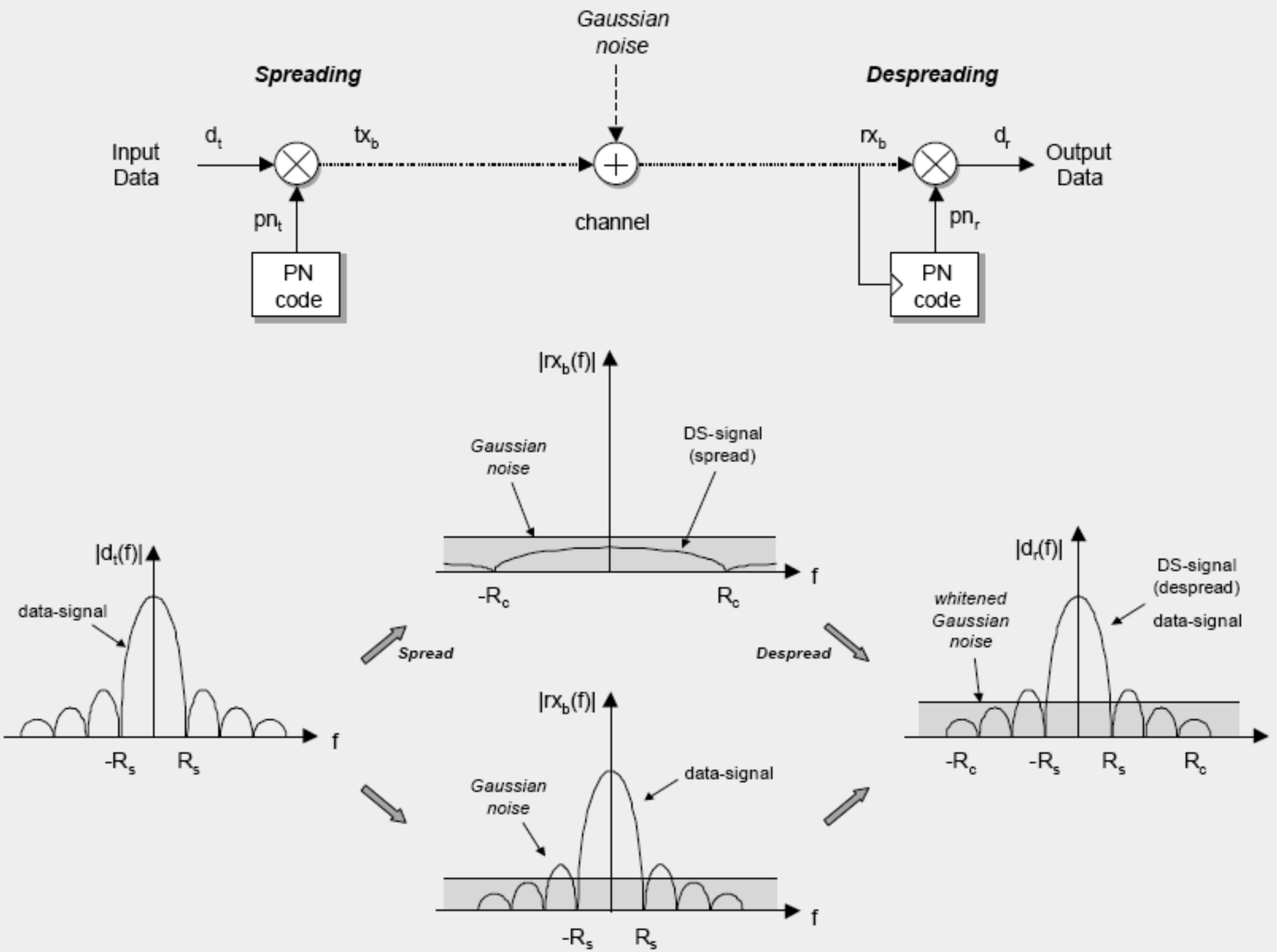

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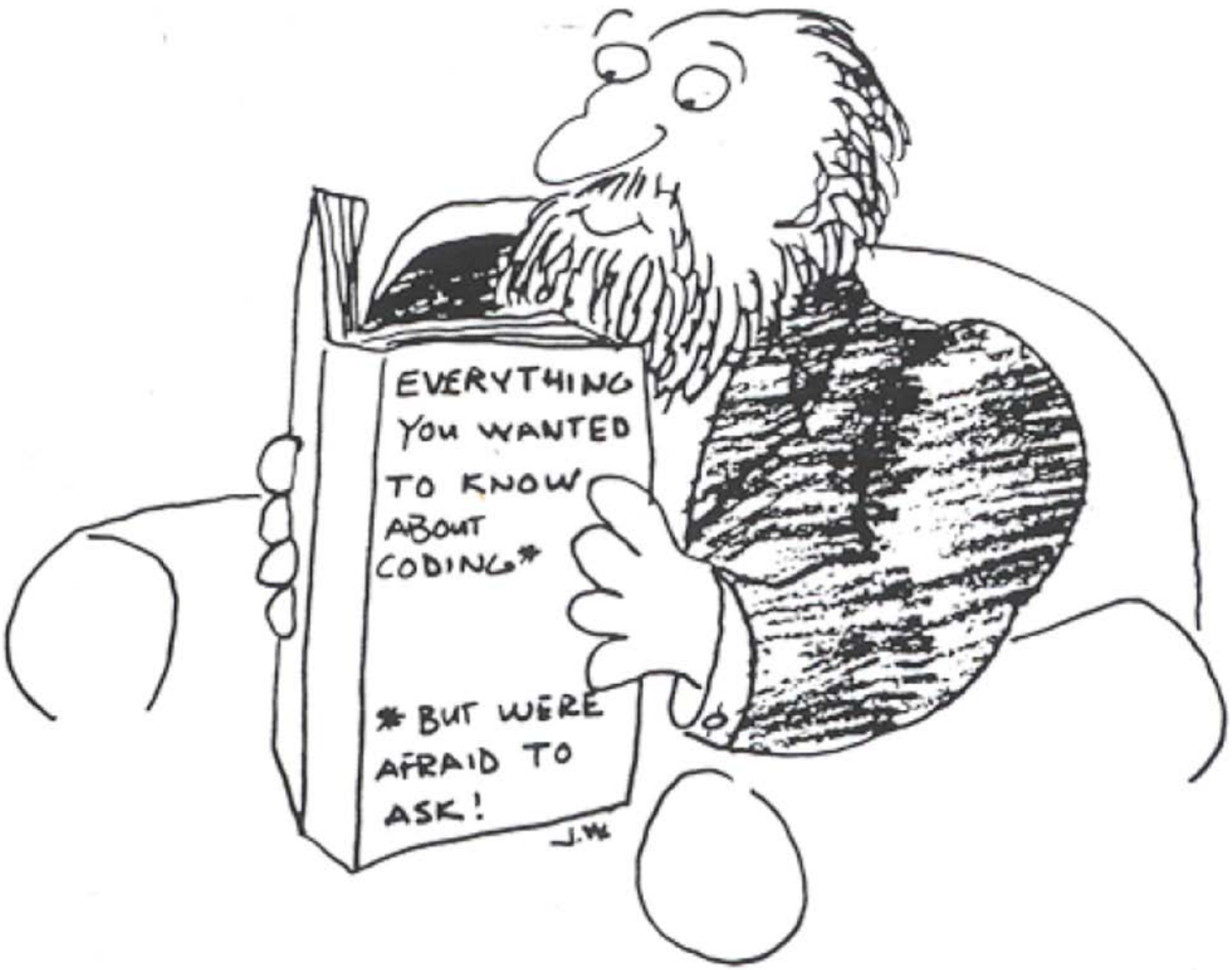
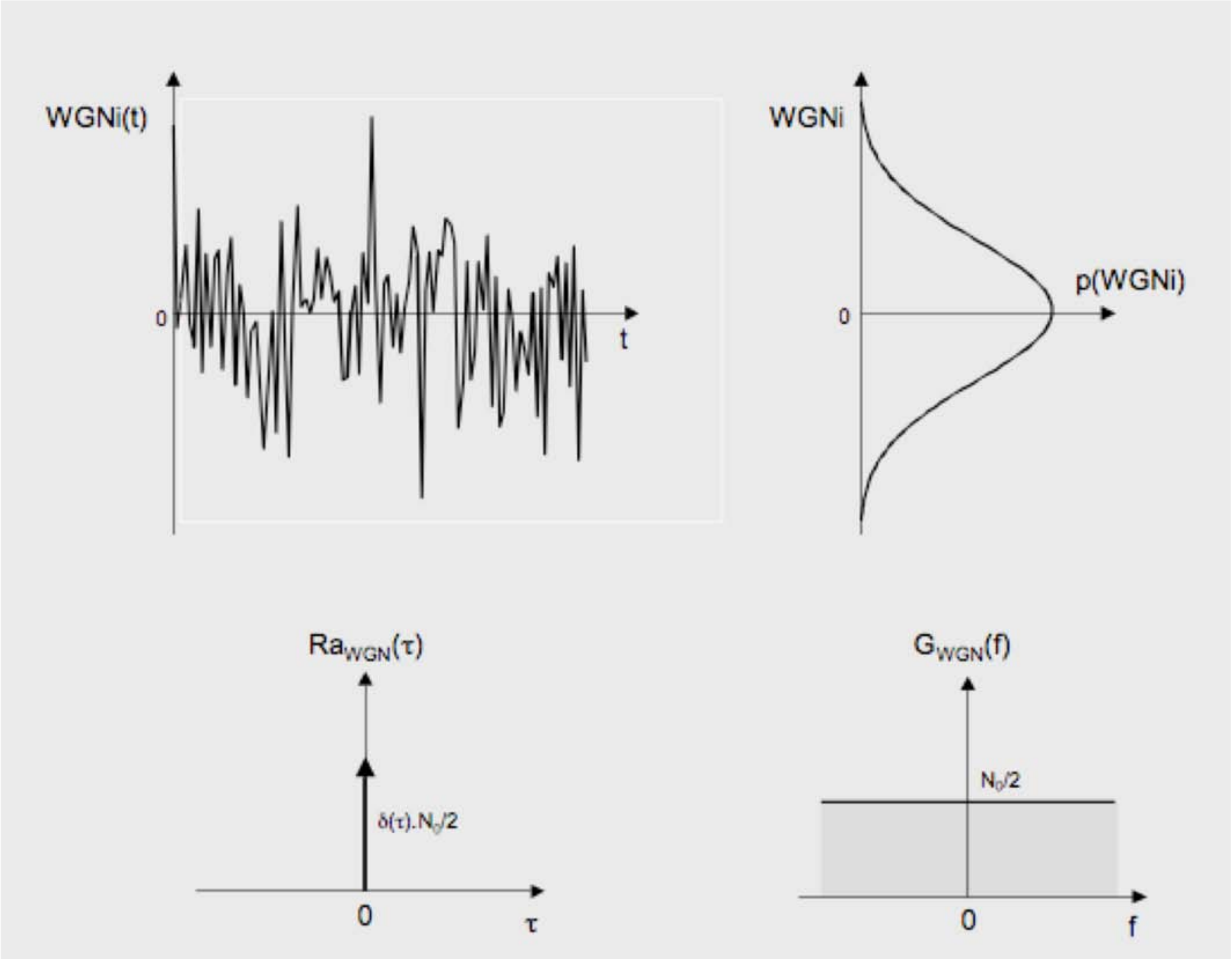
2. Code Sequences



