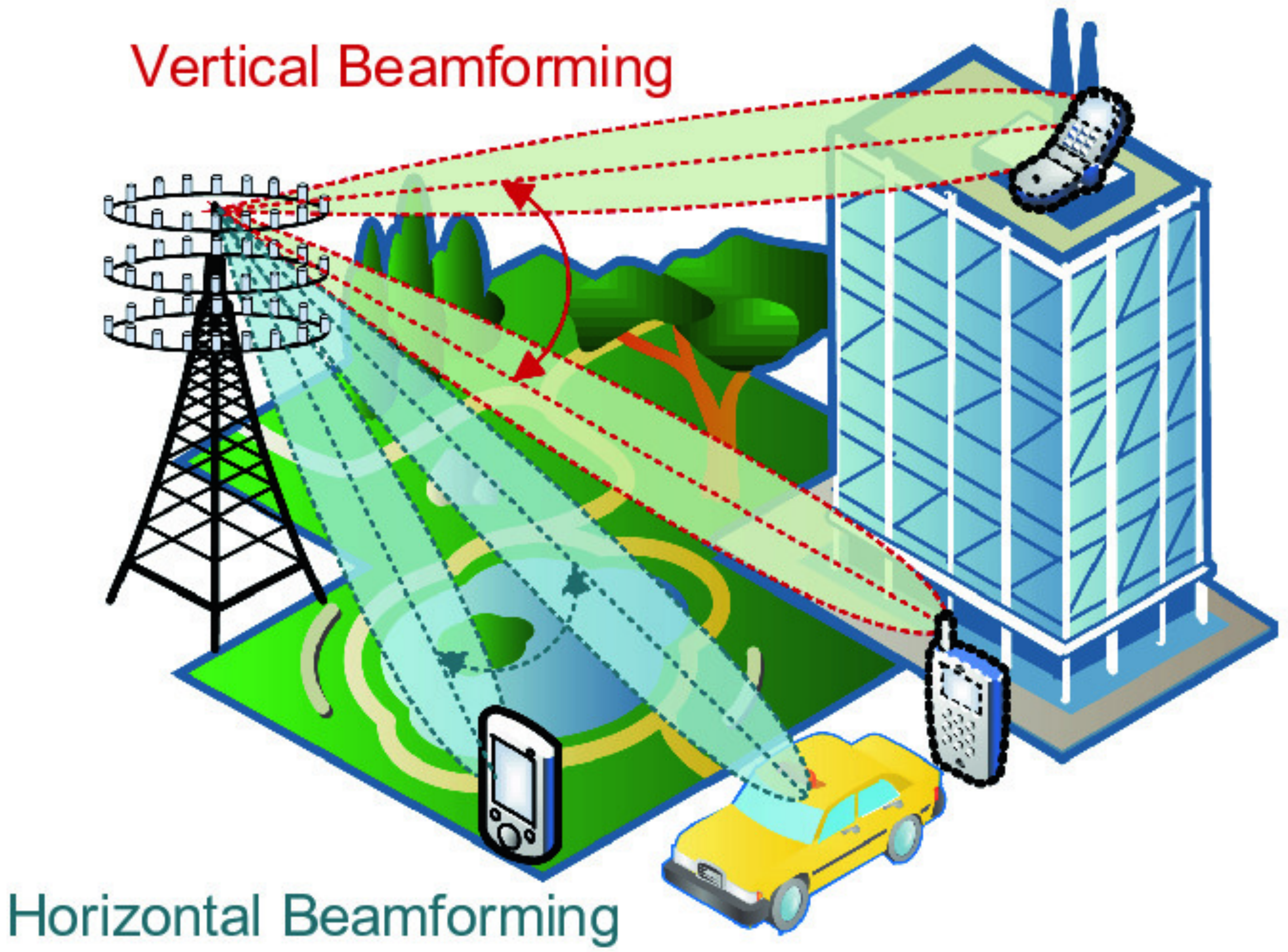
5.1.7 Multiplexing

Multiplexing in wireless communication

- Multiplexing is a transmission technique that allows to send multiple different signals over the same channel.
- Allows parallel communication with multiple users, even without MIMO.
- Leveraged by MAC layer protocols for managing the multiple access.
    - Space division multiplexing (SDM)
    - Frequency division multiplexing (FDM)
    - Time division multiplexing (TDM)
    - Code division multiplexing (CDM)

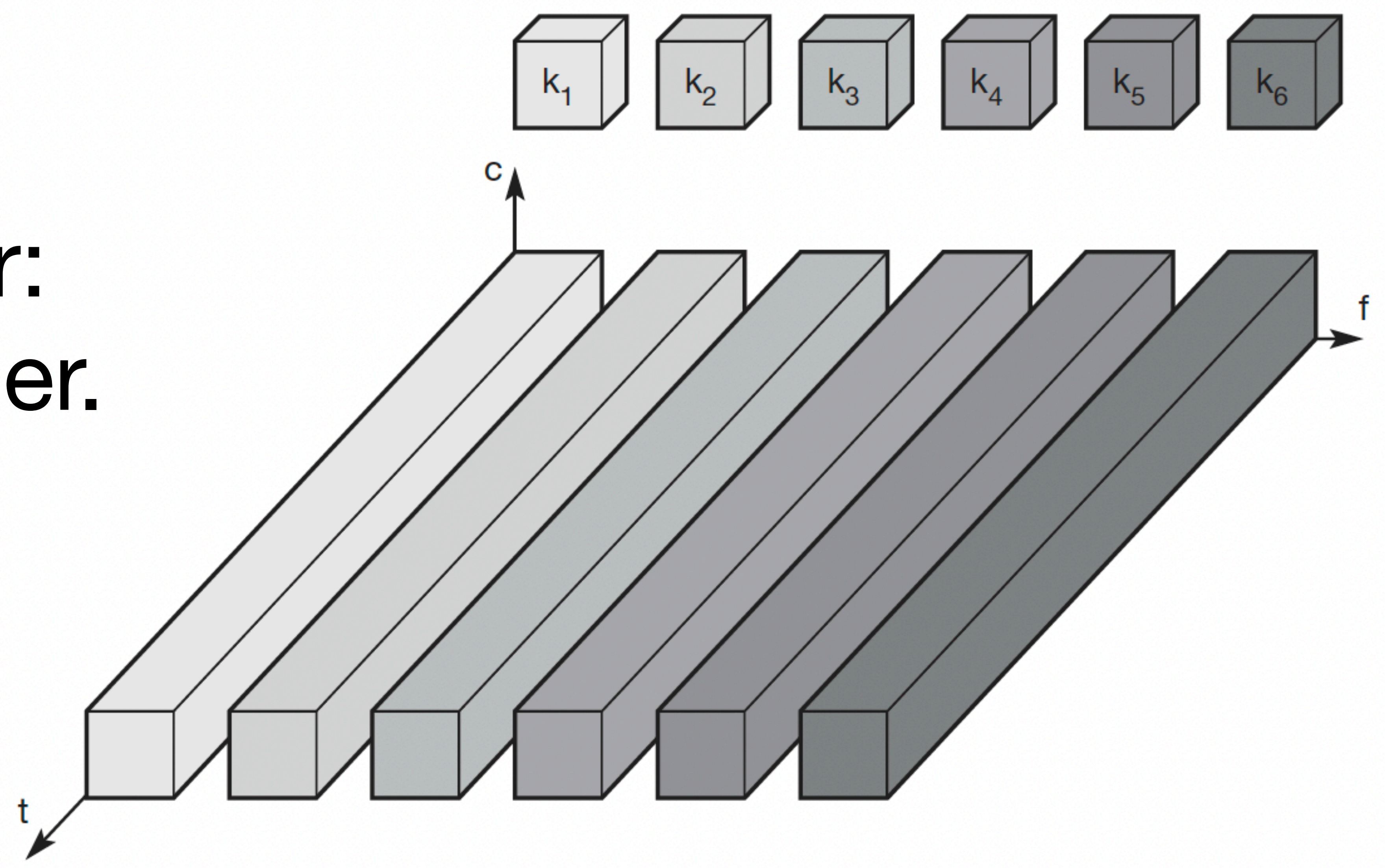
Space Division Multiplexing (SDM)

- SPD is achieved with MIMO technology.
- The channels that are created between a receiver and a transmitter are physically separated, as antennas at the receiver and the transmitter are at a certain distance from each other and can be oriented towards different directions.
  - Smart antennas, i.e., arrays of antennas connected with each other at the same node, can coordinate and adjust themselves and perform beamforming, to send and receive multiple signals in parallel.
- Not to be confused with spatial multiplexing



Frequency Division Multiplexing (FDM)

