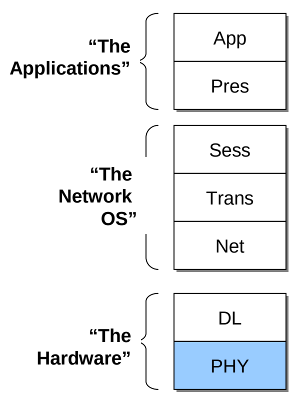
L1: Physical Layer



Typical bandwidth requirements

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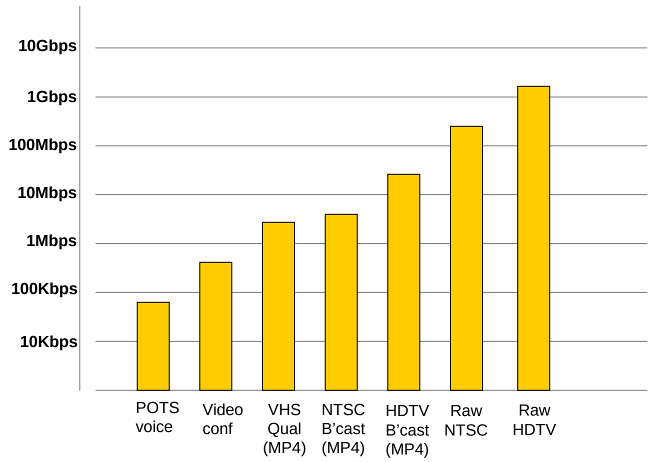

Typical network components

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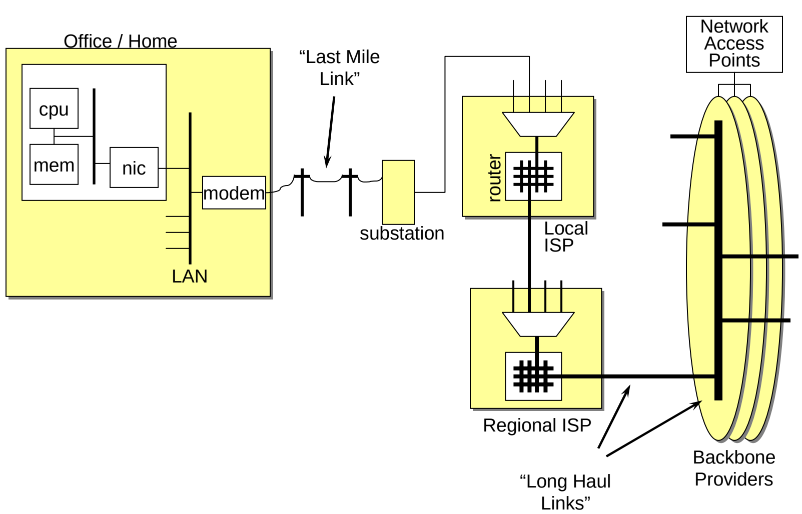

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Common wired last-mile link technologies

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- Analog
  - voice modems
- Digital
  - DSL
  - ISDN
  - Cable modems

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Analog over PSTN

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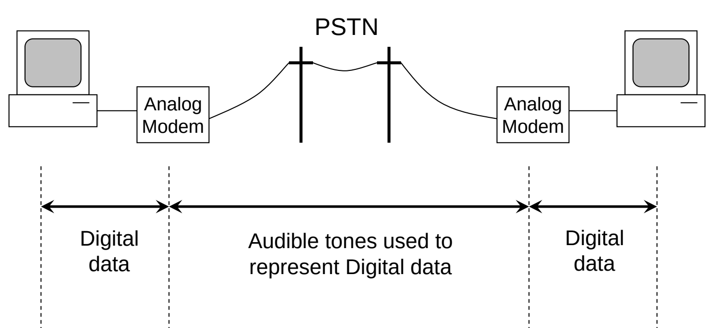
- "PSTN" = "Public Switched Telephone Network" (Standard Phone Service)
  (AKA "Plain old telephone service" -- POTS)



Analog modem encoding methods:
Frequency Shift Keying (FSK)

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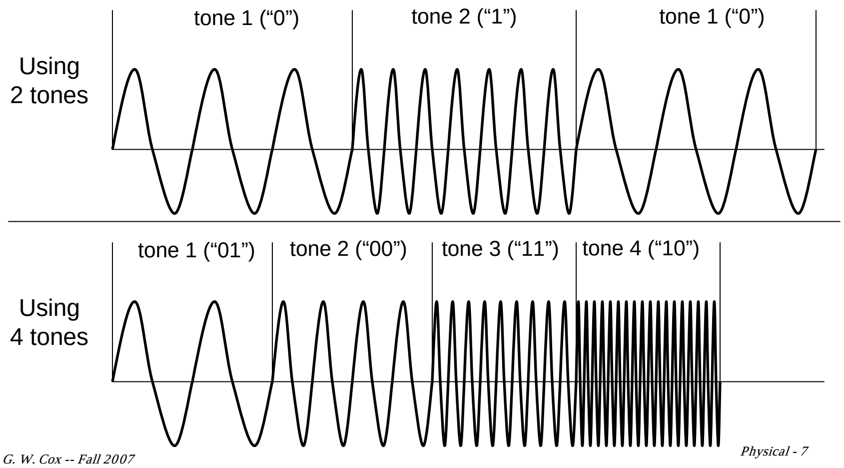
In FSK, Different frequencies (audible tones) represent binary sequences