White Noise Sequences



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III. PSEUDORANDOM SEQUENCE GENERATORS

In Section II, we examined how a purely random sequence can be used to spread the signal spectrum. Unfortunately, in order to despread the signal, the receiver needs a replica of the transmitted sequence (in almost perfect time synchronism). In practice, therefore, we generate pseudorandom or pseudonoise (PN) sequences so that the following properties are satisfied. They

1) are easy to generate
2) have randomness properties
3) have long periods
4) are difficult to reconstruct from a short segment.

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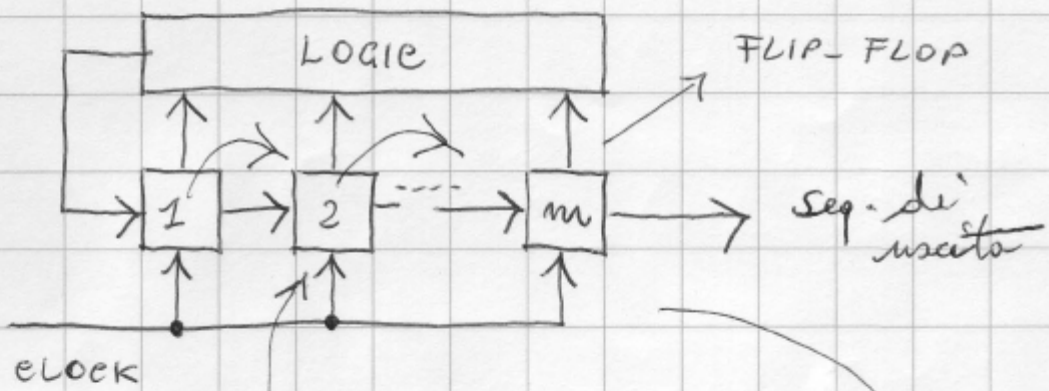
Maximal length sequences (m-sequences)



$s_j(k+1) = s_{j-1}(k)$, $\begin{cases} k \geq 0 \\ 1 \leq j \leq m \end{cases}$

stato del flip-flop

Sono sequenze periodiche di periodo N che può essere al max pari a $2^m - 1$

Al massimo abbiamo 2^m stati (distinti) possibili

The number of possible different states is limited to 2^m

The maximum period N is equal to Nmax = 2^m -1

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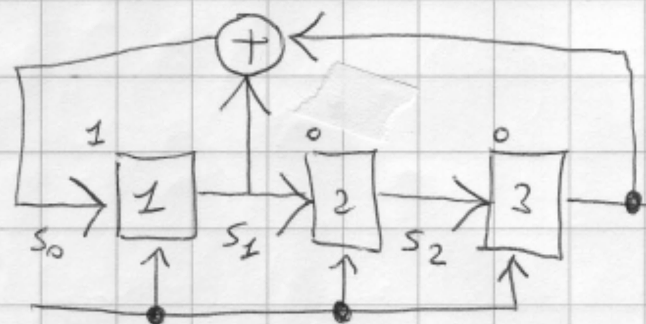
N=2^m -1 : m-sequences

* Se $N = 2^m - 1$ → Seq. a massima lunghezza (m-sequences)



Seq. iniziale: 100 → È indifferente

00111010 ------

$N = 2^3 - 1 = 7$

100, 110, 111, 011, 101, 010, 001, 100, ---

deve essere diversa da 000

* Altra seq. iniziale → c'è solo un ritardo nella sequenza generata

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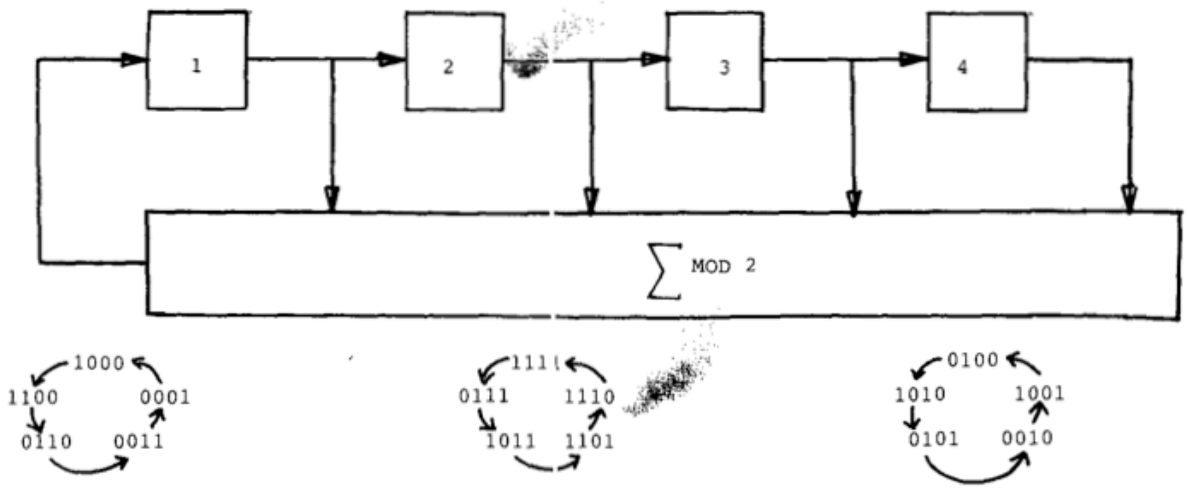

Fig. 5. Four-stage LFSR and its state cycles.