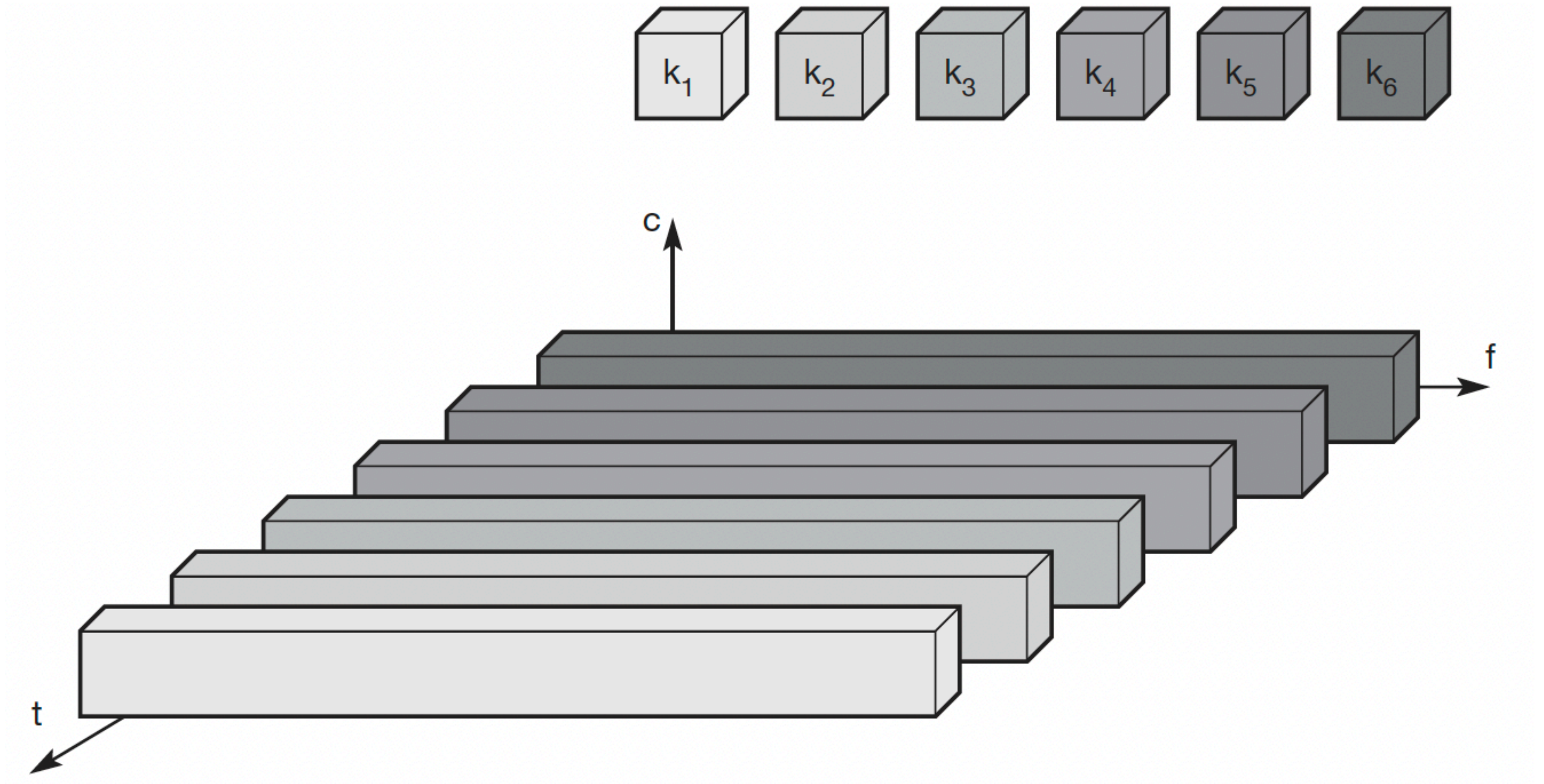
- Frequency division multiplexing (FDM) subdivides the frequency range into several non-overlapping frequency bands (mentioned it before).
- Different sub channels have their own frequency band.
- Senders using a certain frequency band can use this band continuously.
- Guard bands are needed to avoid frequency band overlapping (“adjacent channel interference”).
- Simple multiplexing scheme, does not need complex coordination between sender and receiver: the receiver only has to tune in to the specific sender.
  - works good for FM radios, but not for mobile communication (imagine having one channel for each mobile device).
- Does not require MIMO.

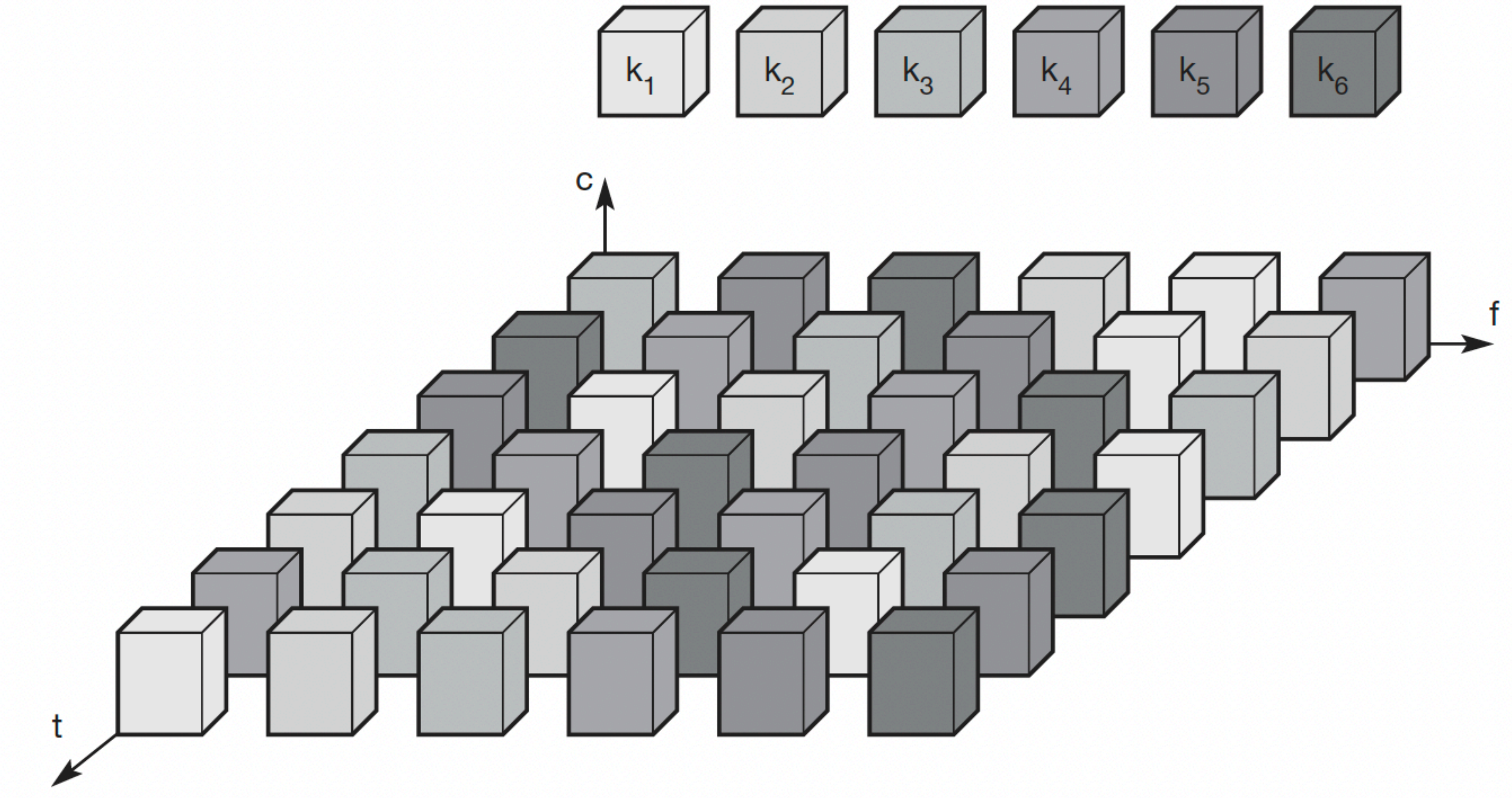


Time Division Multiplexing (TDM)

- Each channel is given the whole bandwidth for a certain amount of time.
- All senders use the same frequency but at different points in time.
- Guard spaces (i.e., time gaps) have to separate the time slots when the senders use the medium.
- Does not require MIMO.

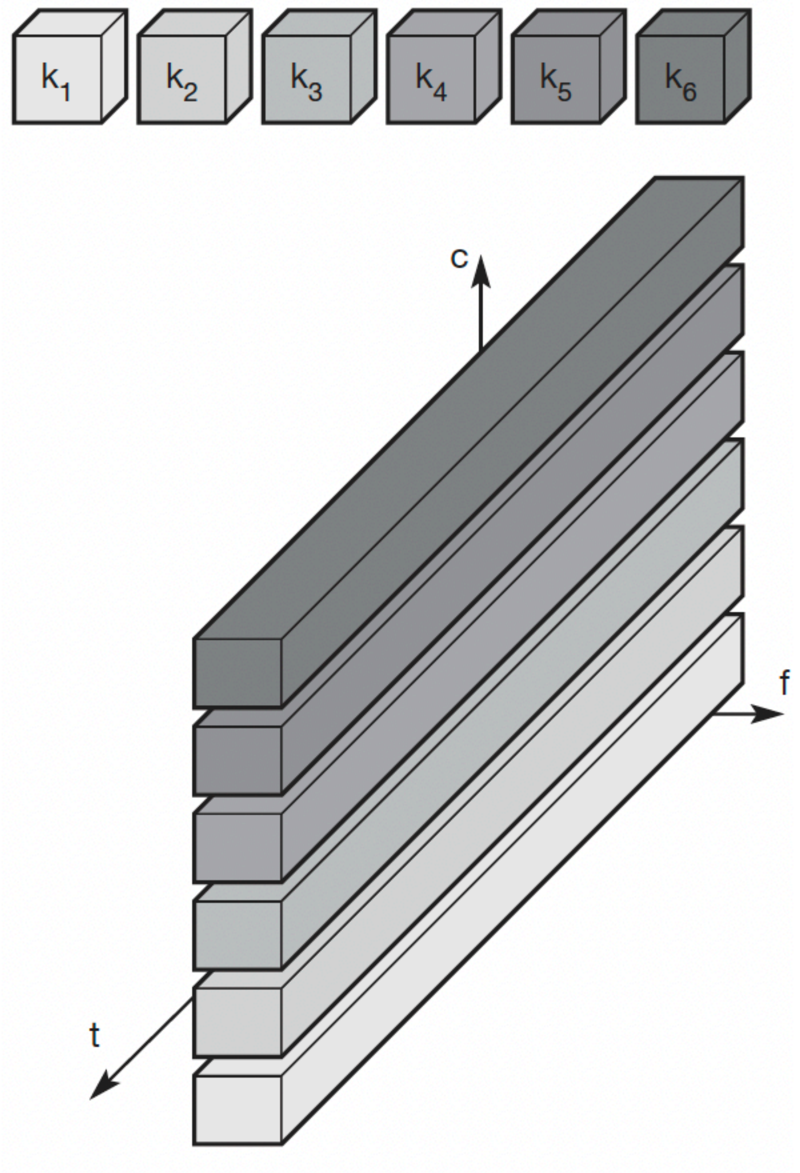
- Can be combined with FDM.





