Multiple Access Protocols

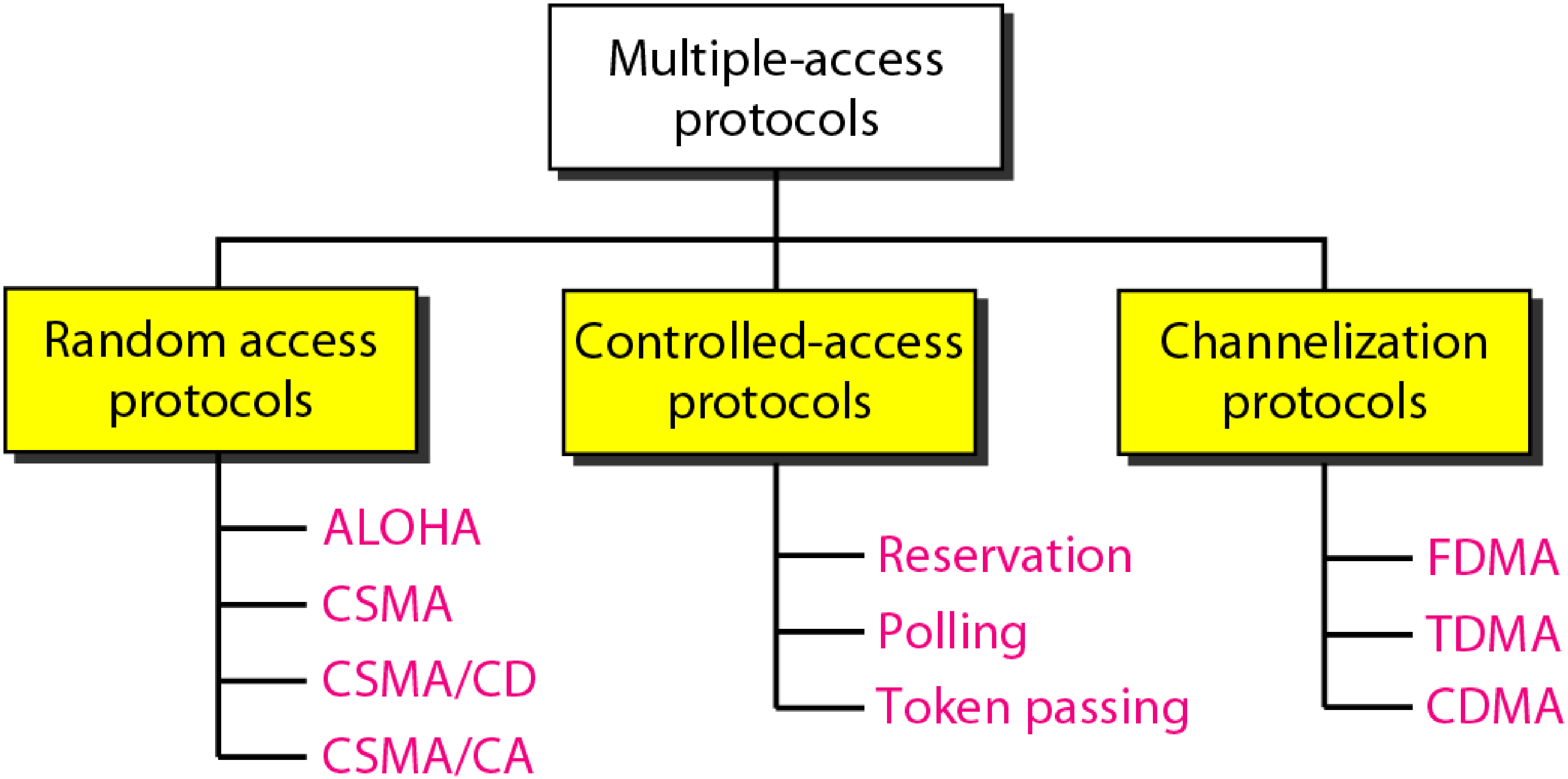
- A **multiple access channel** is one where the received signal at a destination node depends on the signal transmitted by several source nodes.
- **Channel Allocation**: The coordination of the usage of a single channel among multiple source – destination pairs.
- The algorithm which implements the channel allocation are called **medium access control** (MAC) or multiple access protocols.
- MAC protocols can be classified into
  – Conflict free protocols:
  – Random access protocols:

Multiple Access Protocols

- A **Conflict free protocols**: Collisions are completely avoided by allocating the channel access to sources in a predetermined manner. Examples are TDMA, FDMA and CDMA. This is equivalent to circuit switching and is inefficient for bursty type of loads.

- **Random access protocols**: These are classified as contention systems where the stations compete to access the channel. The contention could be completely random or controlled.
- Collisions can occur between transmitted packets of different users trying to access the channel.
- A collided packet has to be transmitted until it is received properly at the destination.

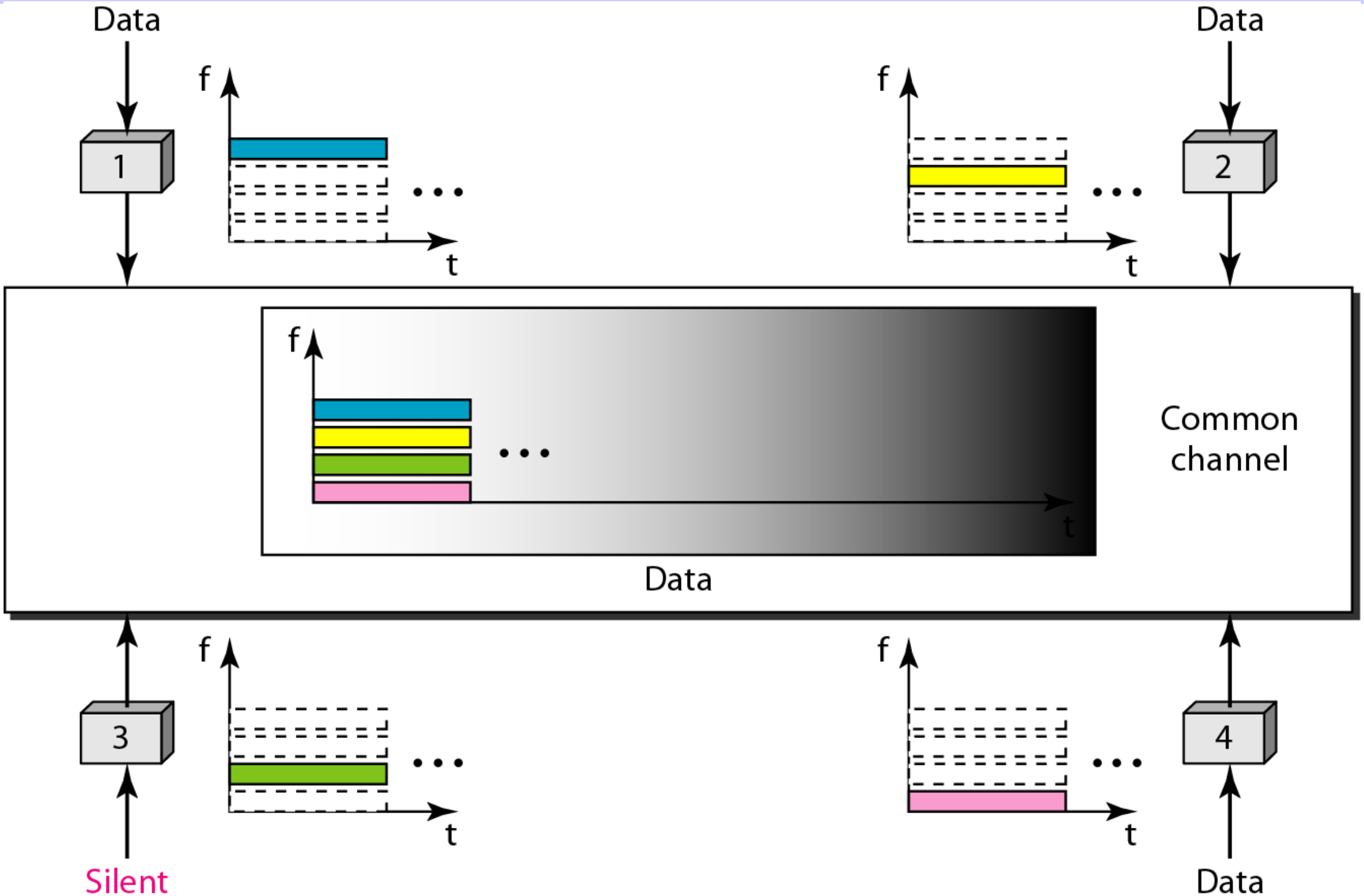
Multiple Access Protocols



Frequency Division Multiple Access (FDMA)

- Let W be the channel bandwidth and let N be the number of users. Each user is allocated W/N of the available B.W for his exclusive use.
- Each user can transmit at any given time provided he uses his own band. Collisions are completely avoided.
- FDMA was used in the first generation of mobile systems known as Advanced Mobile Phone System (AMPS).