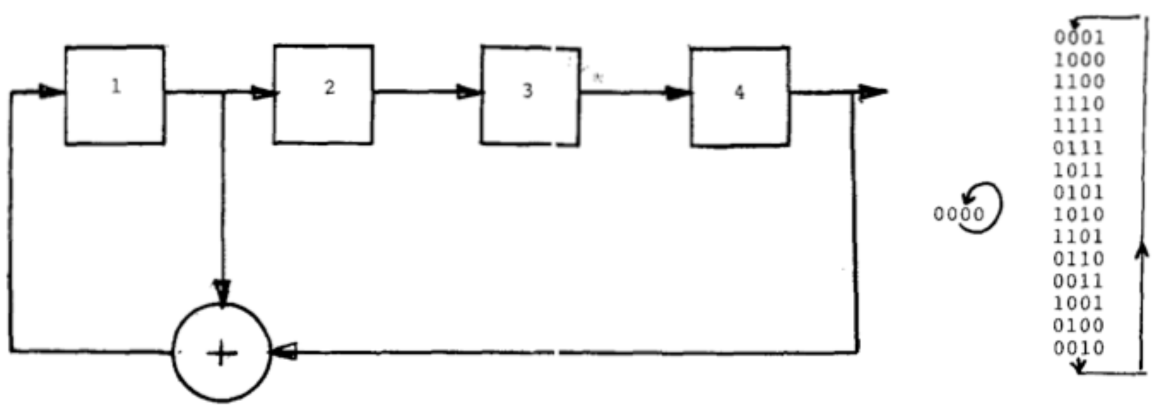

Fig. 6. Four-stage maximal length LFSR and its state cycles.

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Properties of the *m-sequences*

RUN RUN Run Run

0 0 1 1 1 0 1 ------ → 4 run : 2 di $l = 1$, 1 di $l = 2$

8

* balance property: il n° di "1" è maggiore (sempre) di uno rispetto al # di "0"

* metà dei RUN è di lunghezza 1, $\frac{1}{4}$ è di lunghezza 2, $\frac{1}{8}$ è di lunghezza 3, ---

$$n° \text{ di RUN} = \left(\frac{M+1}{2}\right), \quad M = 2^m - 1$$

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Properties of the *m-sequences*

If we do have a maximal length sequence, then this sequence will have the following pseudorandomness properties [4].

1) There is an approximate balance of zeros and ones (2^{r-1} ones and $2^{r-1} - 1$ zeros).

2) In any period, half of the runs of consecutive zeros or ones are of length one, one-fourth are of length two, one-eighth are of length three, etc.

3) If we define the ± 1 sequence $C_n' = 1 - 2C_n$; $C_n = 0, 1$, then the autocorrelation function $R_C'(\tau) \triangleq 1/L \; \Sigma_{k=1}^{L} C_k' C_{k+\tau}'$ is given by

$$R_{C'}(\tau) = \begin{cases} 1, & \tau = 0, L, 2L \cdots \\ -\dfrac{1}{L}, & \text{otherwise} \end{cases} \tag{29}$$

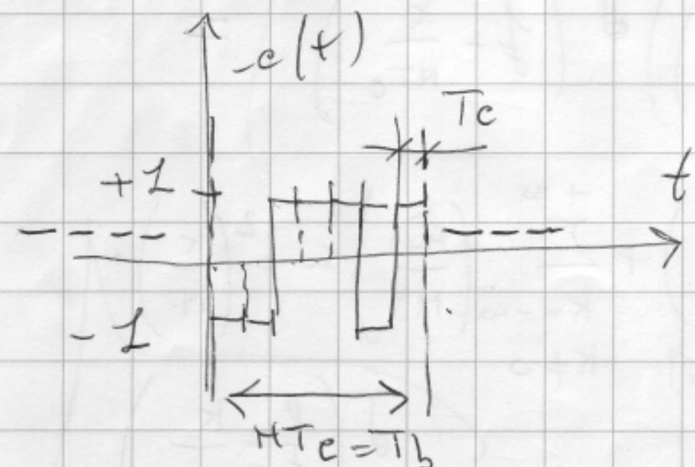
where $L = 2^r - 1$.

Power Spectral Density

* $T_b = M T_c \rightarrow$ tempo di chip

(periodo)

$$R_c(\tau) = \frac{1}{T_b}\int_{-T_b/2}^{T_b/2} \overset{\pm 1}{c(t)\,c(t-\tau)}\,dt = \begin{cases} 1 - \dfrac{(M+1)}{M T_c}|\tau|, & |\tau| \le T_c \\ -\dfrac{1}{M}, & \text{altrove (nel periodo)} \end{cases}$$



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$$\mathrm{rect}\left(\frac{\tau}{MT_c}\right)$$

$$R_c(\tau) = \left[-\frac{1}{M} + \left(1 + \frac{1}{M}\right) \mathrm{tri}\left(\frac{\tau}{T_c}\right)\right] * \delta_{MT_c}(\tau)$$

$$S_c(f) = \frac{1}{M^2}\,\delta(f) + \frac{(M+1)}{M^2} \sum_{\substack{n=-\infty \\ n \neq 0}}^{+\infty} \mathrm{sinc}^2\left(\frac{n}{M}\right) \delta\left(f - \frac{n}{MT_c}\right)$$