Example: Binary sequence = “01001110”



Analog modem encoding methods:
Phase Shift Keying (PSK)

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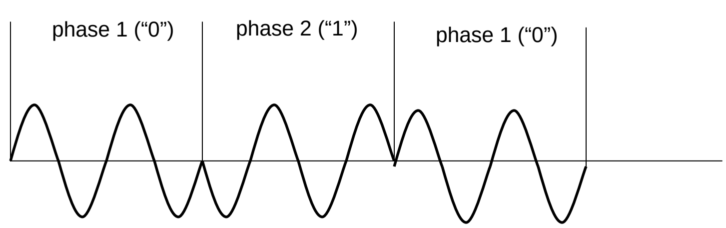
In PSK, Different signal phases represent binary sequences

Example: Binary sequence = “01001110”



Modern modems use a combination of FSK and PSK plus more advanced coding techniques

How do we talk about a modem's "speed"?

Two rates are significant:

1. The rate at which we change the signal (tone or phase) This is the "Baud rate"
2. The resulting bit rate (usually <u>not</u> = Baud rate)

300 bps (Bell 103)	300 Baud
1200 bps (Bell 212A)	300 Baud
2400 bps (CCITT V.22)	600 Baud
9600 bps (CCITT V.32)	2400 Baud
14.4 Kbps (CCITT V.32bis)	2400 Baud

Examples: Bit rate vs. Baud Rate

Example: Bit rate > Baud rate

A modem uses FSK with 16 tones. It can transmit a max of 1000 tones per second. What is the modem's Baud rate? Bit rate?

Baud rate = 1 Kbaud

Since there are 16 tones, we expect each tone to represent log2(16)=4 bits.

So the modem can transmit 4 x 1000 = 4 Kbps

Example: Bit rate < Baud rate

A high-reliability modem uses FSK with 2 tones. It can transmit a max of 1000 tones per second. For redundancy, every bit is transmitted twice. What is the modem's Baud rate? Bit rate?

Baud rate = 1 Kbaud

Since there are 2 tones, we expect each tone to represent log2(2)=1 bit.

Since each bit is sent twice, the bit rate is 500 bps

Digital Last-mile technologies

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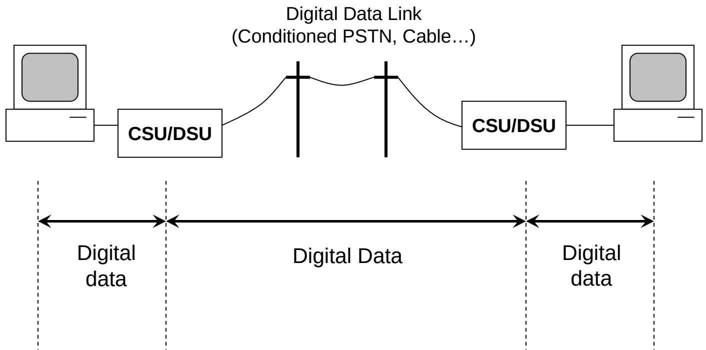
Digital Modems -- CSU/DSU = "Channel Service Unit / Data Service Unit"



Some Digital Technologies

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- **PSTN-based**
  - Asymmetric Digital Subscriber Line (ADSL)
    - Up to 8.5Mbps to subscriber, 640Kbps from subscriber
    - Limited to about 3 mi from substation
  - Integrated Services Digital Network (ISDN)
    - Up to 128K bps
- **Cable Modem**
  - 20-40 Mbps to subscriber, about half that from subscriber
  - 100 Mbps theoretical max

Common Wired Media types

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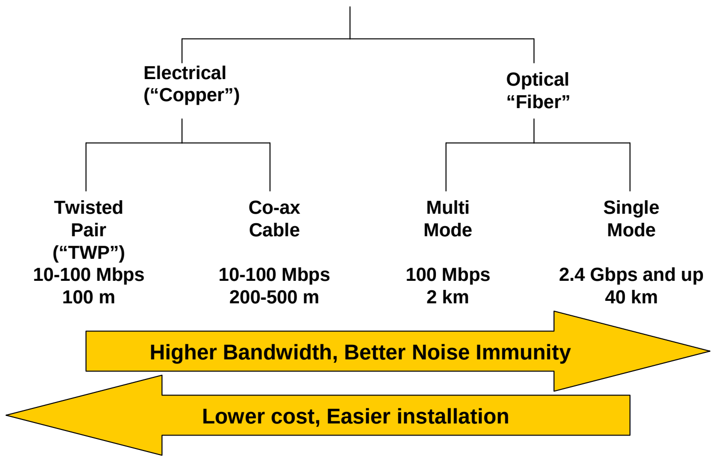