Frequency-Division Multiple Access (FDMA)



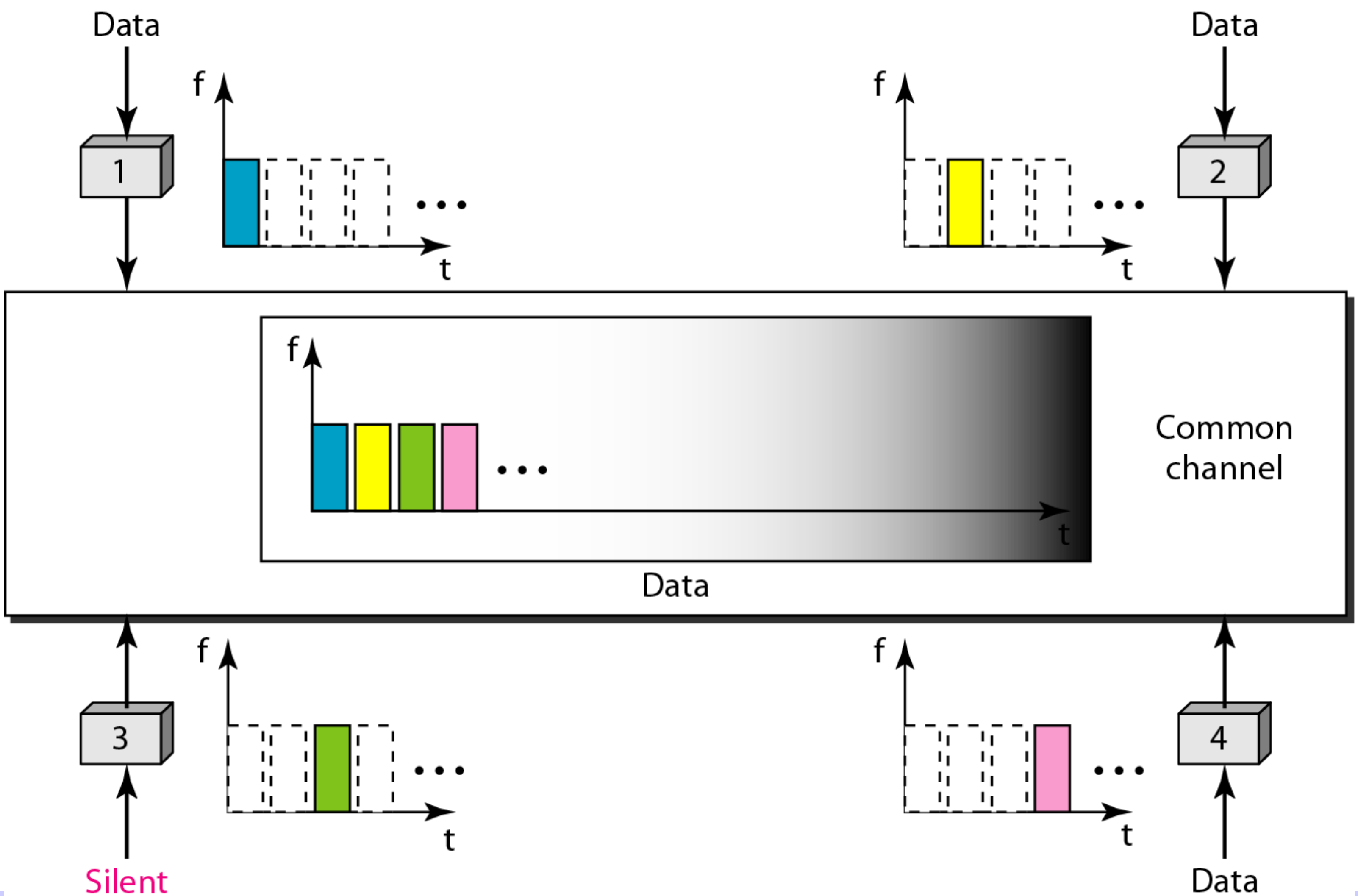
Frequency Division Multiple Access (FDMA)

- **Advantages**:
  - FDMA is simple and **efficient**, especially, when the number of sources is small (and constant) and each user has data to send.
  - It does not require coordination between stations.
- **Disadvantages**:
  - FDMA is **inefficient** when the number of sources is large and varying.
  - It is also inefficient when the sources send the information in a bursty manner; channel is underutilized.
  - Some stations may not have data to send while others have bursty data.

Time Division Multiple Access (TDMA)

- Let N be the number of sources. The time axis is divided into N slots and each slot is allocated to a source.
- Each source transmits only during its slot, avoiding the possibility of a collision.
- When a user transmits during its slot, it utilizes the entire B.W. of the channel and this B.W. will be made available to the next user during the succeeding time slot.
- The collection of the N slots is called a **cycle**.
- TDMA requires some form of synchronization.
- TDMA suffers from the same disadvantages as FDMA, namely, the underutilization when the sources have intermittent and inactive data sources.

Time Division Multiple Access



Code Division Multiple Access (CDMA)

- Let N be the number of sources.
- The N users **occupy the same frequency band** and **transmit / receive messages simultaneously in time**.
- Different users are distinguished by distinct codes assigned to them.
- CDMA relies on a technique called **spread spectrum** in which the transmitted signal occupies a bandwidth much larger than the BW of the message
- The third generation (3 G) of mobile communications uses CDMA.

Spread Spectrum and CDMA

- **Spread spectrum**: A technology in which the bandwidth of a signal is spread before transmission.
  - Distinct advantages of being **secure** and **robust** against intentional interference (jamming).
  - Applicable to digital as well as analog signals because both can be modulated and "spread".
  - It is the digital applications in particular CDMA that made the technology popular in various wireless data networks.
  - Two ways of implementing spread spectrum: ***frequency hopping*** *(to be presented later)* and ***direct sequence*** *(to be discussed next)*

Spread Spectrum

- Let W_1 be the bandwidth of signal $x_1(t)$; narrowband signal

  W_2 be the bandwidth of signal $x_2(t)$; wideband signal

  W be the bandwidth of signal $\mathbf{y(t) = x_1(t)\, x_2(t);}$

Where **y is a product of two time functions**

- Since this is a multiplication in the time domain, then the spectrum of y(t) is a convolution in the frequency domain.

$$\mathbf{Y(f) = X_1(f) * X_2(f)}$$

- The bandwidth of y(t)

$$\mathbf{W = W_1 + W_2}$$

- If $W_2 >> W_1$, then

$$\mathbf{W \approx W_2}$$

- **Conclusion**: When a narrowband signal is multiplied by a wideband signal, the result is a wideband signal.