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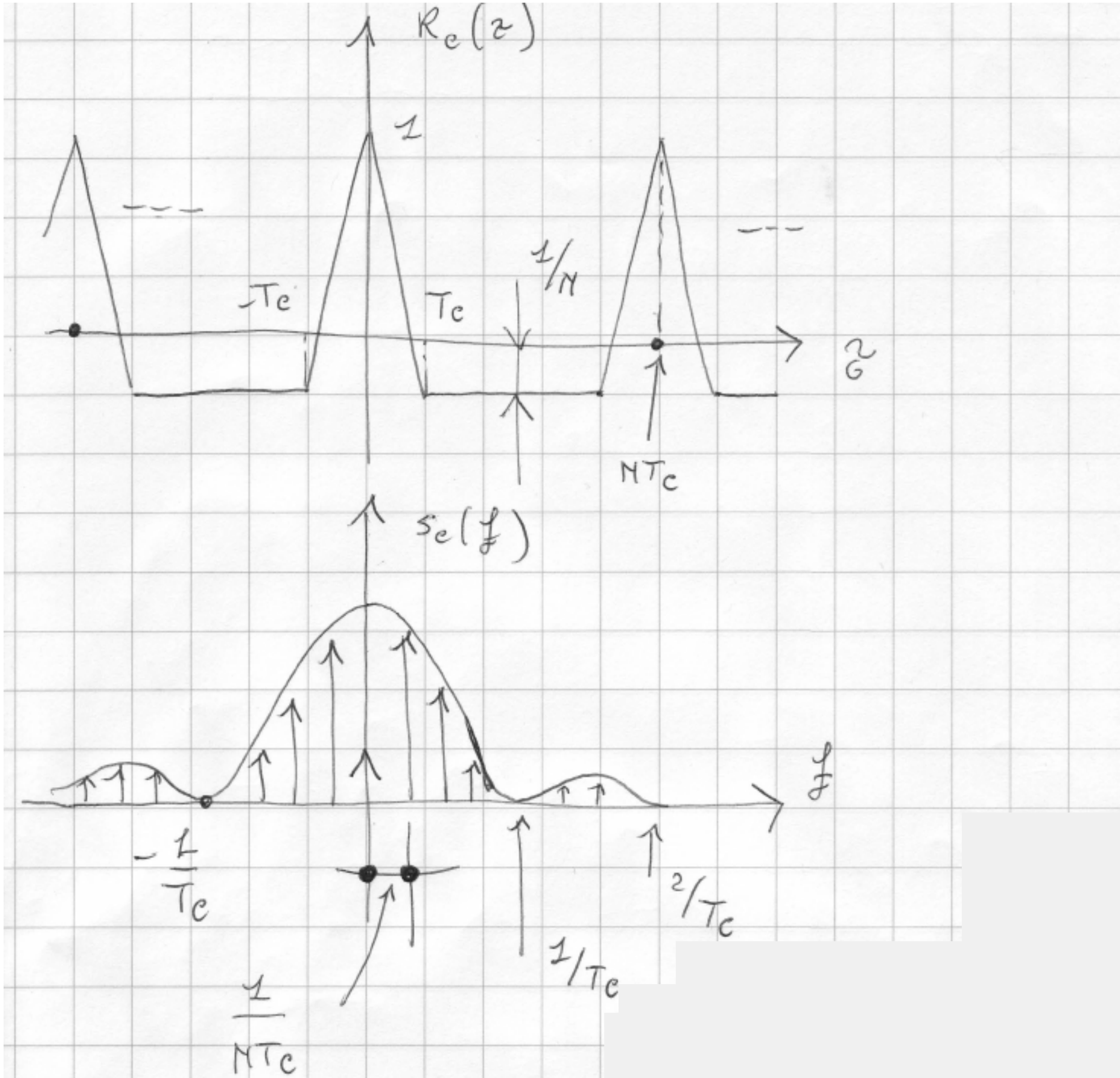

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Spectral properties of m-sequences

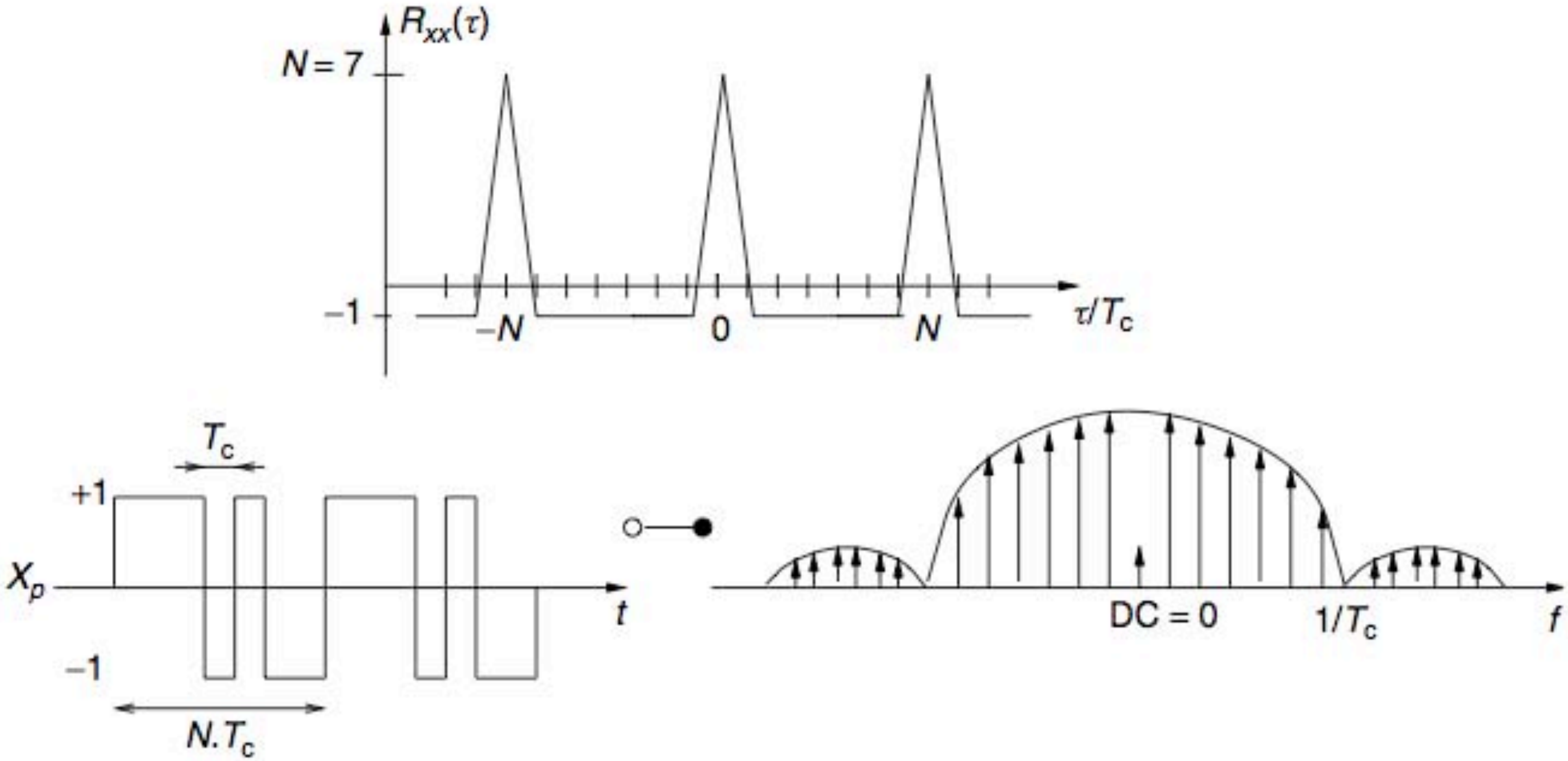

Figure 5.17 Autocorrelation and the frequency occupation of a periodic sequence

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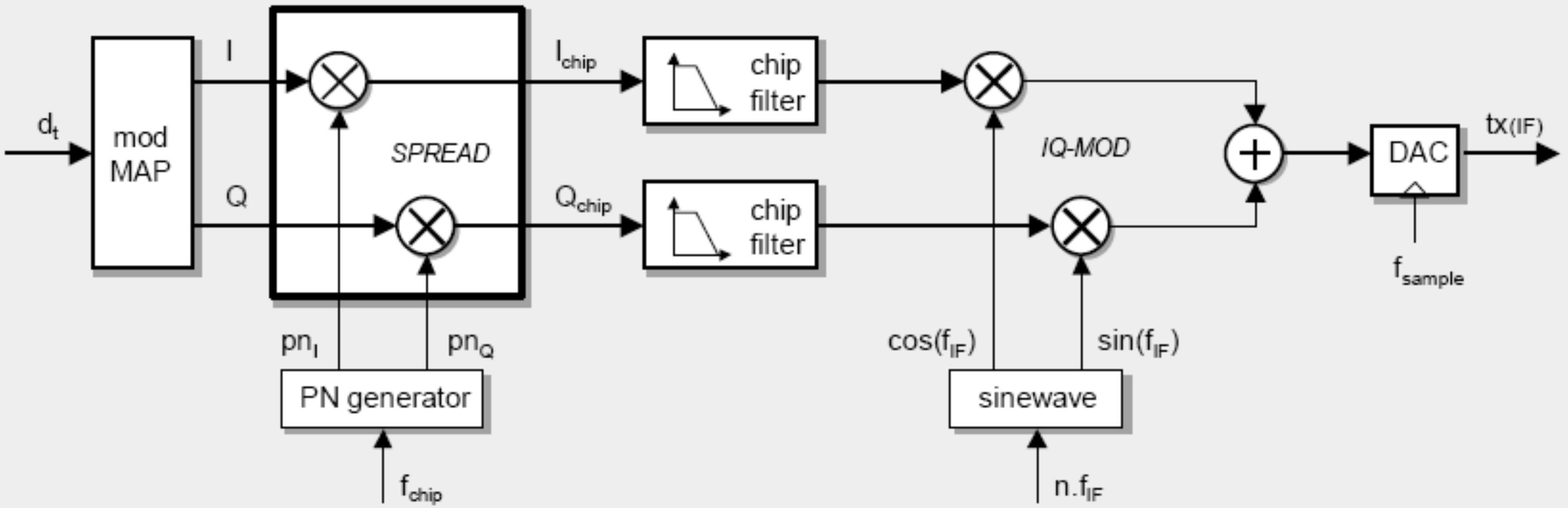
6. Transmitter Architecture