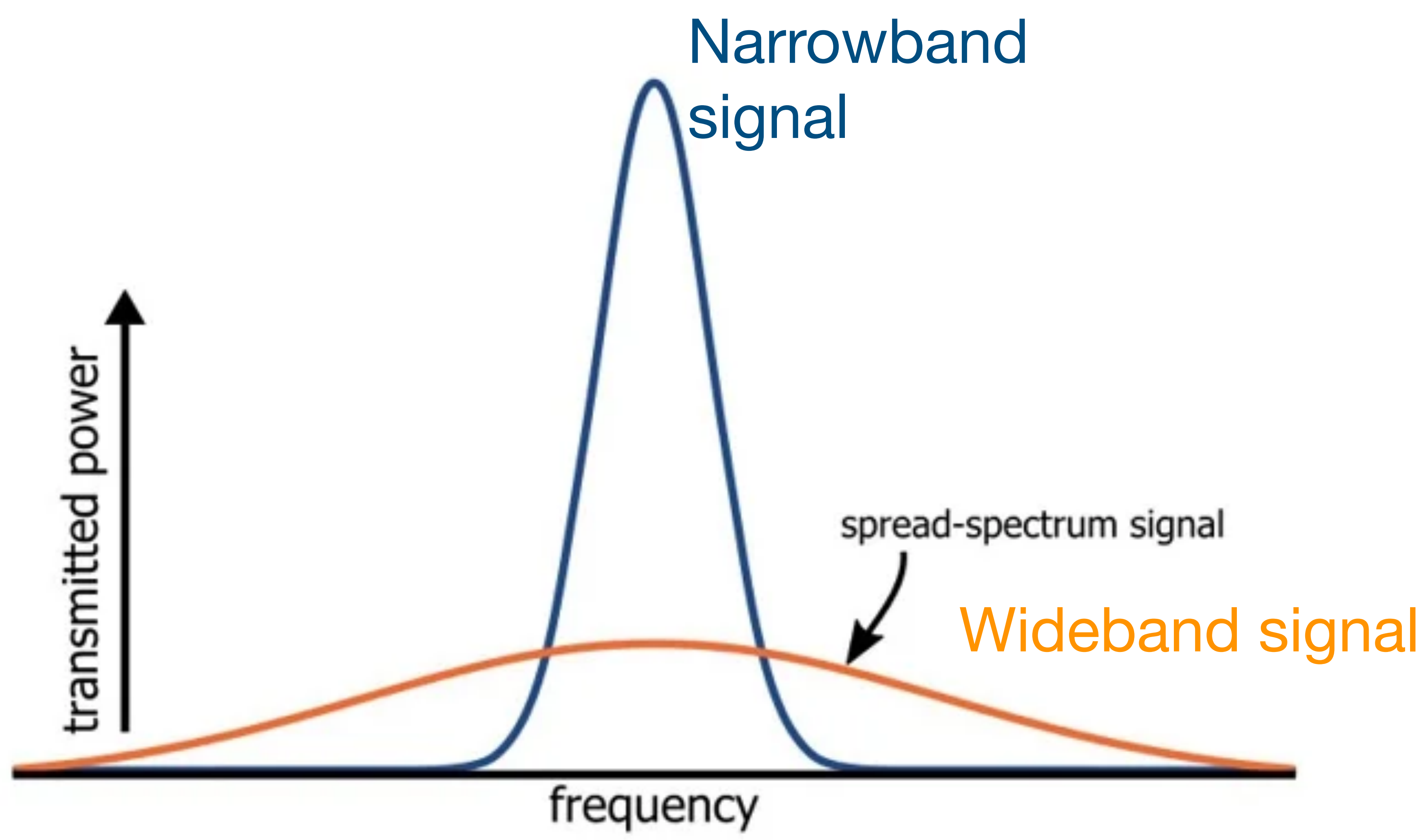
Code Division Multiplexing (1)

- Code Division Multiplexing allows different channels to use the same frequency and the same time for transmission.
- Separation is now achieved by assigning each channel its own ‘code’.
- Every day life example: people in the same room talking simultaneously at the same voice level in different languages.
- To achieve this, CDM uses **spread spectrum techniques**.



Spread Spectrum

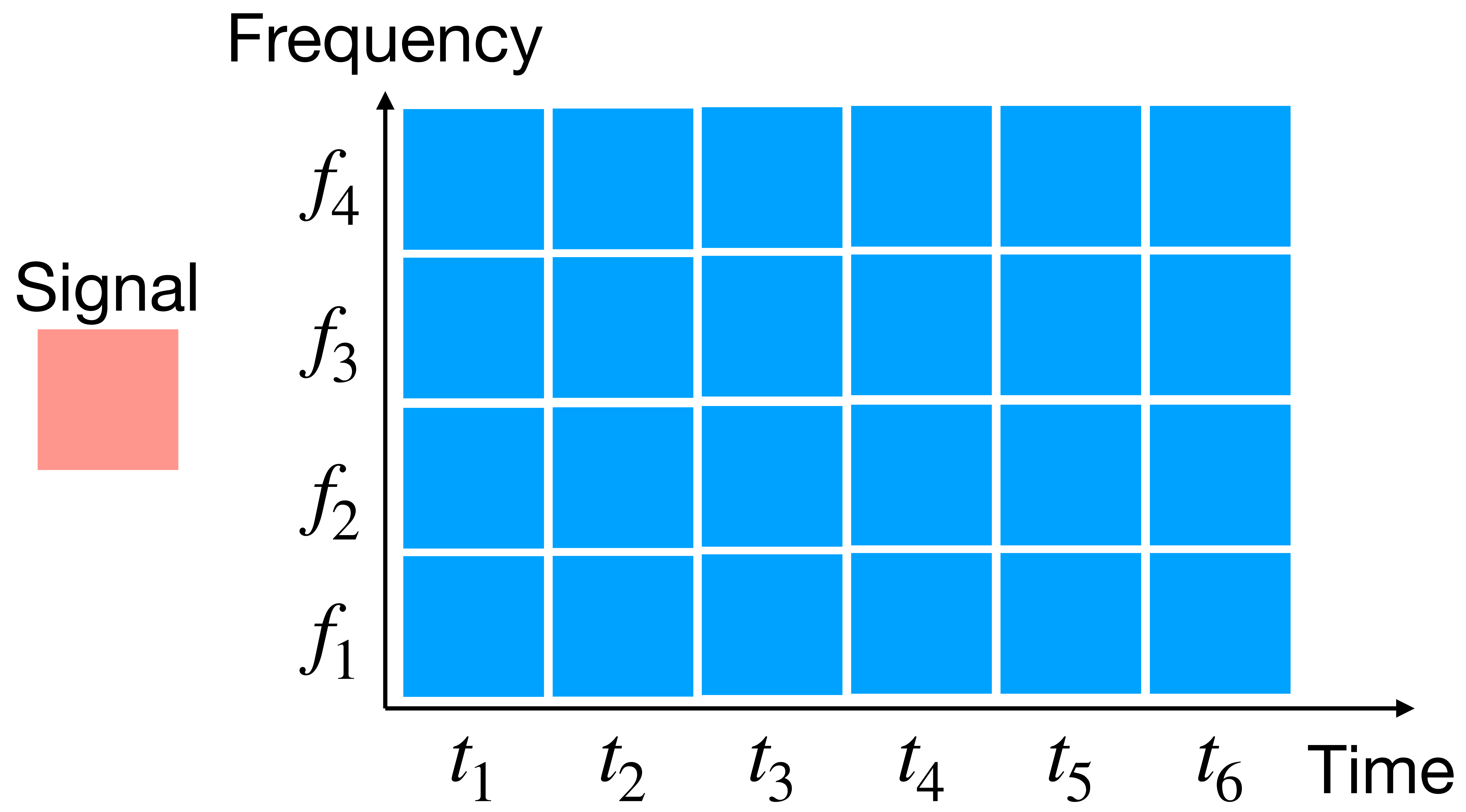
- Spread spectrum techniques involve spreading the bandwidth to transmit data.
- Narrowband signals are transformed into spread-spectrum signals.
  - The power of the signal remains the same
  - The resulting signal is barely distinguishable from noise (higher security).



  - The receiver has a way to distinguish the original signal.
- Two main techniques: Frequency Hopping SS (FHSS) and Direct Sequence SS (DSSS).

Frequency Hopping Spread Spectrum (FHSS) (1)

- Uses a combination of Frequency Division Multiplexing and Time Division Multiplexing, with guard bands.



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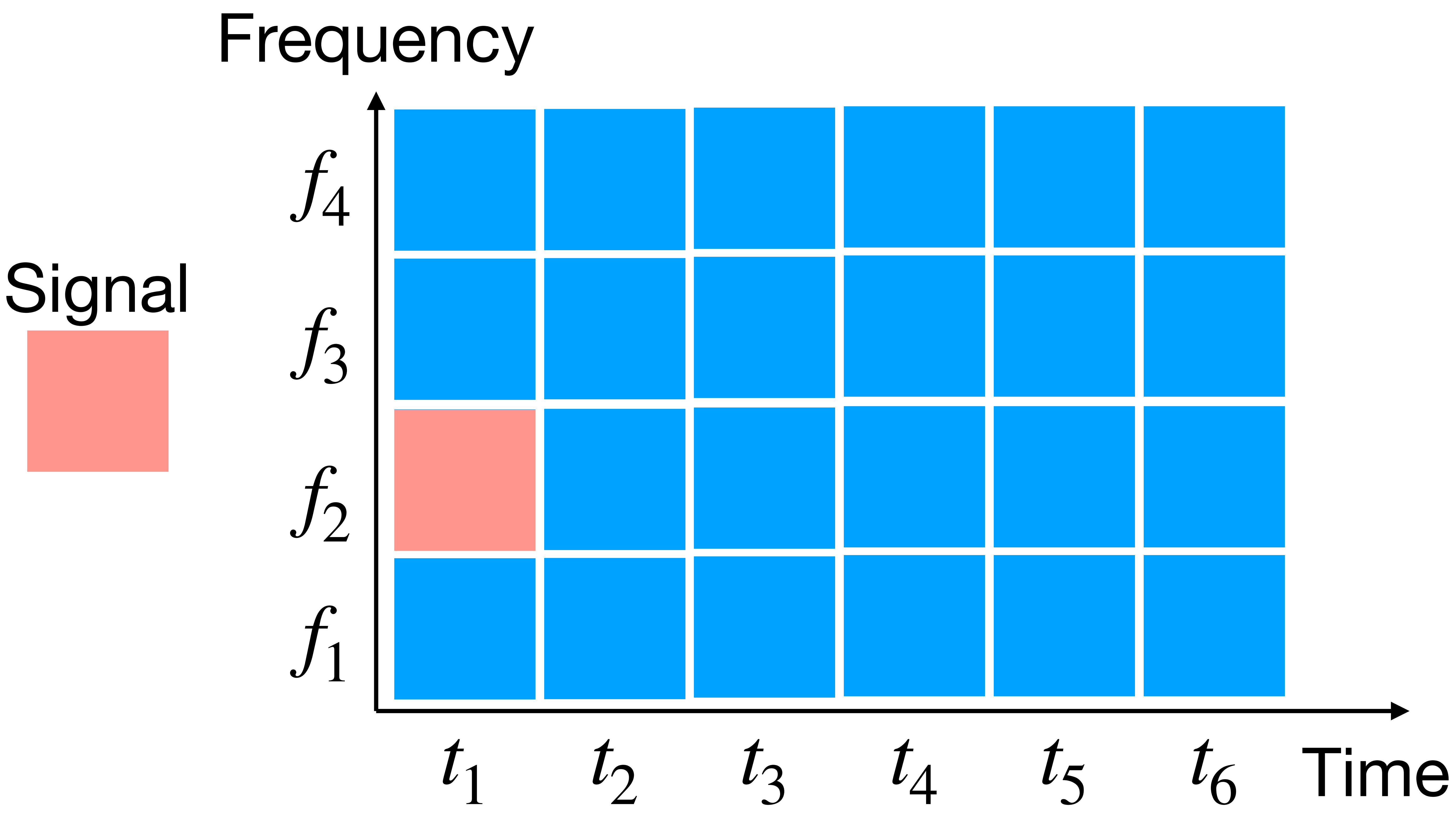