Spread Spectrum

Spread data rate

- using an orthogonal code (channelization code) such as the **Walsh- Hadamard sequences**
  - Provides mutual orthogonality among all users in the same cell
- using a **pseudonoise** PN sequence (scrambling code)
  - Provides mutual randomness (low cross correlation) between users in different cells

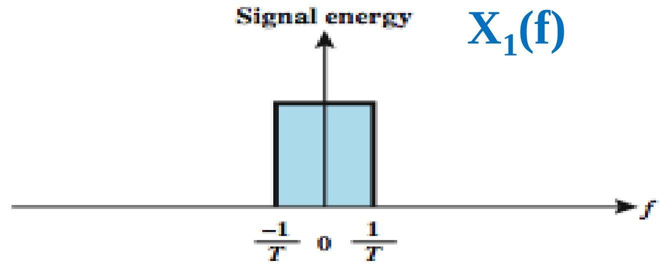
What can be gained from apparent waste of spectrum?

- Immunity from various kinds of noise and multipath distortion
- Can be used for hiding and encrypting signals
- Several users can independently use the same higher bandwidth with very little interference

Concept of spreading the spectrum

Message Signal: Narrowband

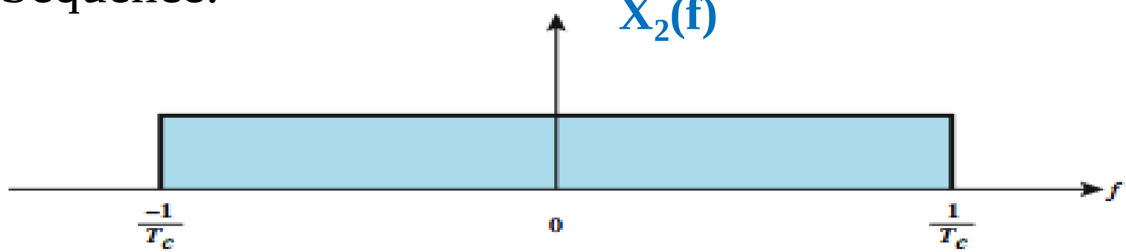
$X_1(f)$



(a) Spectrum of data signal

Spreading Sequence: Wideband

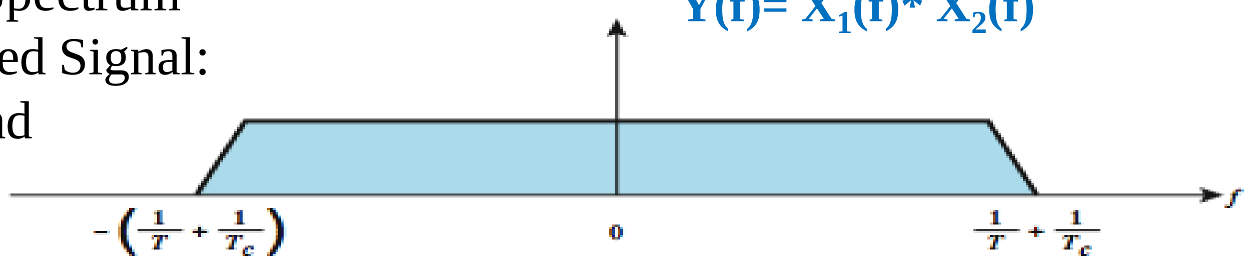
$X_2(f)$



(b) Spectrum of pseudonoise signal

Spread Spectrum Modulated Signal: Wideband

$Y(f) = X_1(f) * X_2(f)$



(c) Spectrum of combined signal

Spread Spectrum
Basic Transmitter and Receiver: Single User

- The next slide shows the block diagram of a spread spectrum transmitter (multiplying by the carrier signal has been removed for simplicity in the presentation)
- The source produces data at a rate of $r_b = 1/ T_b$ bps.
- This is converted to a polar NRZ baseband signal m(t).
- Each bit in m(t) is multiplied by a code **$C=(c_0\ c_1 \ldots\ c_{N-1})$.**
- This is also converted into a polar NRZ waveform C(t)
- We maintain that **$T_b = N\ T_c$** . N is an integer.
- T_c : is the duration of each pulse in the code.
- Effect of modulation is to increase bandwidth of signal to be transmitted.