A typical architecture of a Direct Sequence Spread Spectrum (DS-SS) transmitter:



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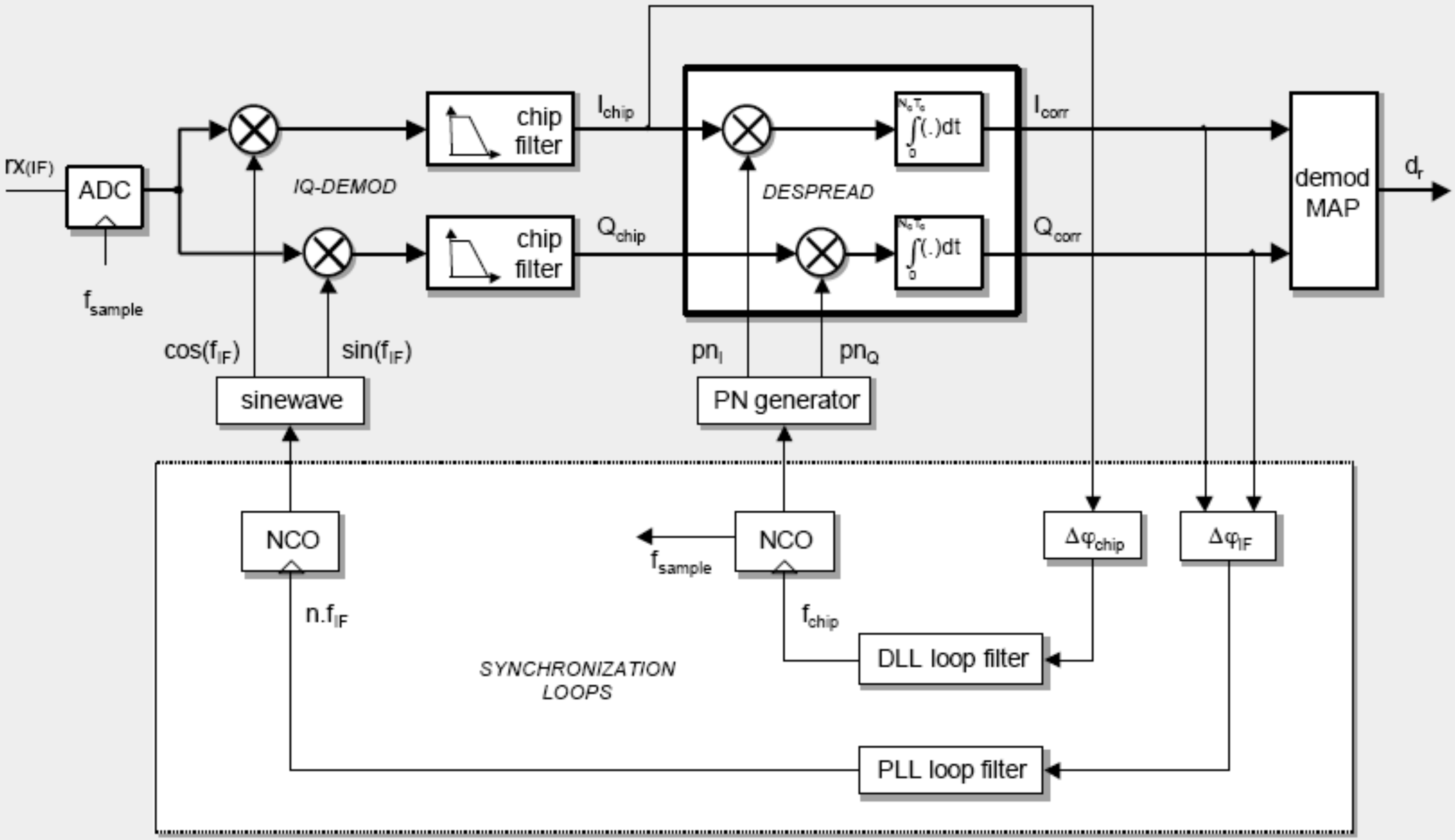
7. Receiver Architecture

A typical architecture of a Direct Sequence Spread Spectrum (DS-SS) receiver:



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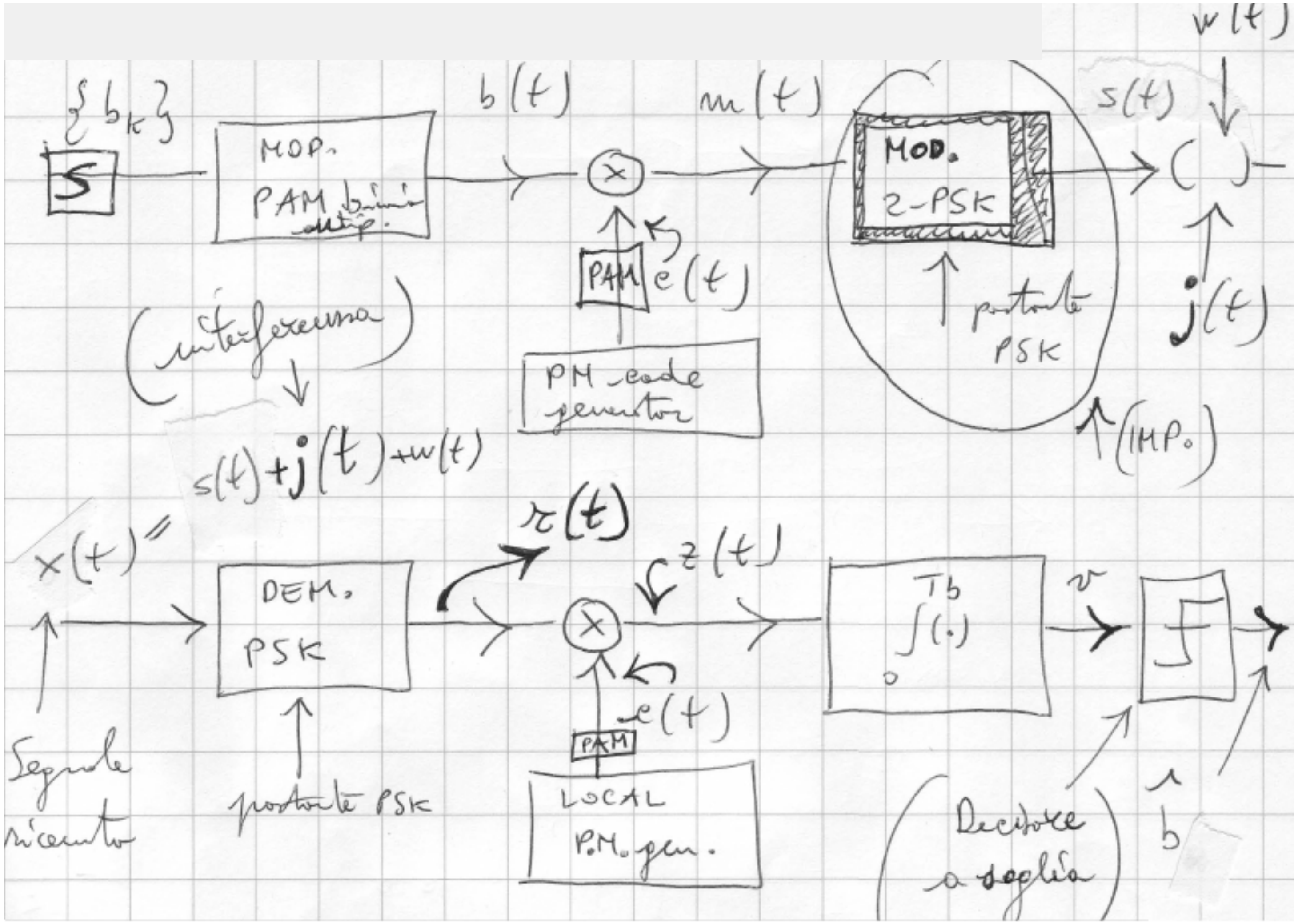
4. System Performances