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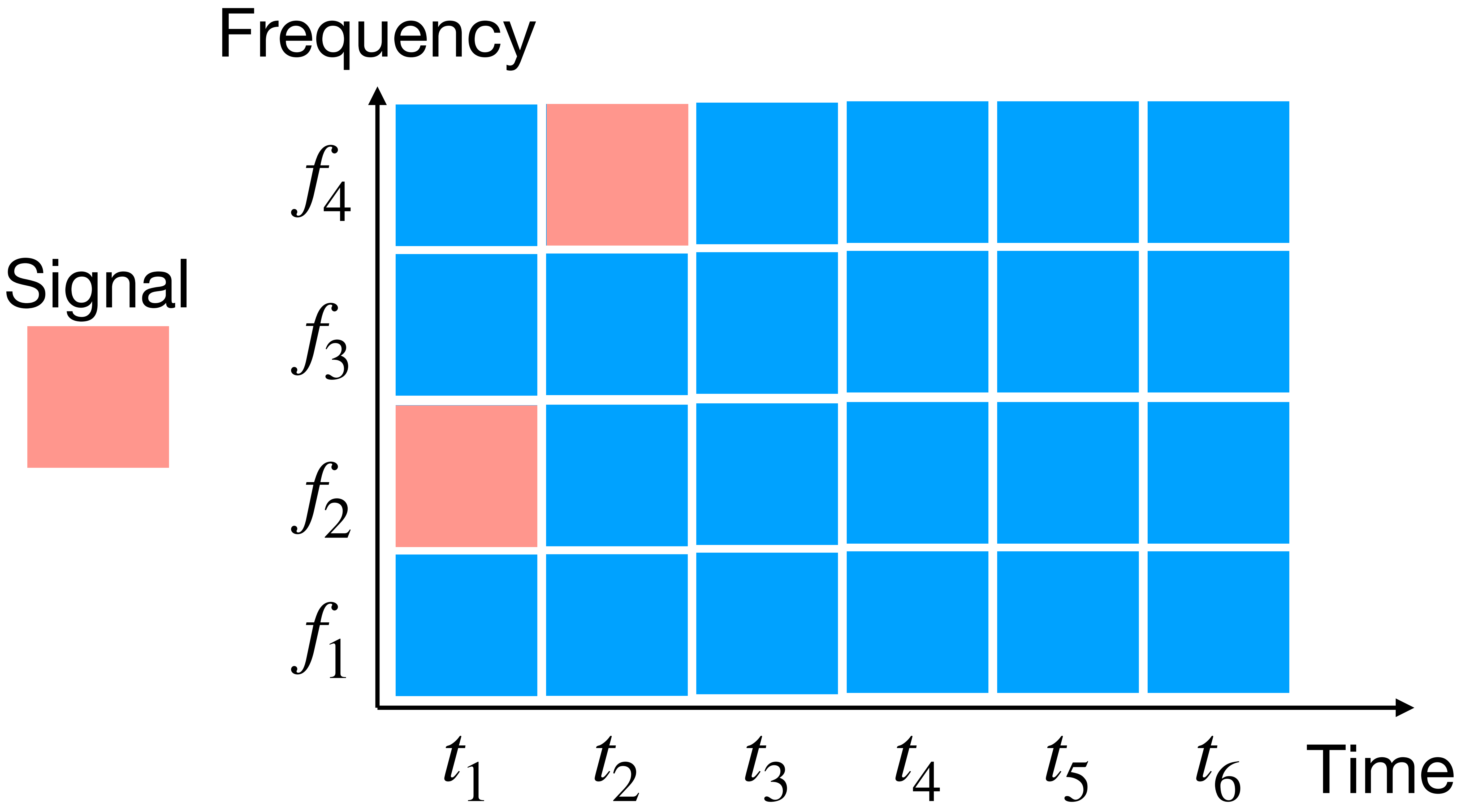

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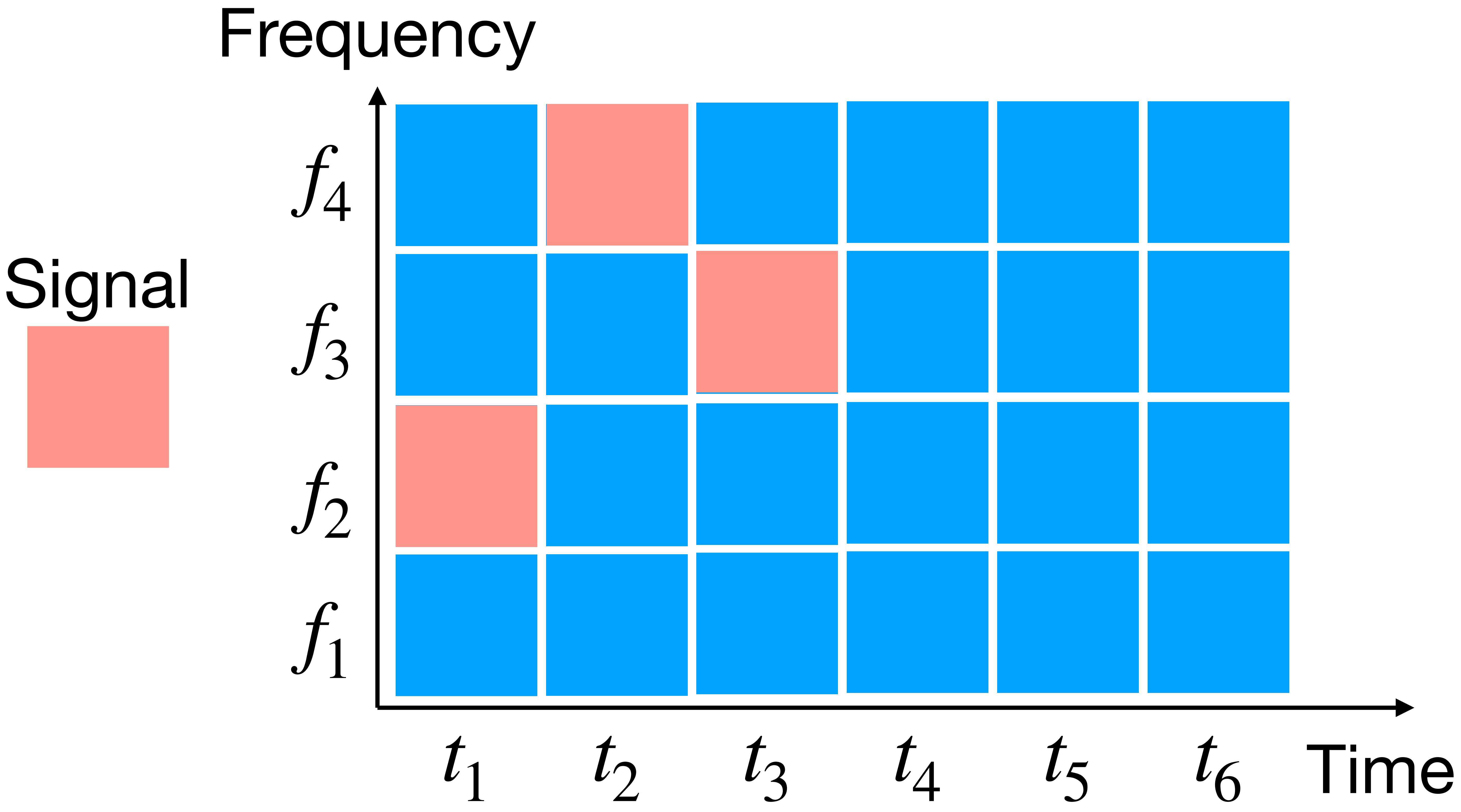