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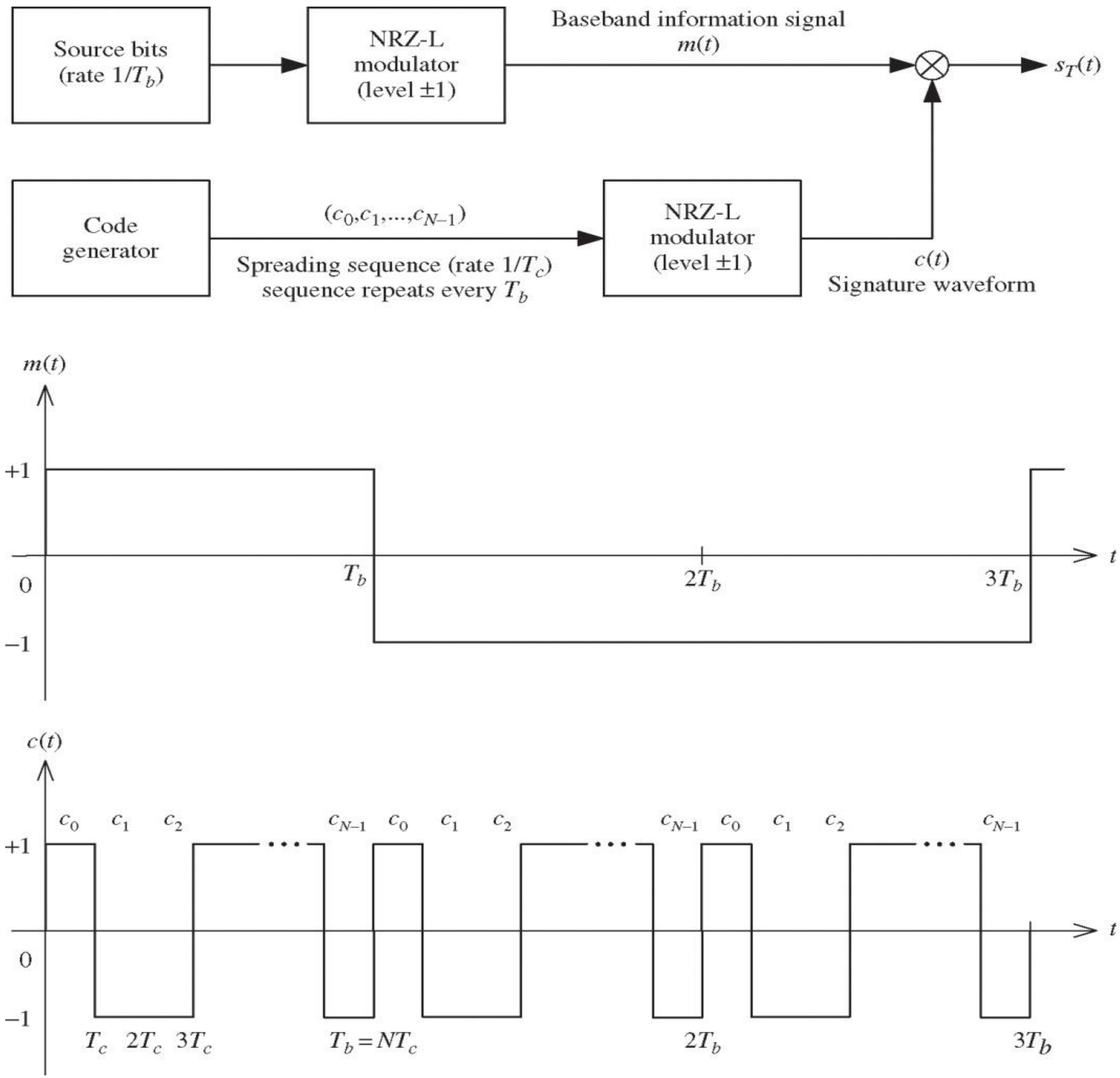
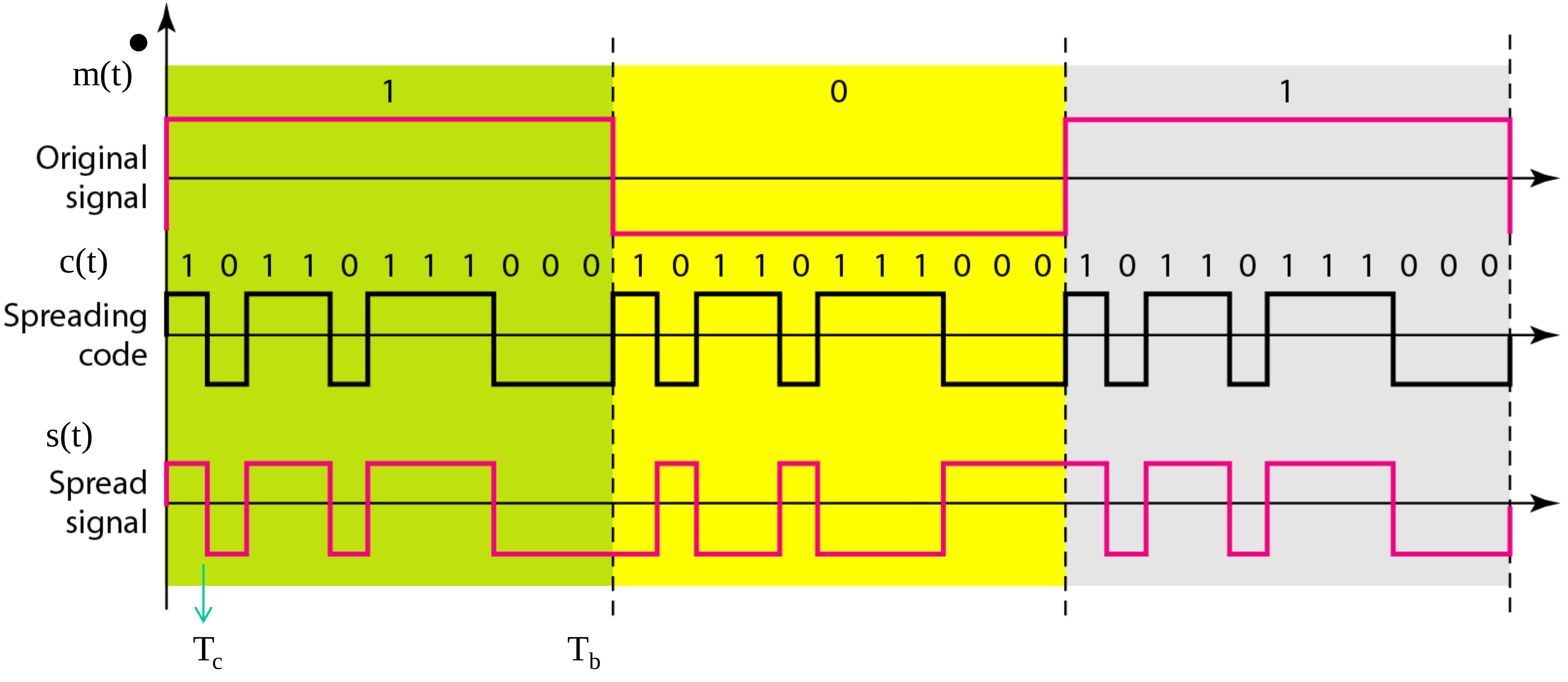
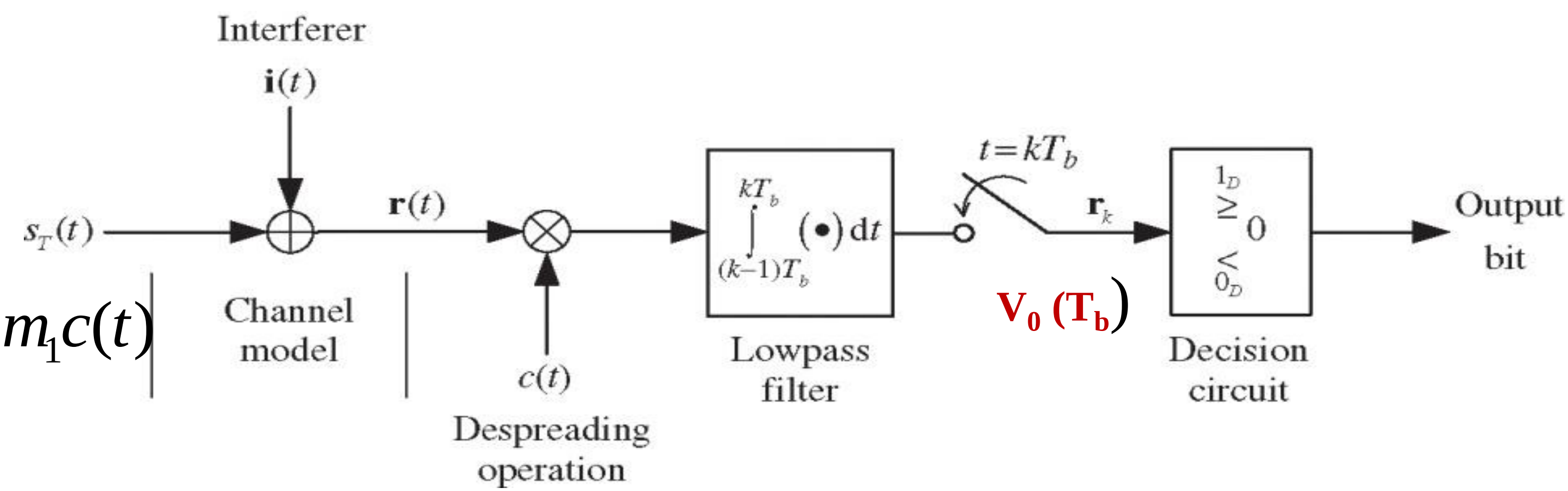


Source bits (rate $1/T_b$)
NRZ-L modulator (level ±1)
Baseband information signal $m(t)$
$s_T(t)$
Code generator
$(c_0, c_1, \ldots, c_{N-1})$
Spreading sequence (rate $1/T_c$) sequence repeats every T_b
NRZ-L modulator (level ±1)
$c(t)$ Signature waveform
$m(t)$
+1
0
−1
T_b
$2T_b$
$3T_b$
t
$c(t)$
c_0 c_1 c_2 c_{N-1}
+1
0
−1
T_c $2T_c$ $3T_c$
$T_b = NT_c$
$2T_b$
$3T_b$
t

Message and Chip Sequence Multiplication



Receiver Side: No Interference Assumed



$m_1 c(t)$

$V_0(T_b)$

Here we assume that the interference i(t)=0.