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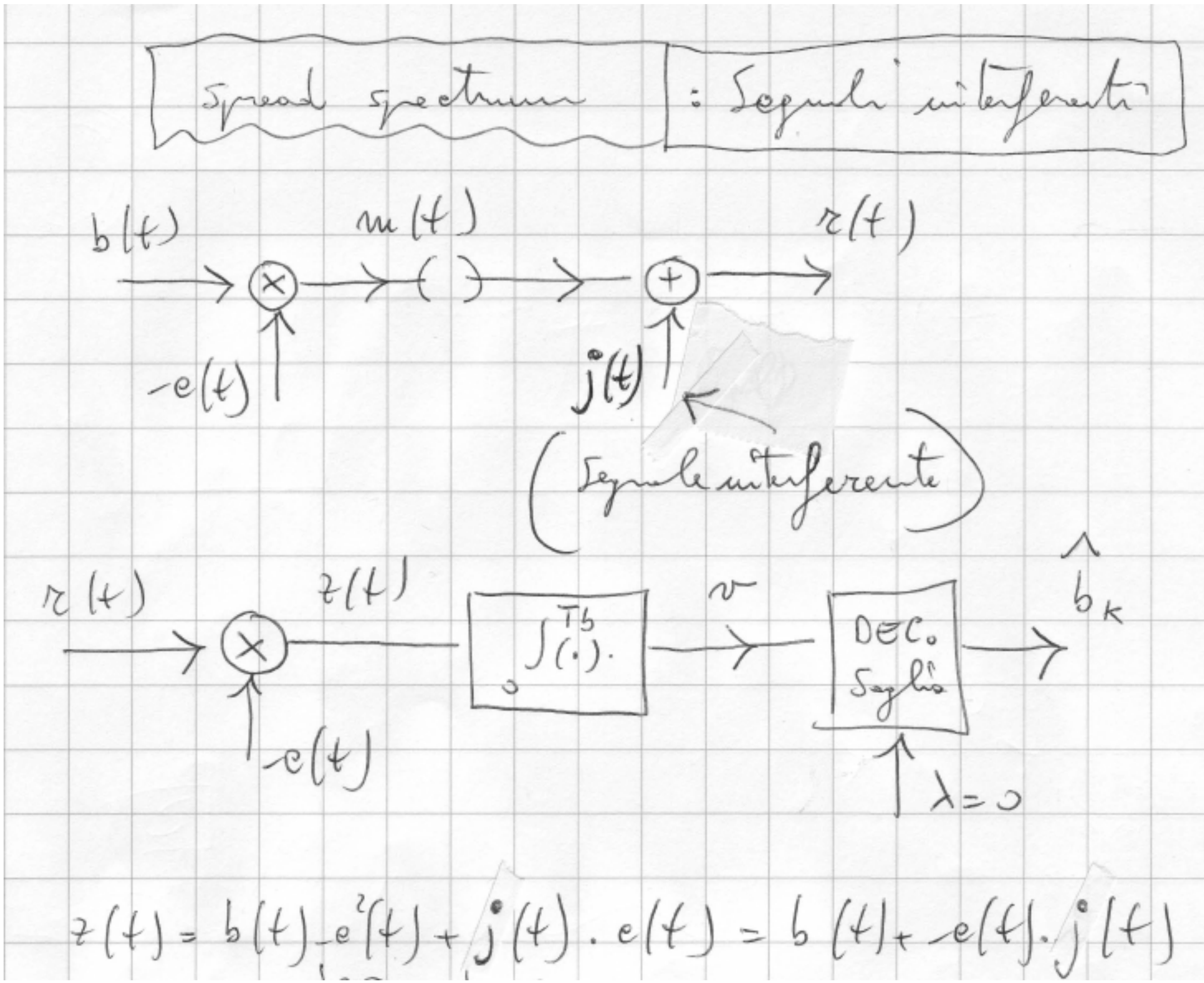
Interference



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Error Probability

$$P(E) \simeq Q\left(\sqrt{\frac{E_b}{J T_e/2}}\right)$$

è come un AWGN (circa...)

J = POT. dell'interferente

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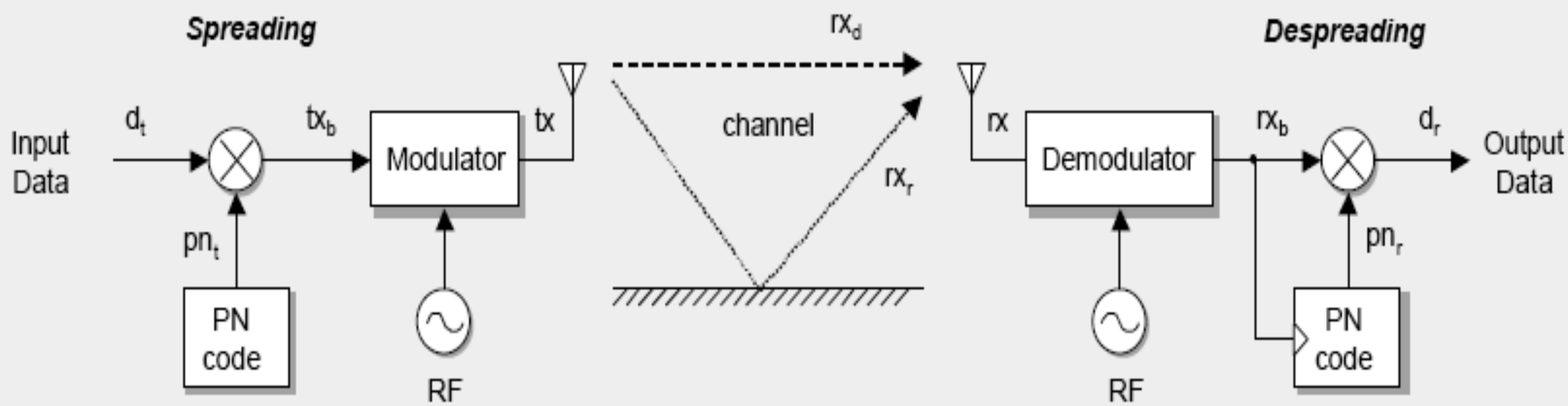
Robustness to Multipath Fading

Suppose two discrete paths: a direct path and only one non-direct path (delayed by a time τ compared to the direct path).