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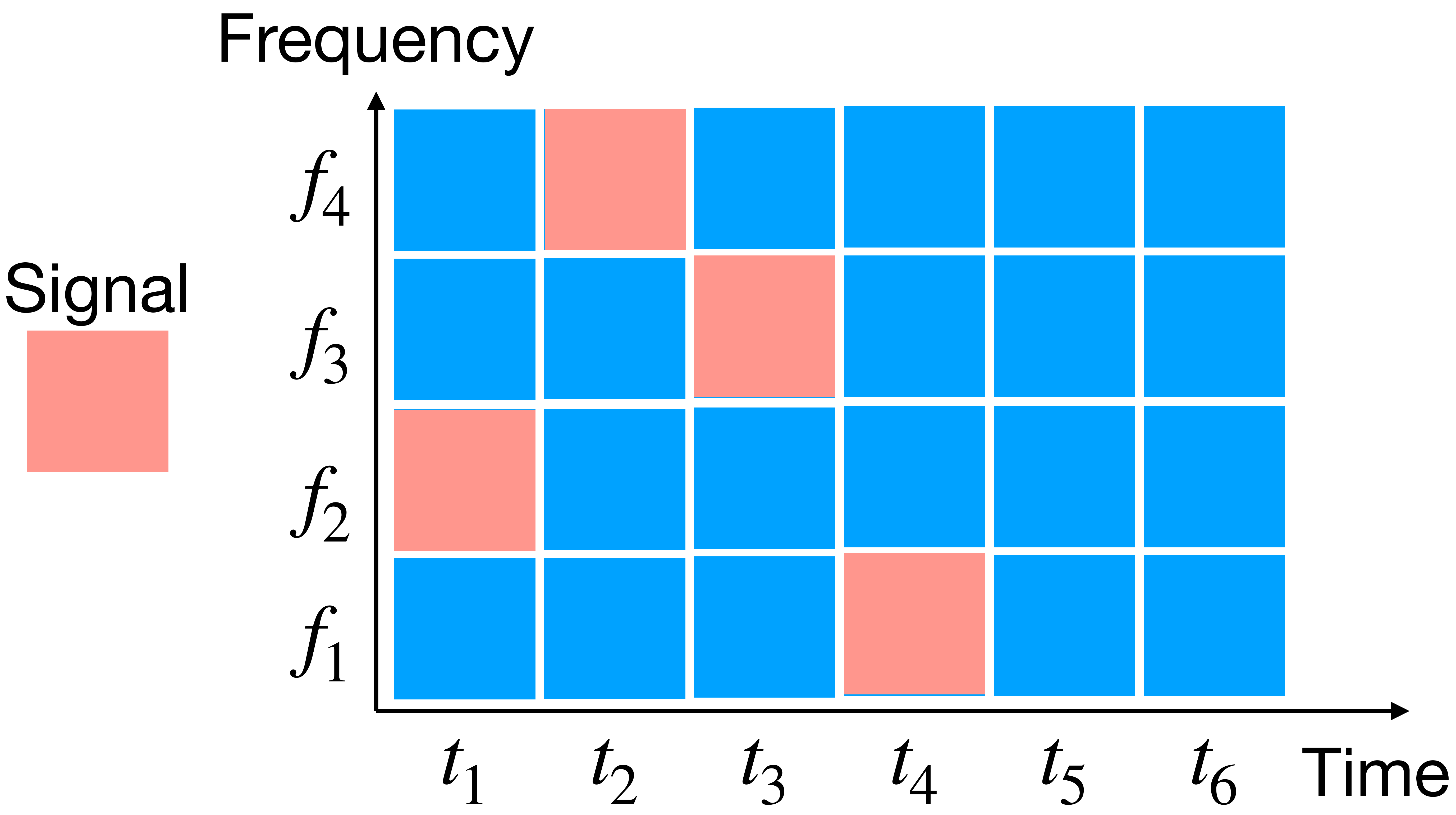

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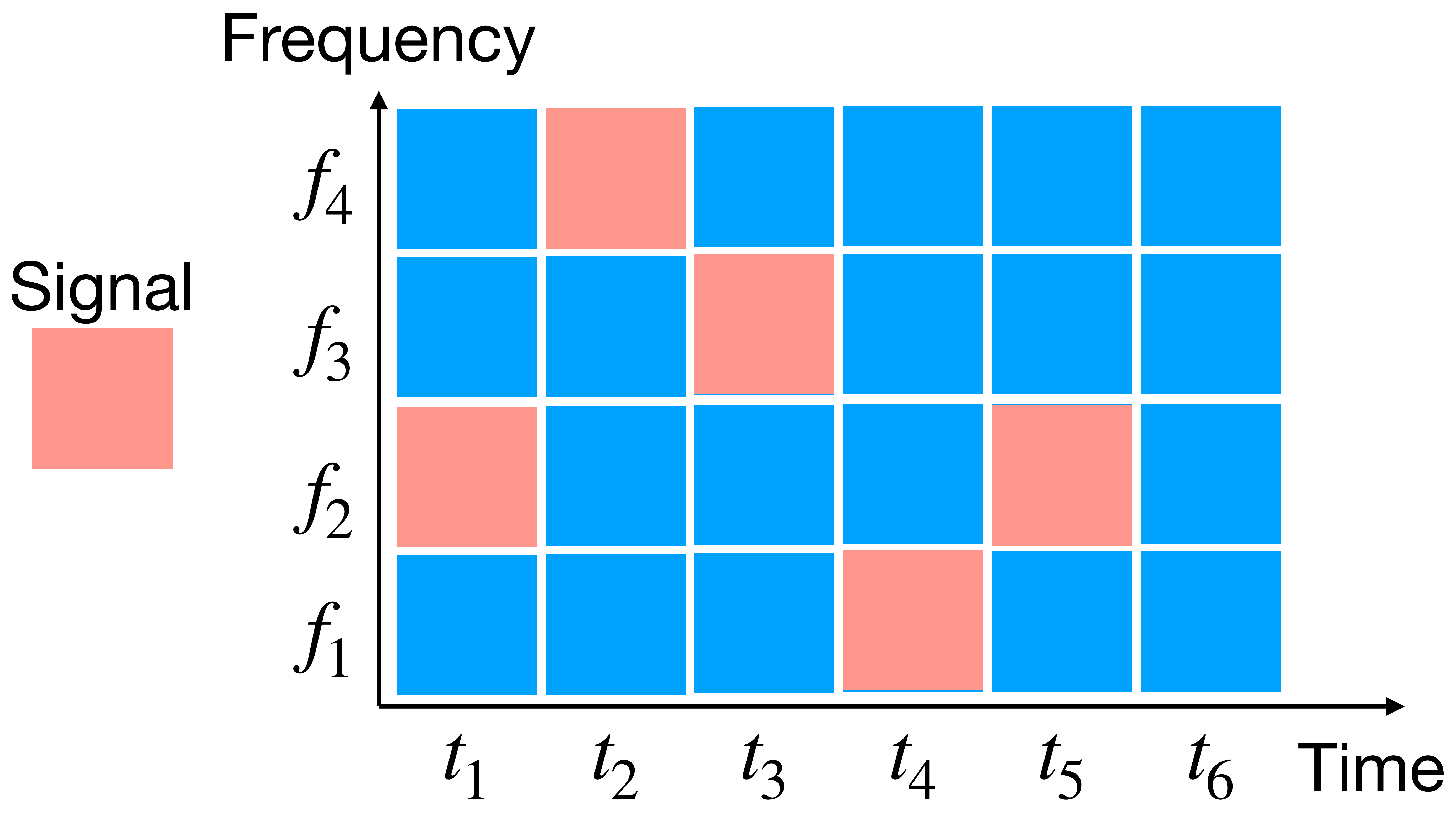

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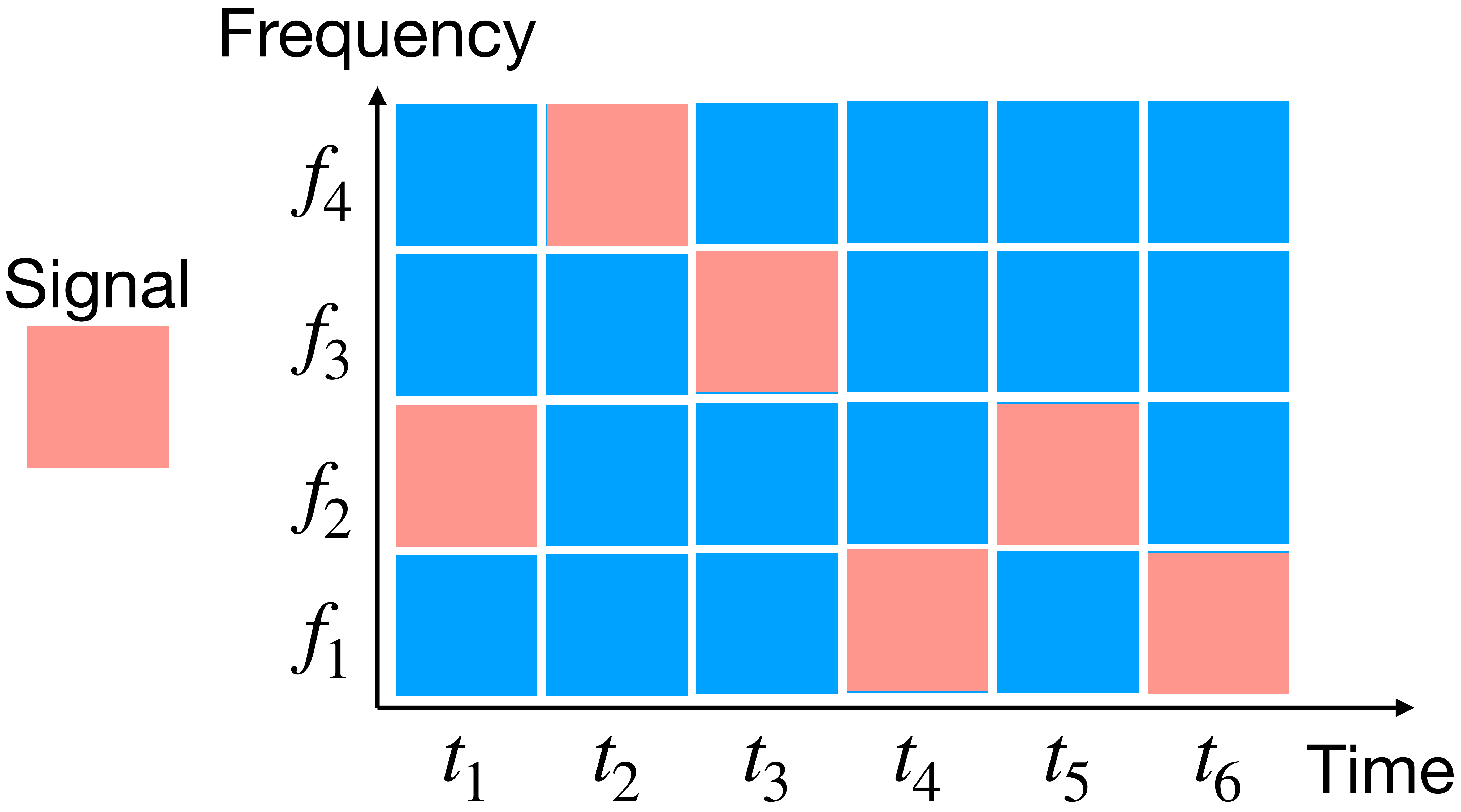