$$V_0(T_b) = \int_0^{T_b} [m_1 c(t)] c(t) dt$$

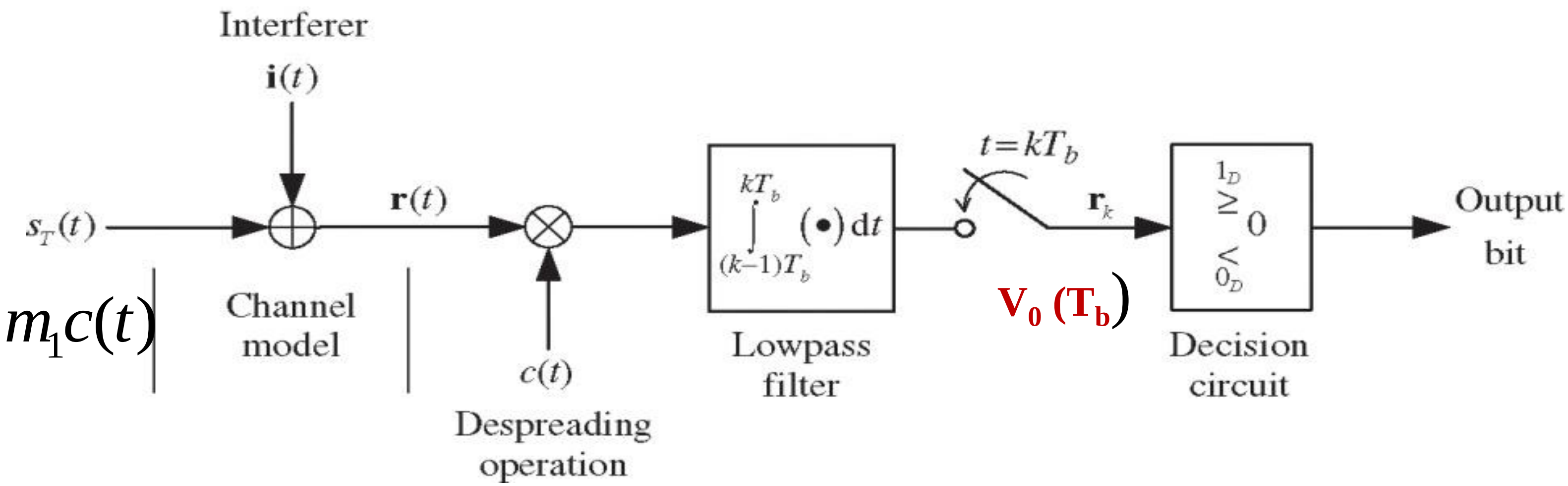
$$\int_0^{T_b} c^2(t) dt = T_b$$

$$= m_1 \int_0^{T_b} c^2(t) dt$$

Output is proportional to message: Perfect Demodulation

$$= m_1 T_b$$

Receiver Side with Interference



Here we assume the presence of a jamming signal i(t) that occupies the same bandwidth as the message signal

$$V_0(T_b) = \int_0^{T_b} [m_1 c(t) + i(t)] c(t) dt$$

$$\int_0^{T_b} c^2(t) dt = T_b$$

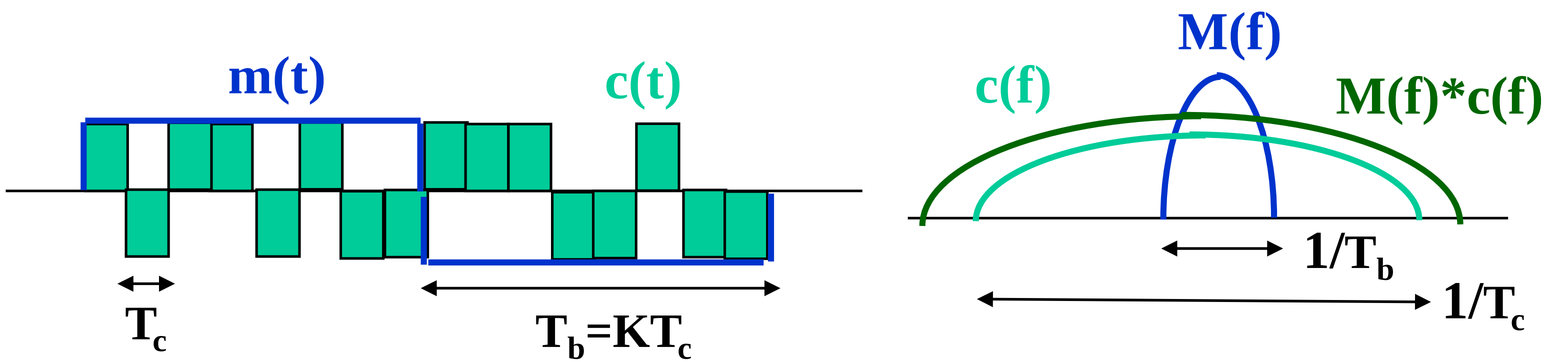
$$= m_1 \int_0^{T_b} c^2(t) dt + \int_0^{T_b} i(t) c(t) dt$$

$$= m_1 T_b + \int_0^{T_b} i(t) c(t) dt$$

Output= Desired signal component + noise component

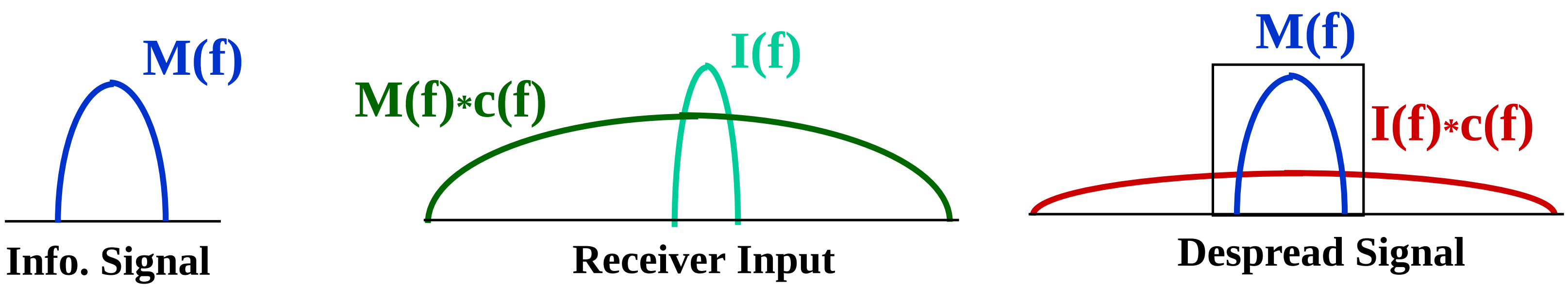
Direct Sequence Spread Spectrum: Effect of Interference

- Bit sequence modulated by **chip** sequence



- Spreads bandwidth by large **gain factor (G) = T_b / T_c = N**
- Despread by multiplying received signal by c(t)
- Spread spectrum mitigates ISI and narrowband interference

ISI and Interference Rejection



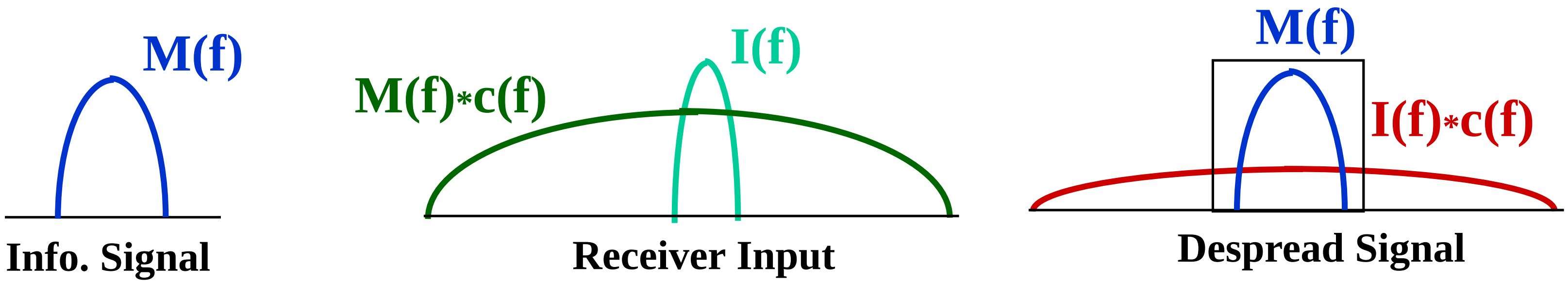
- The effect of multiplying the interference signal at the receiver side with the spreading sequence is to spread the spectrum of the interference noise over the wide bandwidth.
- The signal component returns to occupy the message bandwidth.
- Only a fraction of the noise power that falls within the message bandwidth is admitted at the receiver output

Without spread spectrum **With spread spectrum**

$S/N = P_M/P_I$ $S/N = P_M/(P_I/N) = N\ (P_M/P_I)$

- Spread spectrum increases the signal to interference ratio by the processing gain $T_b\ /\ T_c = N$.