τ = differential time delay between the two paths $\quad 0 < \tau < T$

θ = random angle phase between the carrier of the direct and the non-direct path

α = attenuation of the secundary path

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$$m_1(t) = b_1(t) \cdot c_1(t)$$

$$r_1(t) = m_1(t) + \alpha_1 m_1(t-\tau) + \dots$$

$$v = \int_0^{Tb} r_1(t) \cdot c_1(t)\, dt = \int_0^{Tb} b_1(t)\, c_1^2(t)\, dt + \int_0^{Tb} \alpha_1 \cdot b_1(t-\tau)\, \underbrace{c_1(t)\, c_1(t-\tau)}_{R_c(\tau)}\, dt =$$

è legato a $R_{c_1}(\tau)$!!!

$$= \int_0^{Tb} \underset{\pm 1\,!!!!}{b_1(t)}\, dt + \int_0^{Tb} \alpha_1\, \underset{\pm 1\,!!!}{b_1(t-\tau)}\, \overbrace{c_1(t)\, c_1(t-\tau)}\, dt =$$

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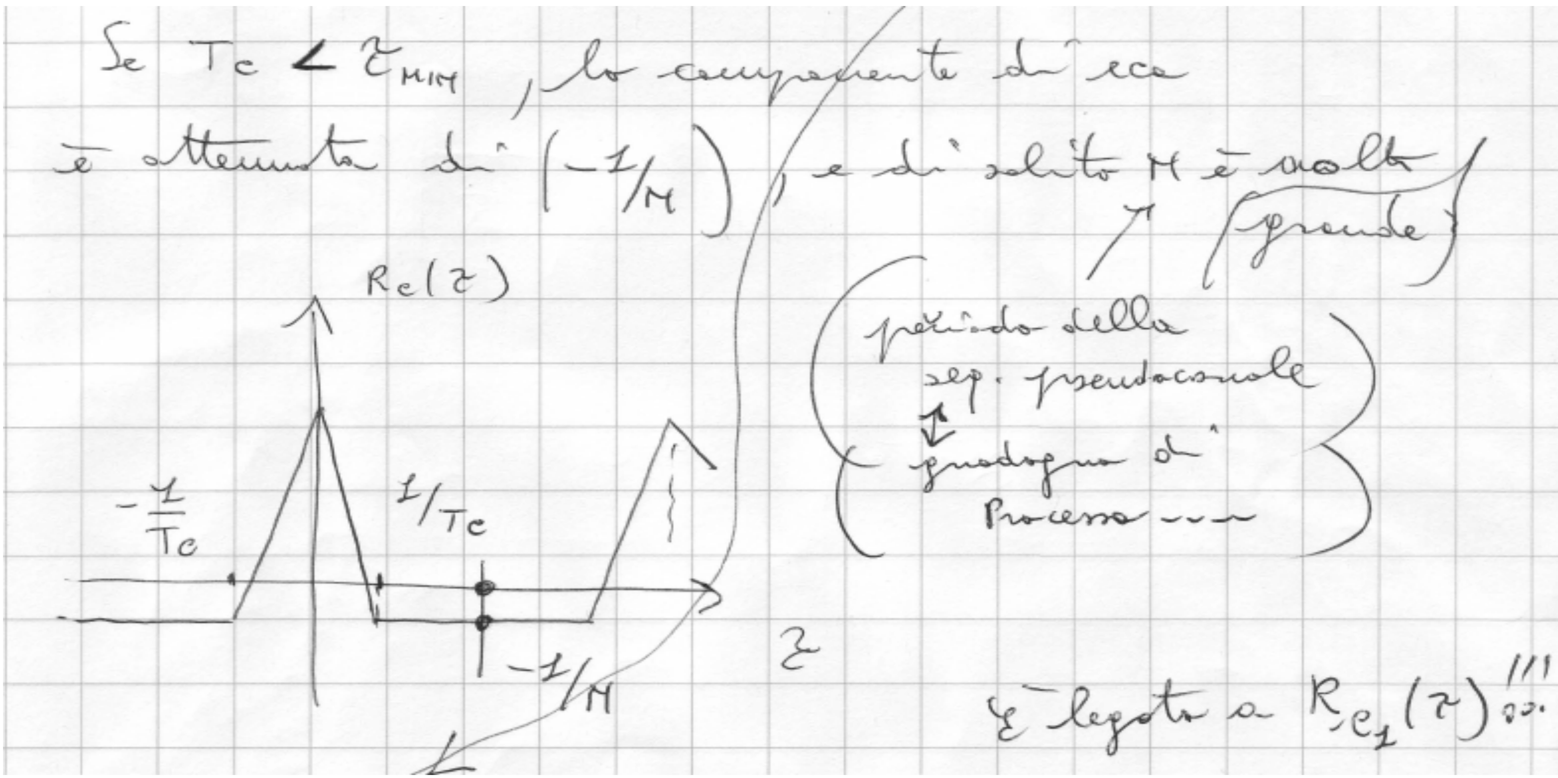
If Tc < Tau_min the echo component is attenuated by 1/N (N is the period of the Pseudo-noise sequence = G, and usually N >> 1).



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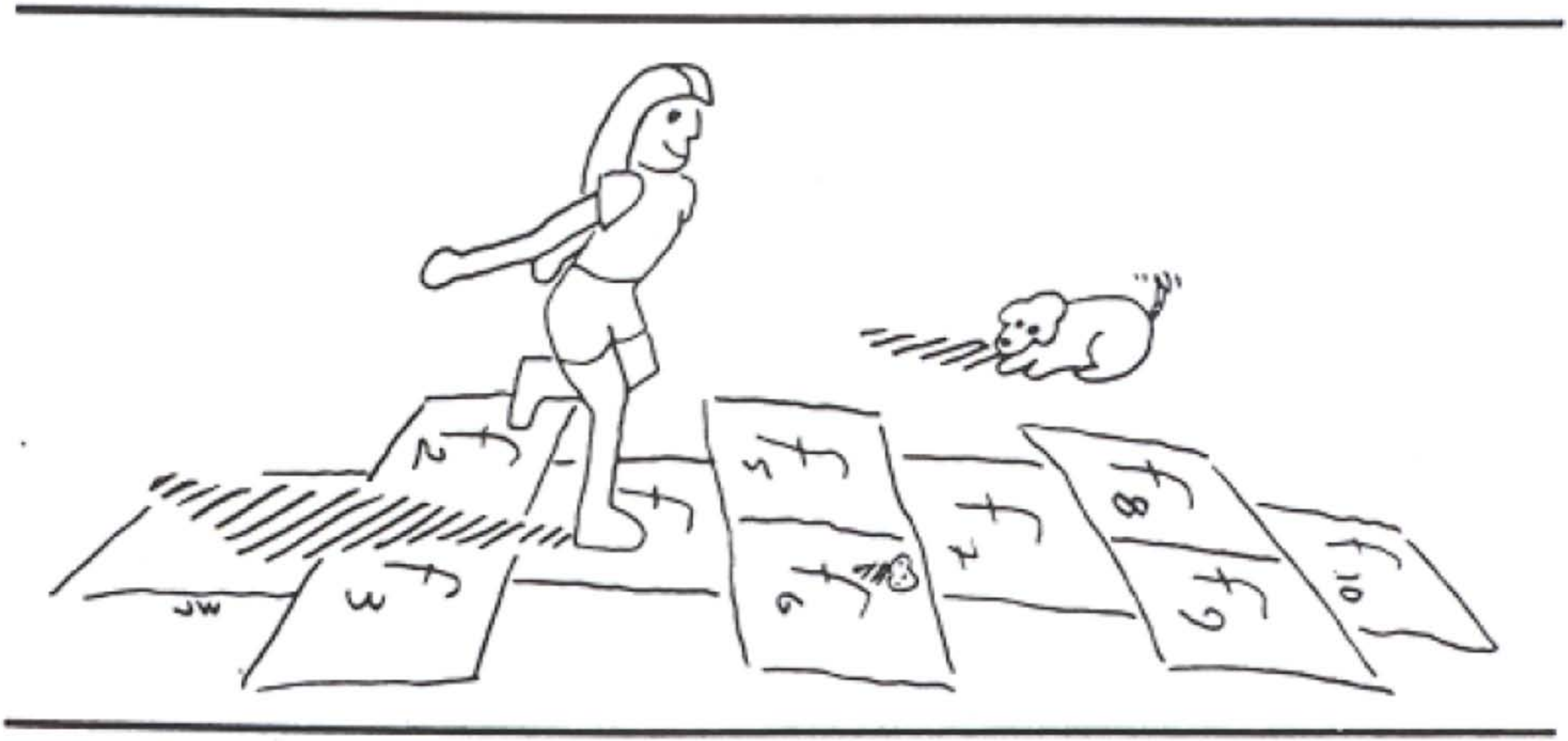
Frequency Hopping Spread Spectrum