The pattern of channel usage is called **hopping sequence.**

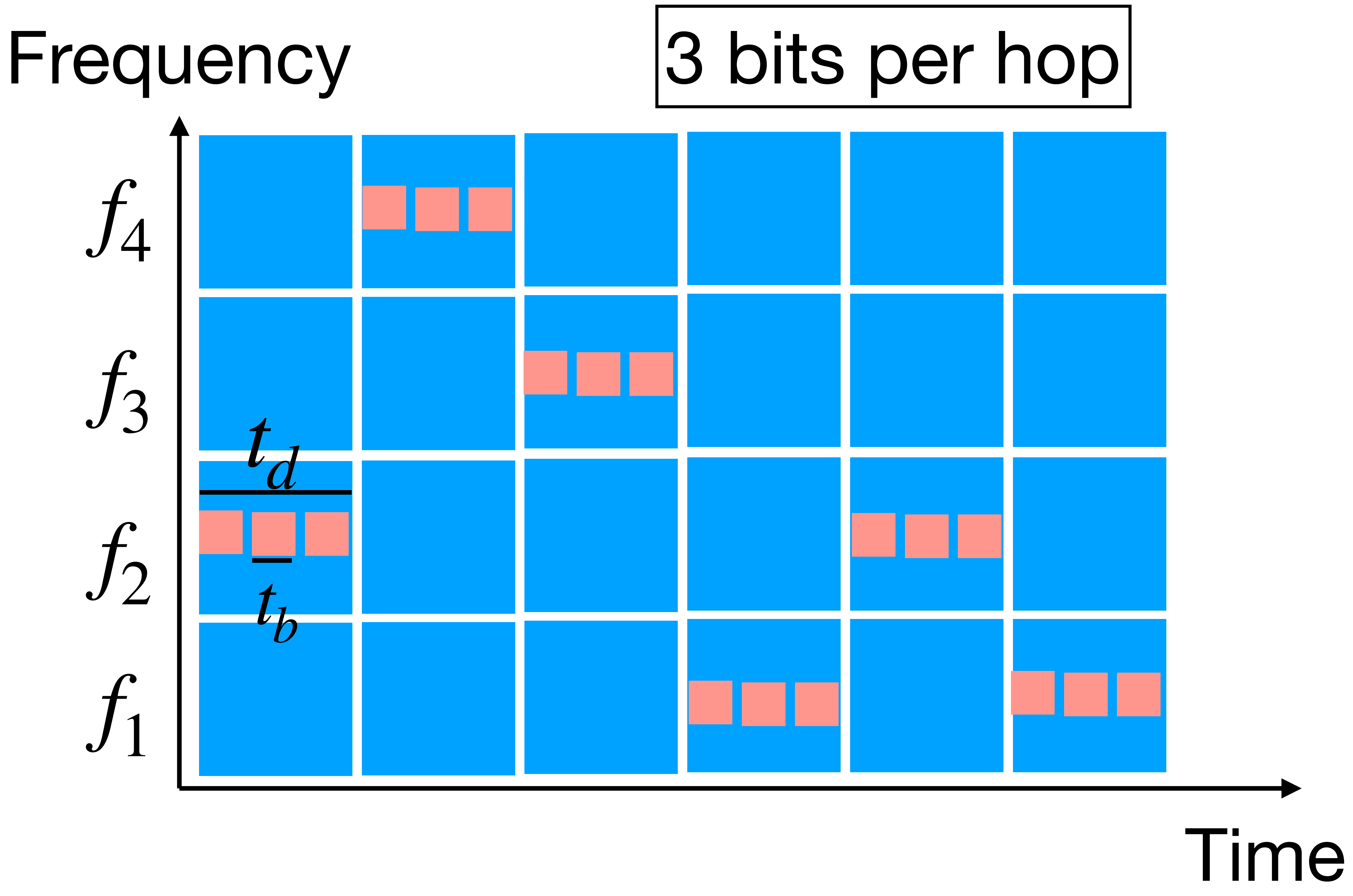
$$f_2\ f_4\ f_3\ f_1\ f_2\ f_1$$

The time spent on a channel with a certain frequency is called **dwell time,** t_d.

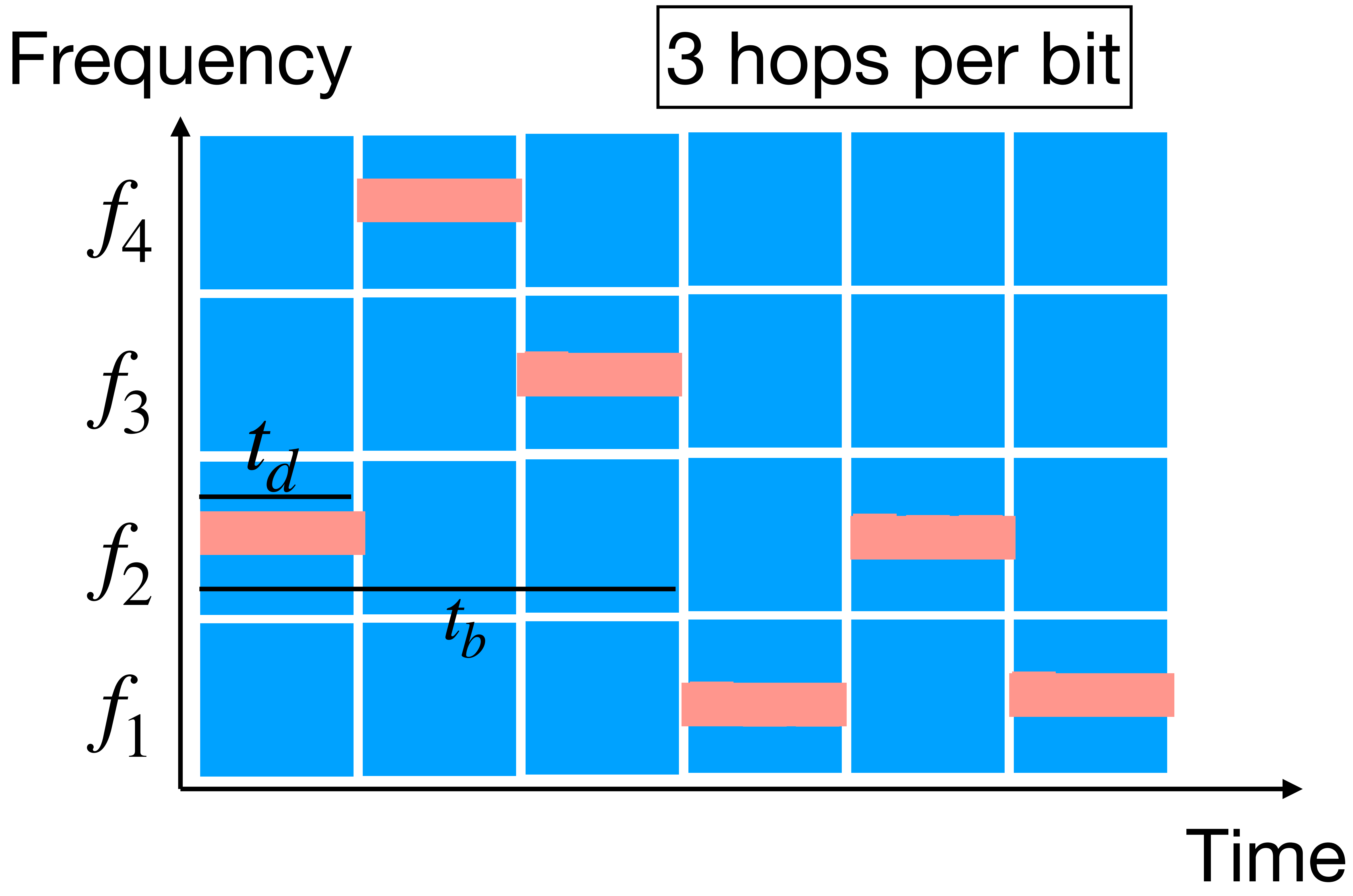
The time required for sending one bit is t_b.

Frequency Hopping Spread Spectrum (FHSS) (2)

- If t_b **<** t_d -> SLOW HOPPING



- If t_b **>** t_d -> FAST HOPPING

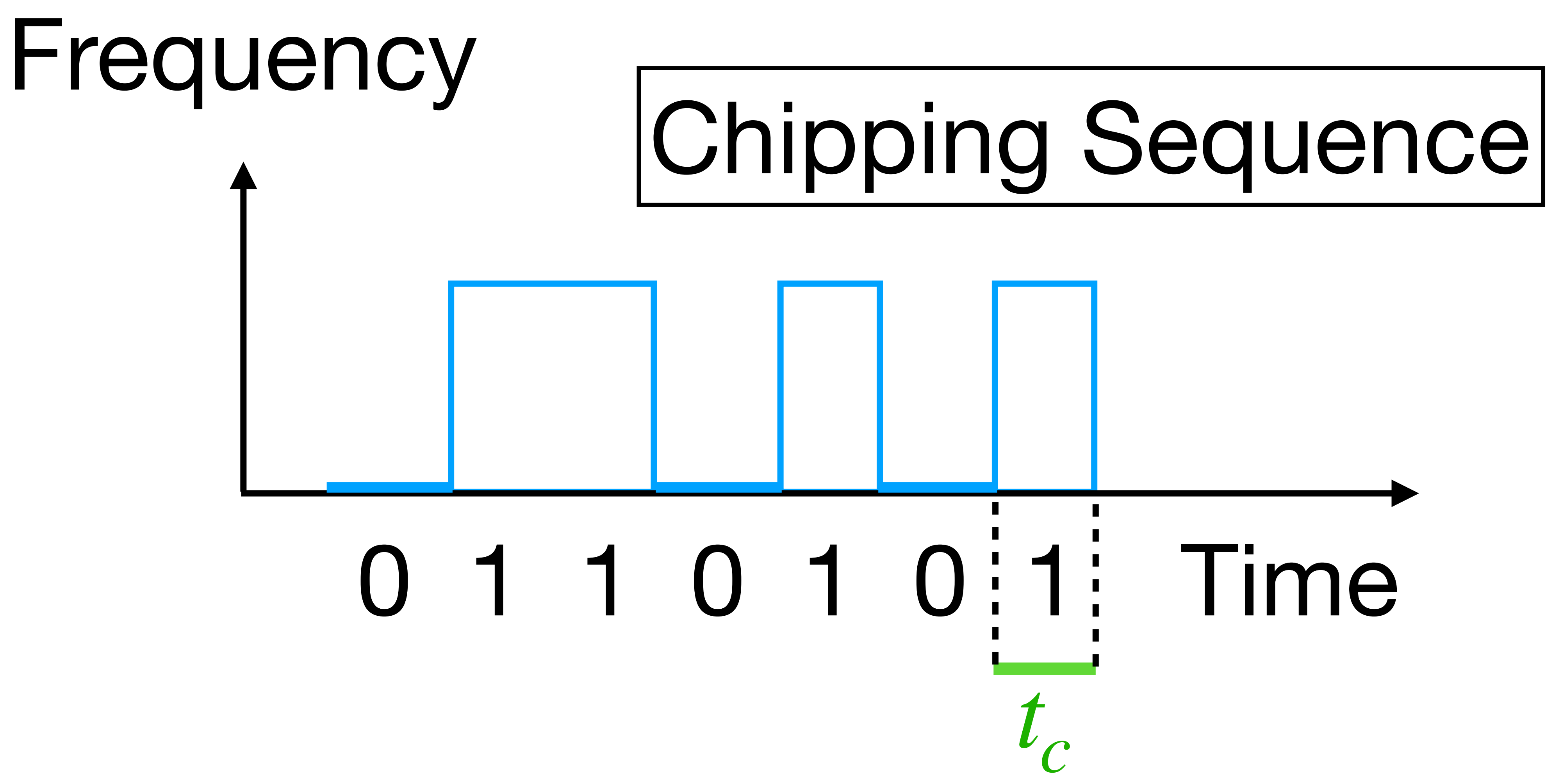


The receiver of an FHSS system has to know the hopping sequence and must stay synchronized.