ISI and Interference Rejection



Without spread spectrum

$$P_b^* = Q\left(\sqrt{\frac{2E_b}{I}}\right)$$

With spread spectrum

$$P_b^* = Q\left(\sqrt{\frac{2NE_b}{I}}\right)$$

- Spread spectrum reduces the effect of any interfering signal by the processing gain $T_b / T_c = N$ and hence reduces the bit error probability.

Code Division Multiple Access (CDMA)

- Consider a system where N users have data to send over a common channel
- All users **share the same frequency band** and **transmit simultaneously in time**
- The data of each user is spread by a unique code or chip , called the **signature waveform.**
- The signature waveforms have to be **orthogonal.**

$$\int_0^{T_b} c_i(t)c_j(t)dt = 0; \quad i \neq j \qquad \int_0^{T_b} c_i(t)c_i(t)dt = T_b; \quad i = j$$

- Used mostly in wireless broadcast channels (cellular, satellite, etc)
- ***Encoded signal*** = (message signal) X (signature waveform)
- ***Decoding:*** inner-product of encoded signal and signature waveform
- Allows multiple users to "coexist" and transmit simultaneously with minimal interference (due to the orthogonality of signature waveforms)

Transmitter and Receiver: Noise-Free System

- Transmitted signal s(t) over one bit interval T_b is:

$$s(t) = m_1 c_1(t) + m_2 c_2(t) + \ldots + m_N c_N(t)$$

- The received signal $r(t) = s(t)$
- To demodulate m_1 , for example, we multiply both sides by c_1 and integrate over T_b .

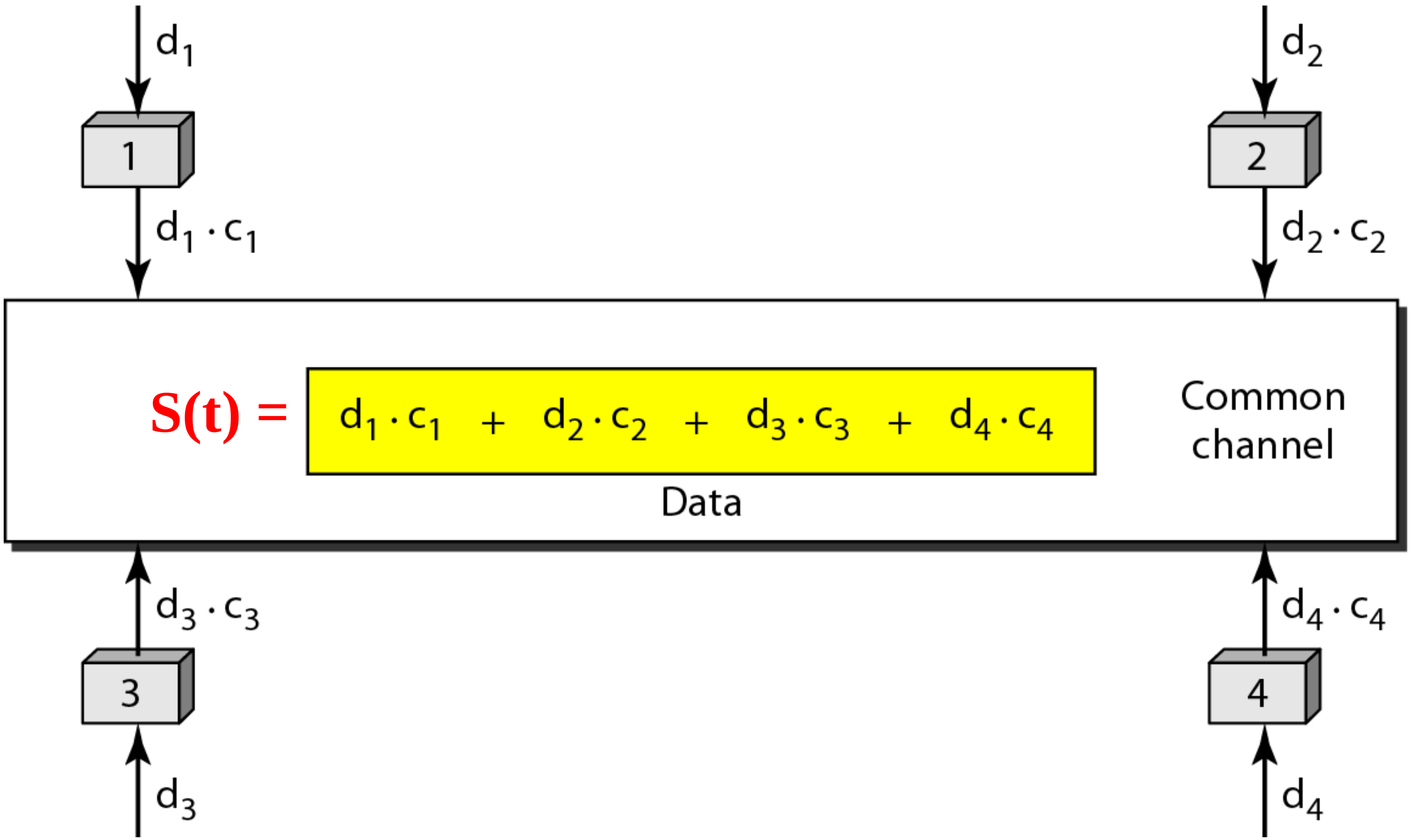
$$\int_0^{T_b} r(t) c_1(t) dt = \int_0^{T_b} c_1(t)[m_1 c_1(t) + m_2 c_2(t) + \ldots + m_N c_N(t)] dt$$

$$V_0(T_b) = m_1 T_b + \int_0^{T_b} c_1(t)[m_2 c_2(t) + \ldots + m_N c_N(t)] dt$$

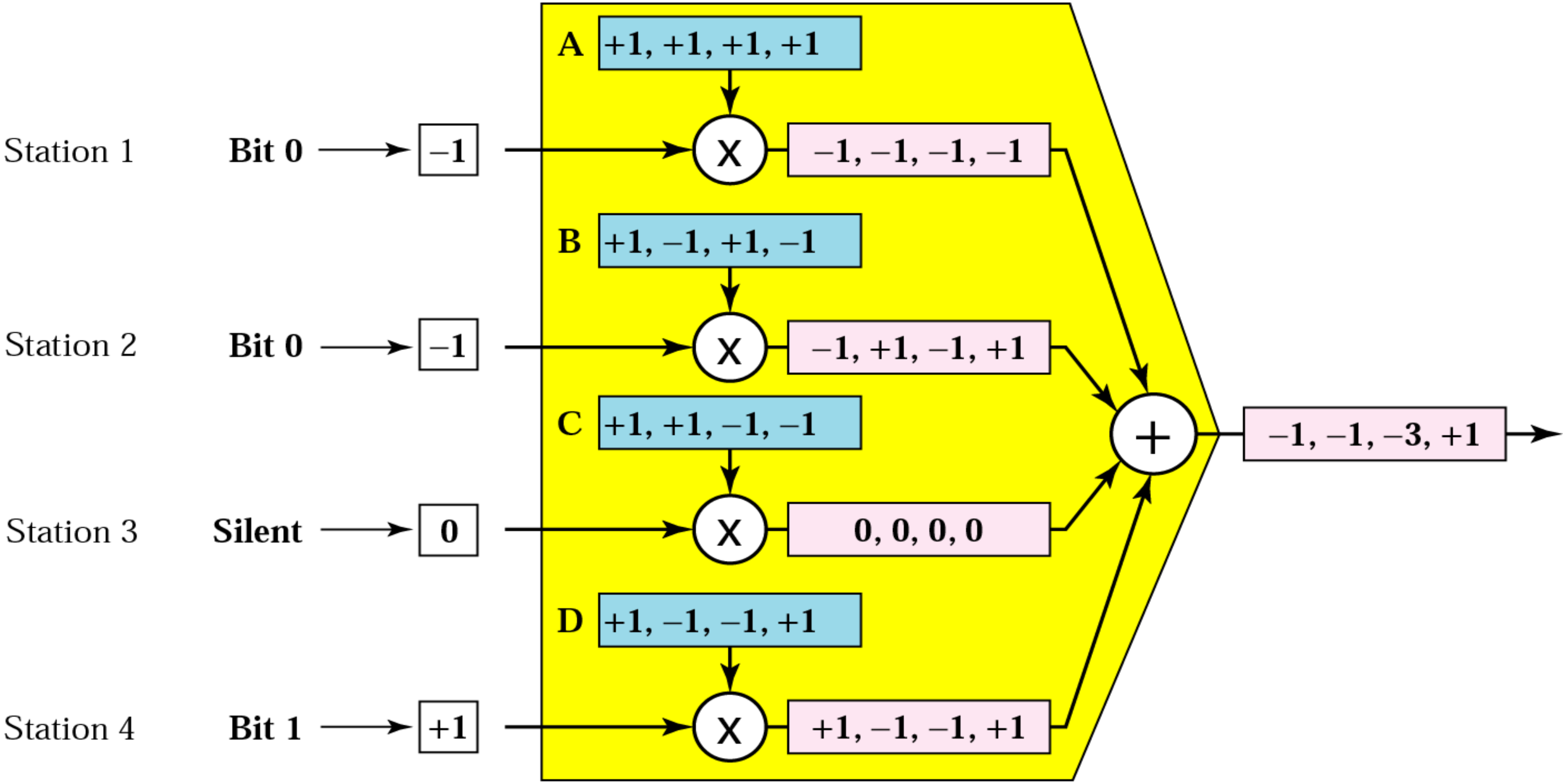
$$V_0(T_b) = m_1 T_b \qquad m_1 = V_0(T_b) / T_b$$