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Frequency Hopping Spread Spectrum

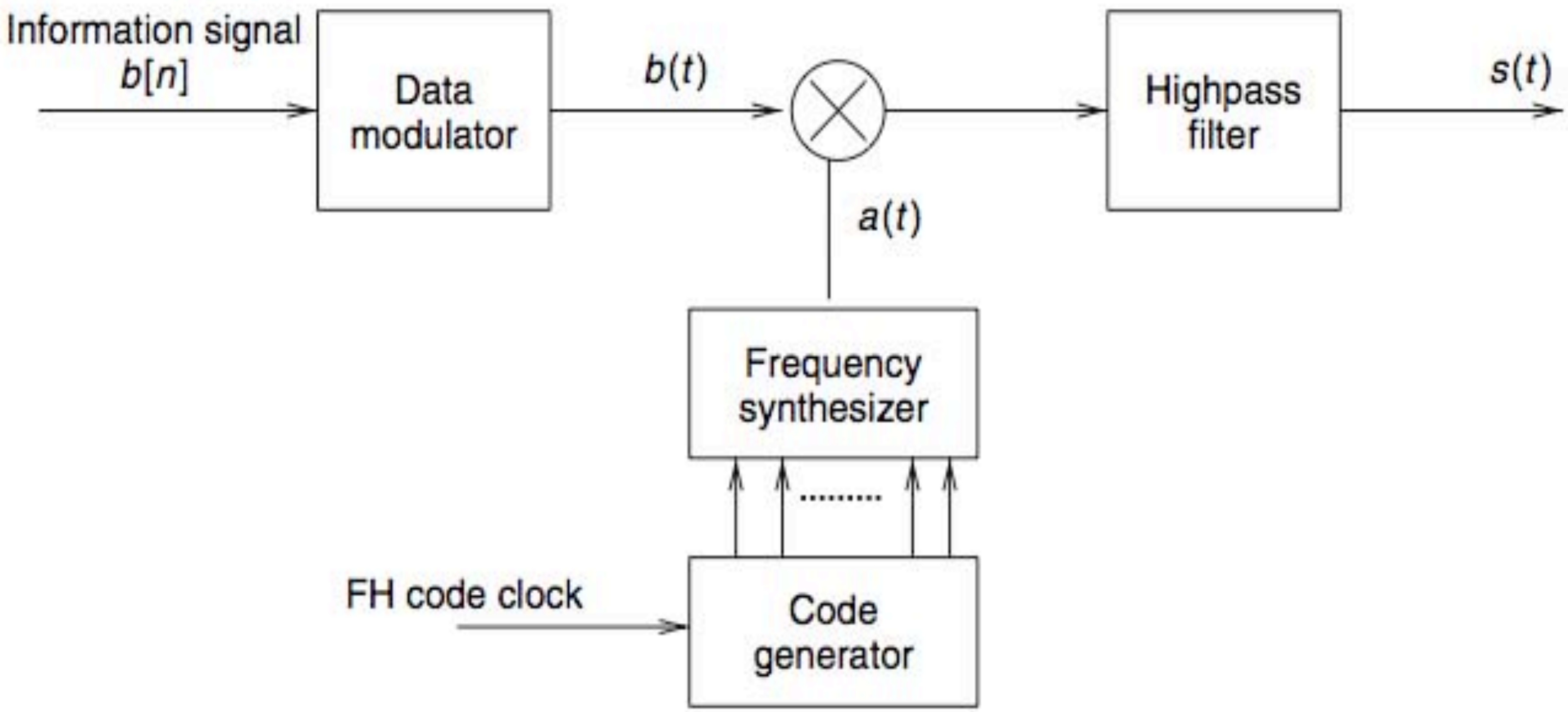

Figure 4.12 Transmitter for FHSS

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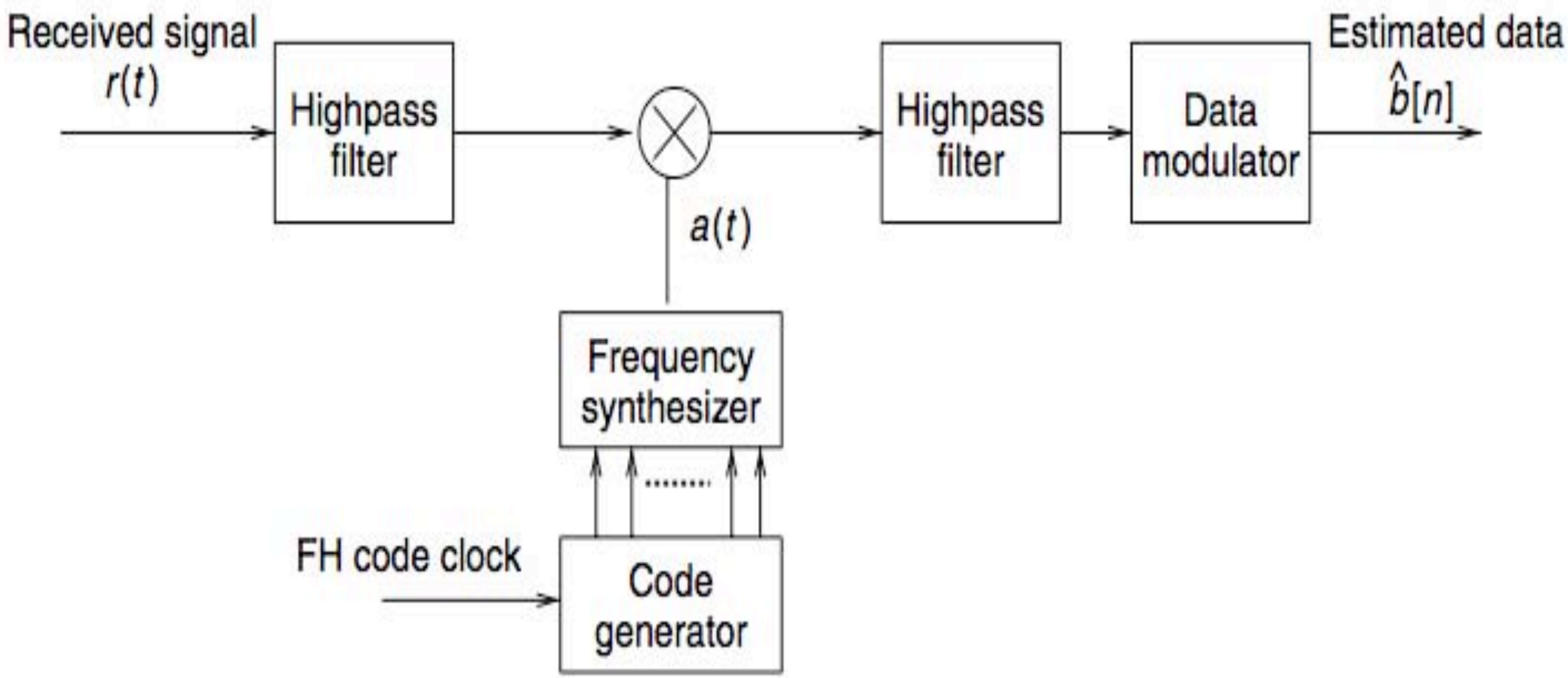

Figure 4.13 Receiver for a FHSS system

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