Direct Sequence Spread Spectrum (DSSS) (1)

- Direct sequence spread spectrum (DSSS) systems take a user bit stream and perform an (XOR) with a so-called **chipping sequence.**
- It consists of a sequence of smaller pulses, called **chips**, with a duration t_c.
- t_b: duration of a bit (inverse of the bit rate). t_b **>** t_c**.**
- If the chipping sequence is generated properly it appears as random noise.

Direct Sequence Spread Spectrum (DSSS) (2)



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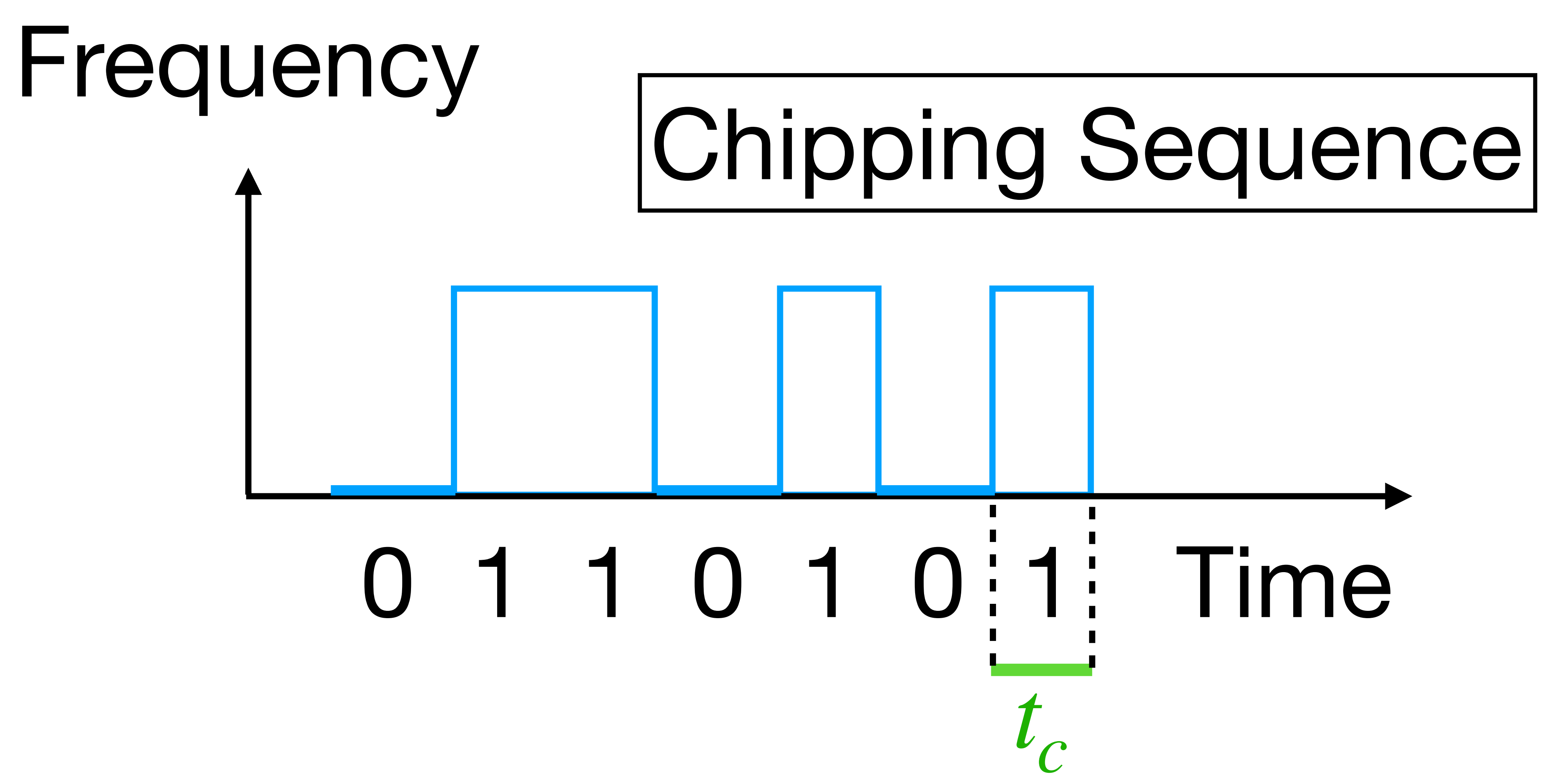