Output = **desired signal term** (Perfect Orthogonality between signature waveforms)

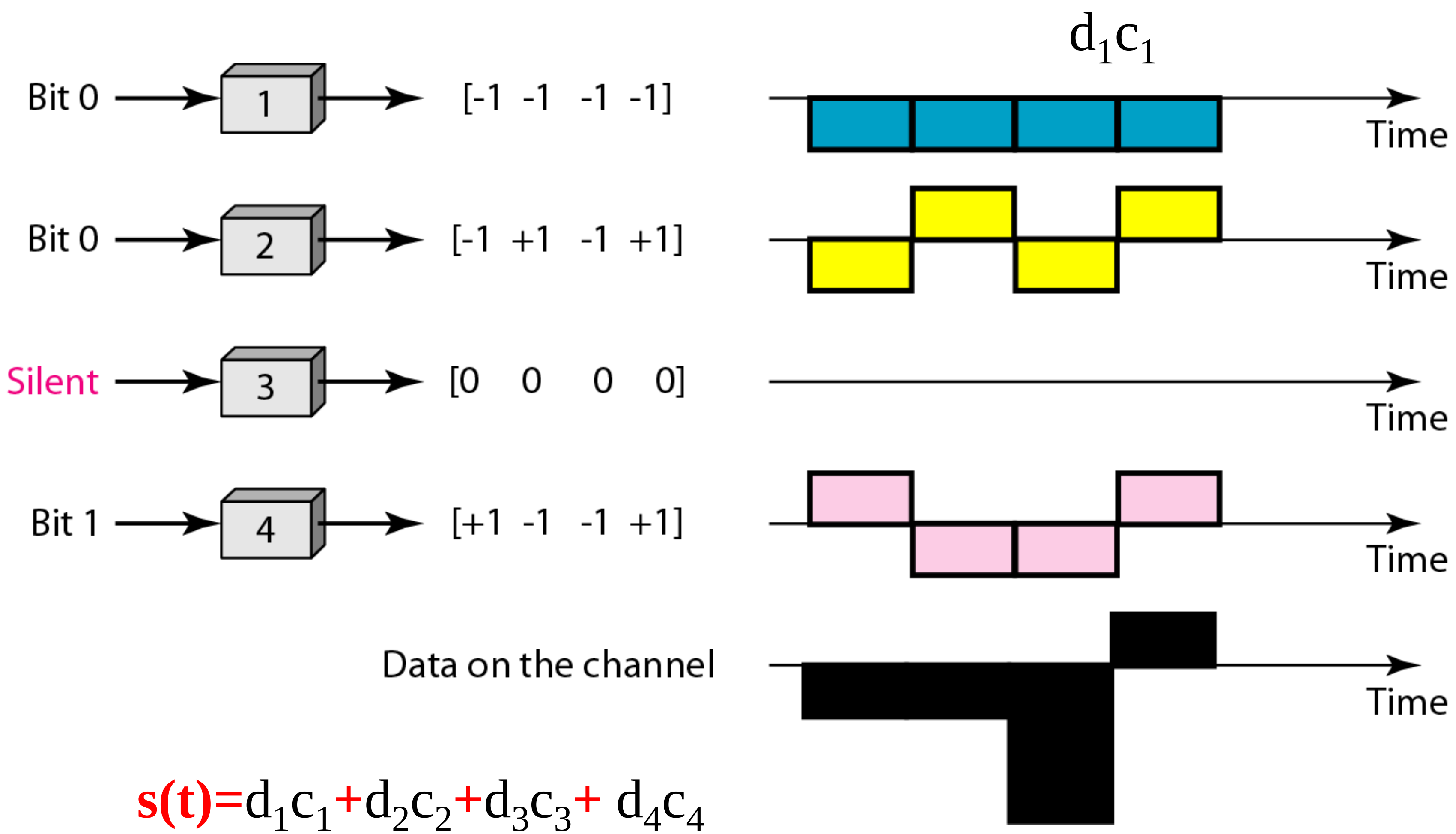
Example: CDMA Encoding



CDMA Encoding Details



Digital signal created by four stations in CDMA



$s(t) = d_1c_1 + d_2c_2 + d_3c_3 + d_4c_4$

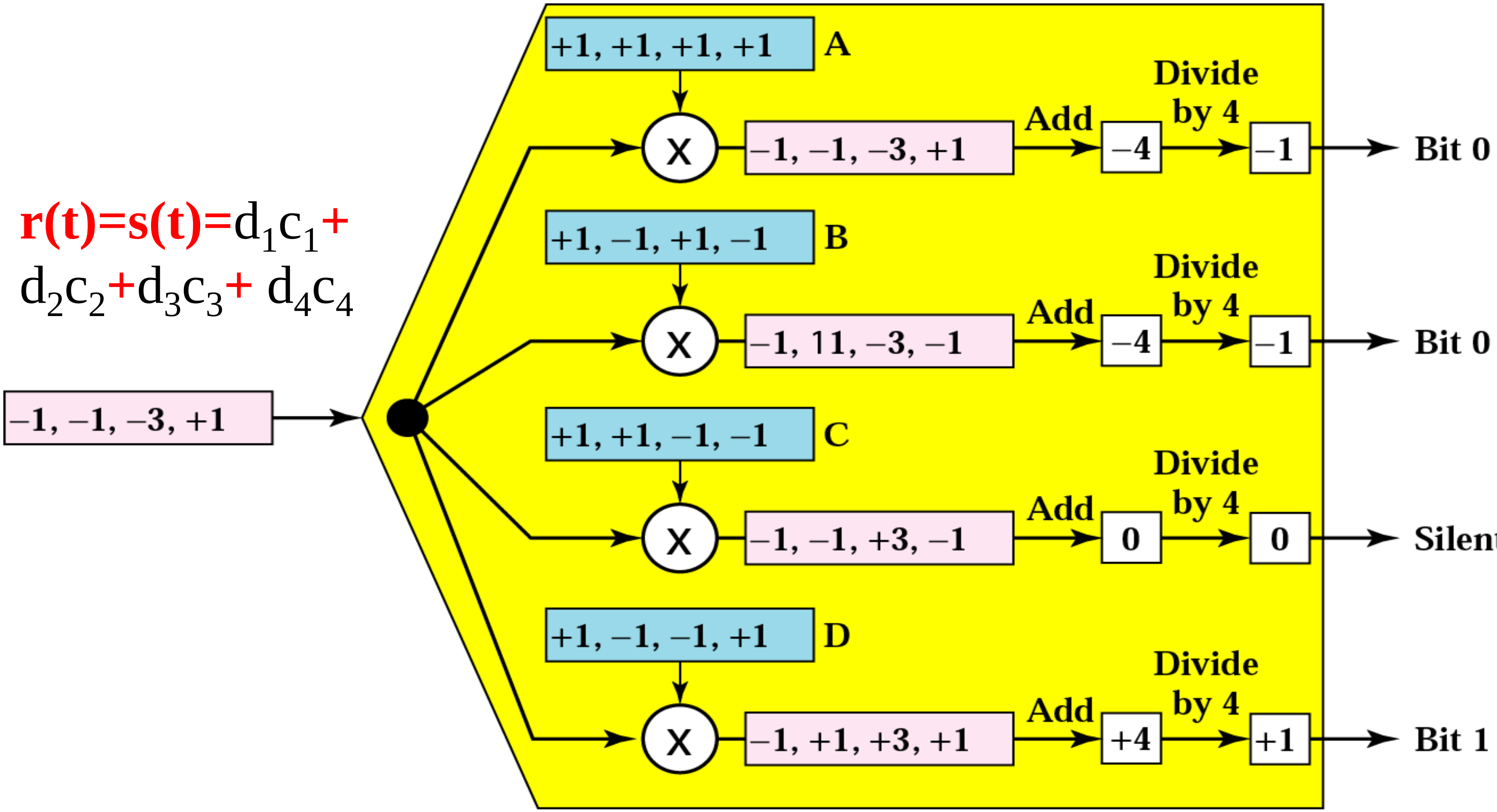
Decoding CDMA

- The input to the demodulator (in our example) is a 4-tuple of values between -4 and +4.
- Each station takes the received signal, and multiplies it by the chip sequence.
- The resulting values are then summed (integrated) to obtain a single value. The result will always be -4, +4, or 0.
- Divide the result by 4 to get a value -1, +1, or 0.
- Decode this result to a data bit of 0, 1, or no data.

$$m_1 = V_0(T_b)/T_b$$

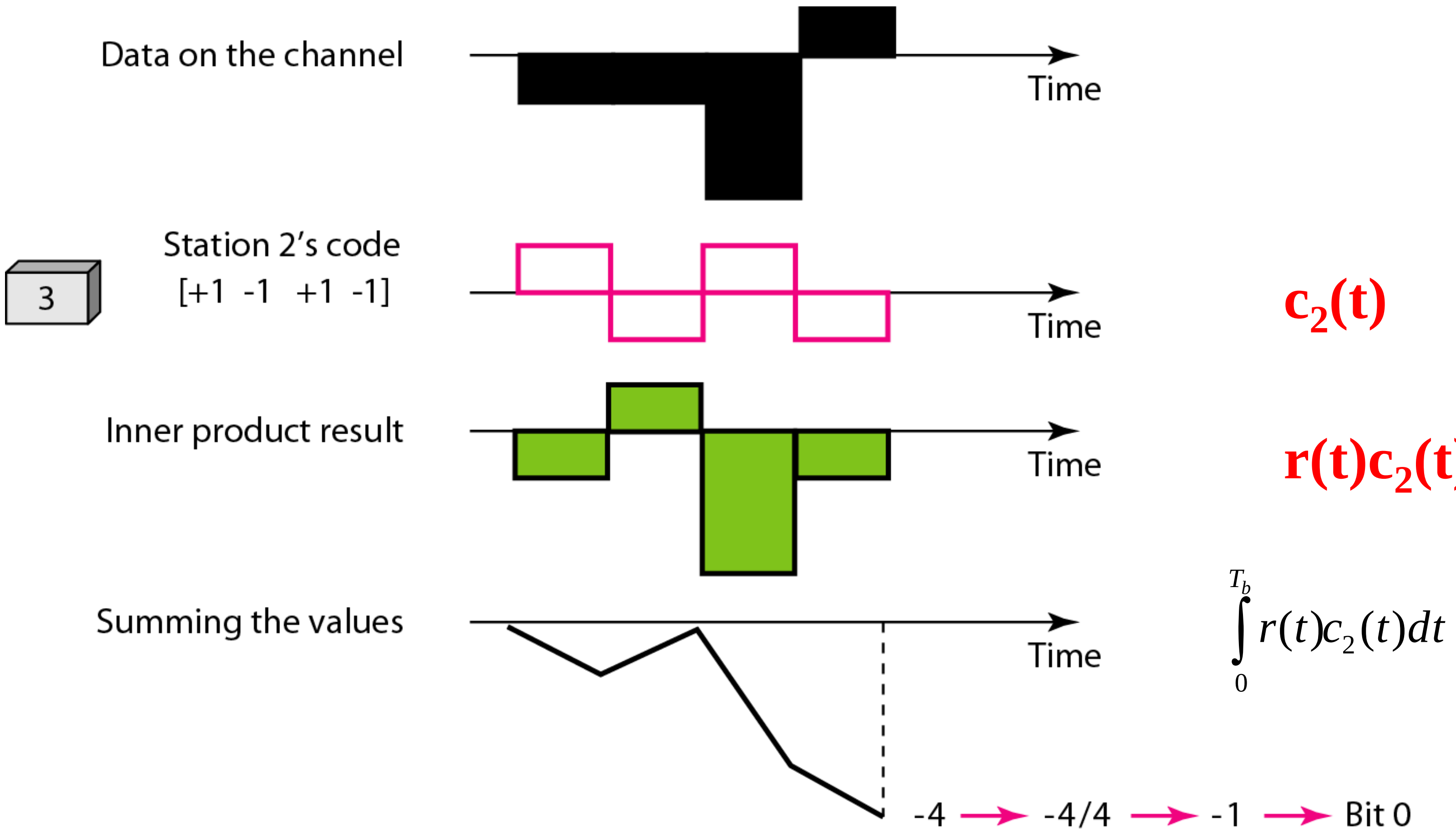
CDMA Demodulation

$\mathbf{r(t)=s(t)=}d_1c_1\mathbf{+}d_2c_2\mathbf{+}d_3c_3\mathbf{+}\ d_4c_4$



Decoding of the composite signal for one in CDMA

$$r(t)=s(t)=d_1c_1+d_2c_2+d_3c_3+d_4c_4$$



Walsh Codes

- Note that perfect coherence is needed at the receiver side to eliminate the multi-access interference (MAI) term (to be explained later)
- One possible set of orthogonal waveforms (used **at the base station of a mobile system in the downlink**) can be generated using what is known as the Walsh- Hadamard sequences.
- These are codes of length *n* consisting of the n rows of the Walsh matrix:

$$H_2 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \qquad H_4 = \begin{pmatrix} H_2 & H_2 \\ H_2 & \overline{H_2} \end{pmatrix}$$

$$H_8 = \begin{pmatrix} H_4 & H_4 \\ H_4 & \overline{H_4} \end{pmatrix} \qquad H_{2n} = \begin{pmatrix} H_n & H_n \\ H_n & \overline{H_n} \end{pmatrix}$$

Walsh Codes

- For H_2 the codes are: (1, 1), (1, -1)
- For H_4 the codes are:

  (1, 1, 1, 1), (1, -1, 1, -1), (-1, -1, 1, 1), (-1, 1, 1, -1)
- **Orthogonality**: Every row is orthogonal to every other row.
- Requires tight synchronization
- **Problem**: Cross correlation between different shifts of Walsh sequences is not zero

Example

What is the number of Walsh sequences if we have 90 stations in our network?

Solution

The number of sequences needs to be **$N = 2^m$**. We need to choose m = 7 and N = 2^7 or 128. We can then use 90 of the sequences as the chips.