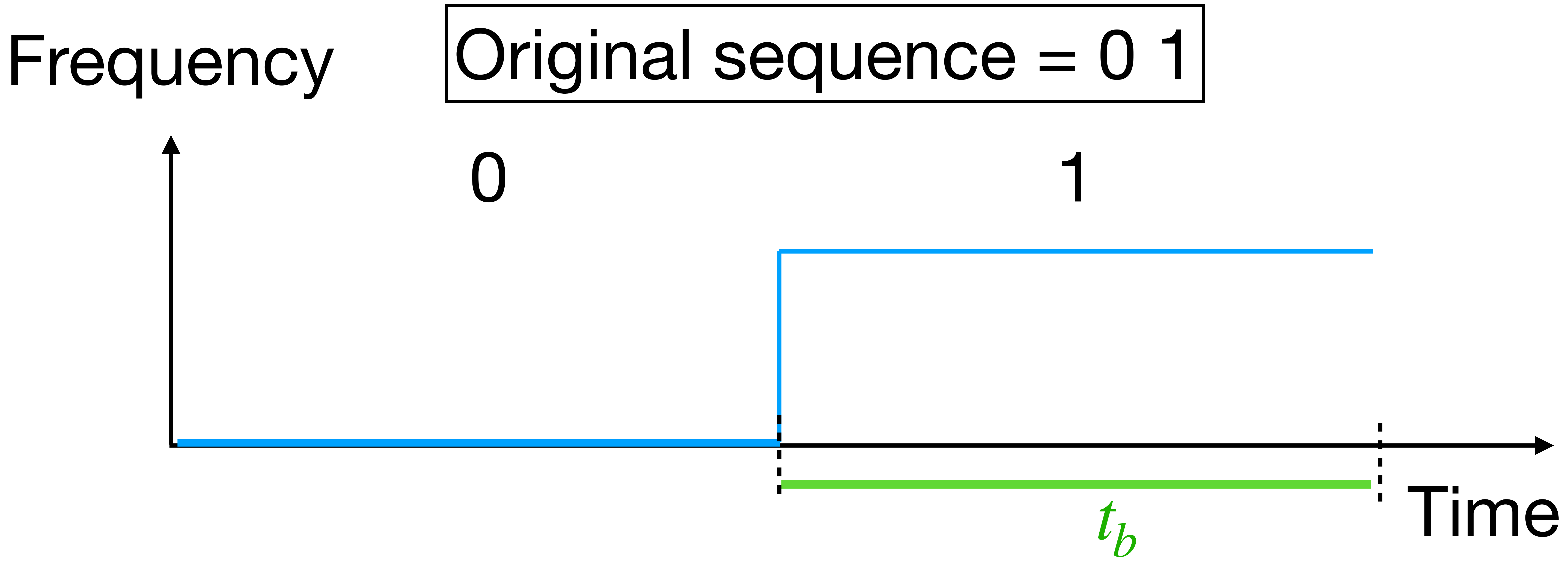

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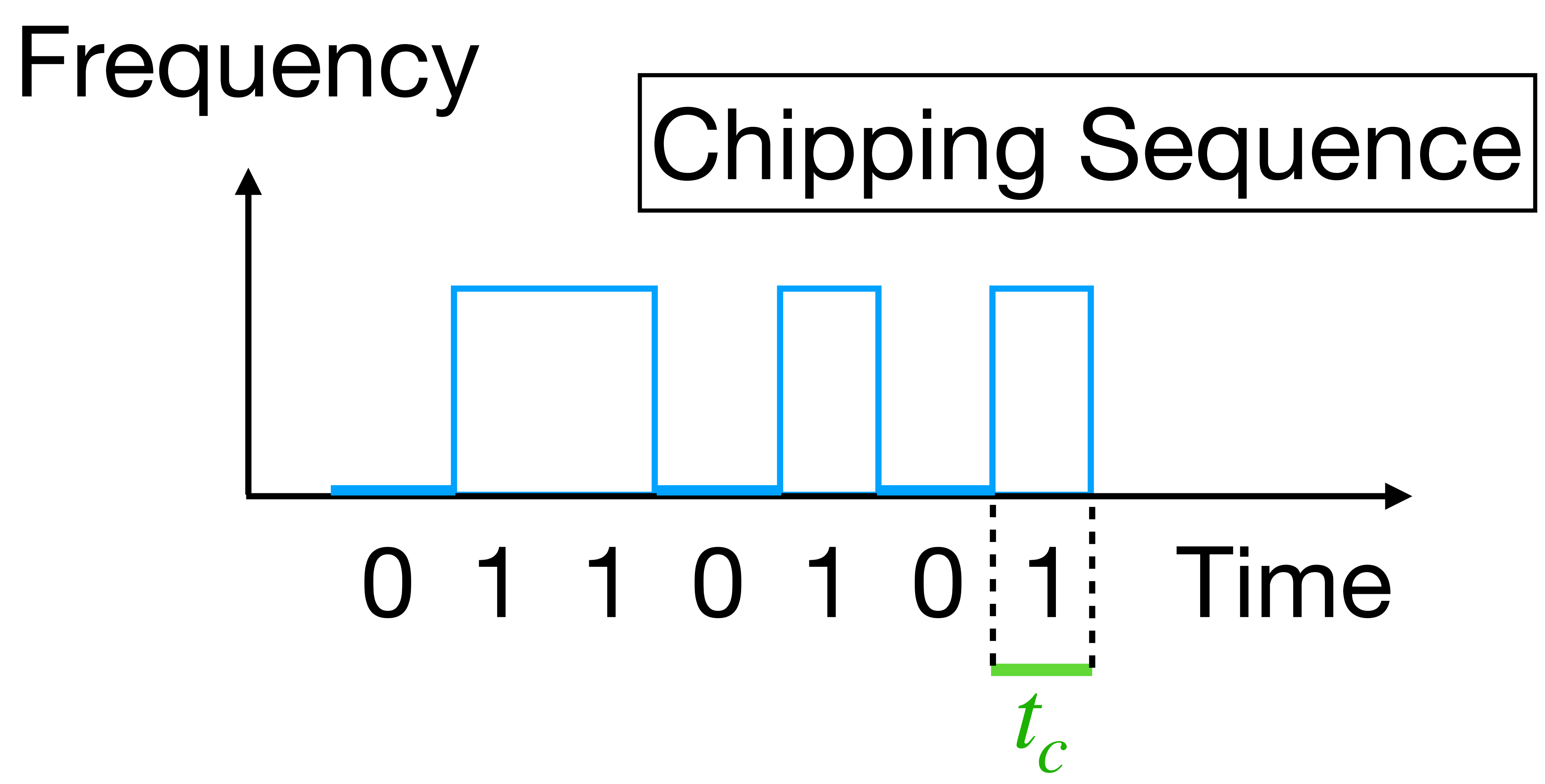

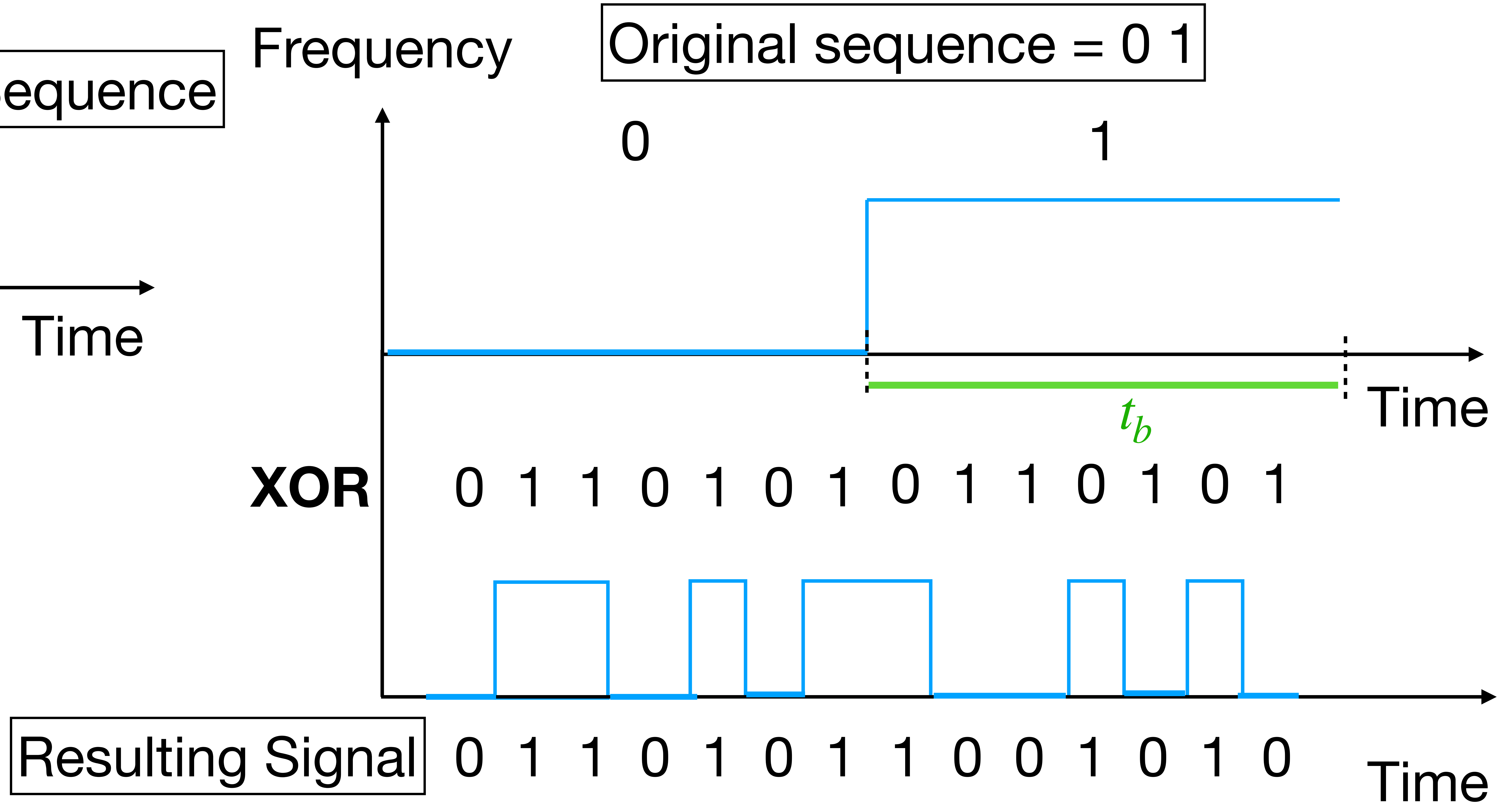

Direct Sequence Spread Spectrum (DSSS) (3)

- The receiver generates the same pseudo random chipping sequence as the transmitter.
- Sequences at the sender and receiver have to be precisely synchronized: the receiver calculates the product of the chipping sequence with the incoming signal.

Received signal	0 1 1 0 1 0 1 1 0 0 1 0 1 0
	XOR
Chipping sequence (repeated)	0 1 1 0 1 0 1 0 1 1 0 1 0 1
	0 0 0 0 0 0 0 1 1 1 1 1 1 1
	0 1

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Chipping sequence (repeated)	0 1 1 0 1 0 1 0 1 1 0 1 0 1	
	0 0 0 0 0 0 0 1 1 1 1 1 1 1	Resulting in ambiguous information here
	0 1	

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Received signal 0 1 1 0 1 0 1 1 0 0 1 0 1 0

XOR

Chipping sequence (repeated) 0 1 1 0 1 0 1 0 1 1 0 1 0 1

---

0 0 0 0 0 0 0 1 1 1 1 1 1 1

0 1

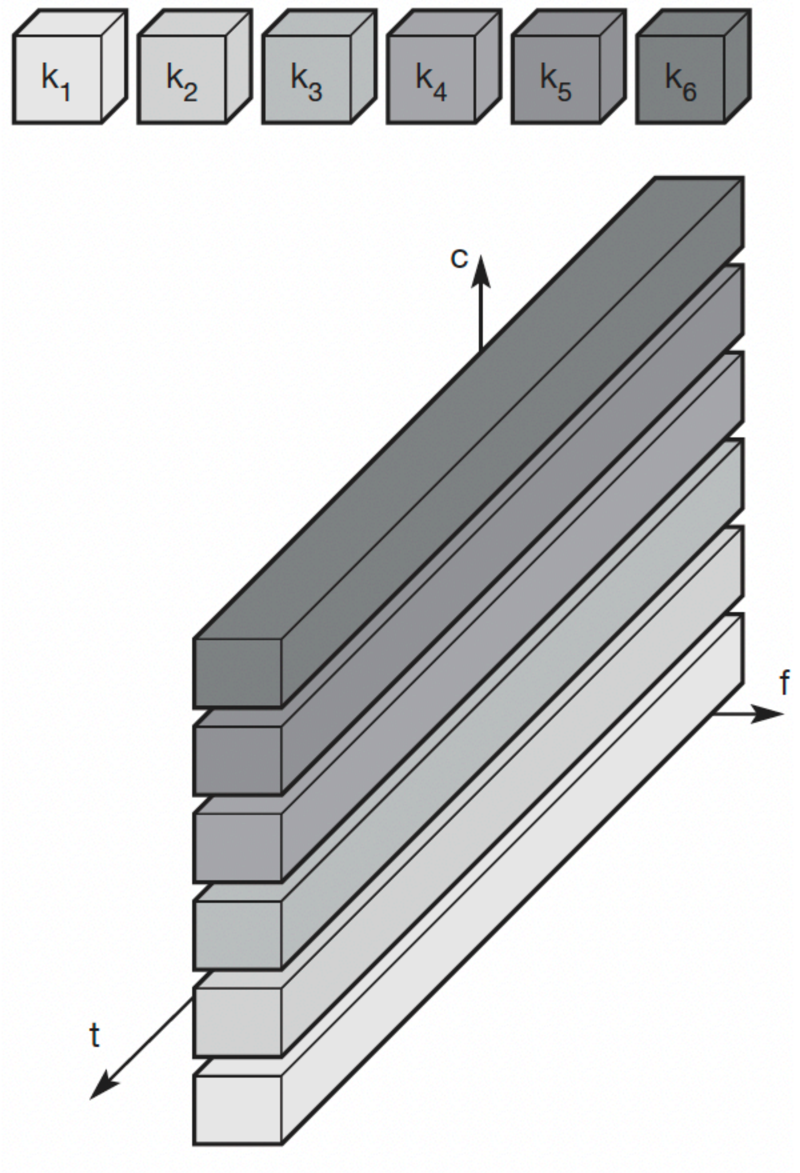
During propagation, errors might occur here

The receiver has correlator and decision modules

Resulting in ambiguous information here

Code Division Multiplexing (2)

- Each channel is assigned with a different code, which can be either a different hopping sequence or a different chipping sequence, depending on the spread spectrum technique used.
- In DSSS, to minimize overlaps between channels, chip codes must distant enough, in particular, they should be orthogonal (their dot product should be equal to 0).



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