NOTE: We'll cover wireless media types in the Wireless part of the course

Co-axial Cable

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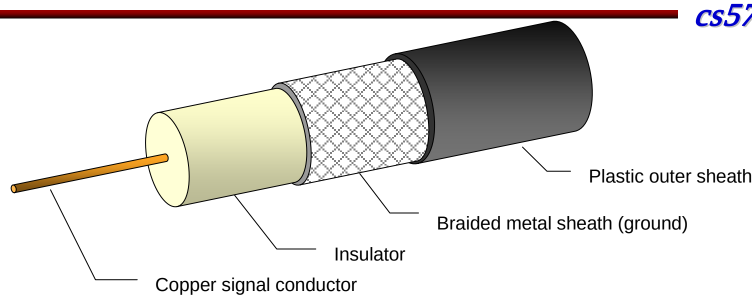

- Common Types
  - "Thinnet" (RG-58 / Belden 9907).
    - Preferred for Ethernet until TWP perfected
    - Good noise immunity
  - "Thicknet" (AKA "Yellow Cable").
    - The original Ethernet cable
    - Excellent noise immunity

Category 5 Twisted Pair (“Cat 5 TWP”)

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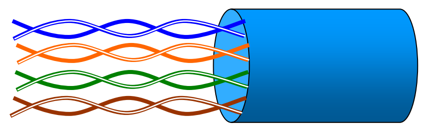

- Derived from telephone wire
- Much cheaper, easier to work with than co-ax
- Less noise immunity than coax
- The dominant networking medium

Fiber optic cable

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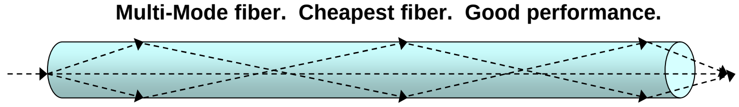
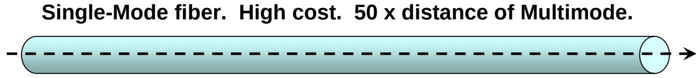
The idea: Pulsed laser light carried by glass fiber.

- Compared to copper:
  - Higher bandwidth
  - Immunity to electrical noise
  - More expensive. Harder to run and maintain
  - Good for Long-Haul backbone applications

Multi-Mode fiber. Cheapest fiber. Good performance.



Single-Mode fiber. High cost. 50 x distance of Multimode.



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Common Long-Haul Link Standards

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- Used in Copper and Fiber: the “T Standards”
  - DS1 (“T1”) - 1.544 Mbps, 24 voice ckts
  - DS3 (“T3”) - 44.7 Mbps, 872 voice ckts (= 28 T1’s)
- Fiber only: the “OC Standards”
  - STS-1 (“OC-1”) - 51.84 Mbps, 810 voice ckts
  - STS-”n” (“OC-n”) - n x 51.84 Mbps
  - Defined up to OC-192 (9.9 Gbps)

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The T Standards

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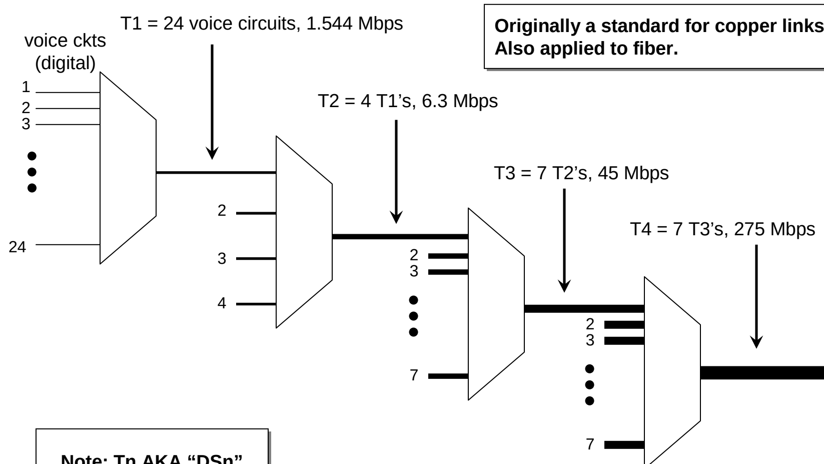
Originally a standard for copper links. Also applied to fiber.



Note: Tn AKA “DSn”

The OC or STS Standards

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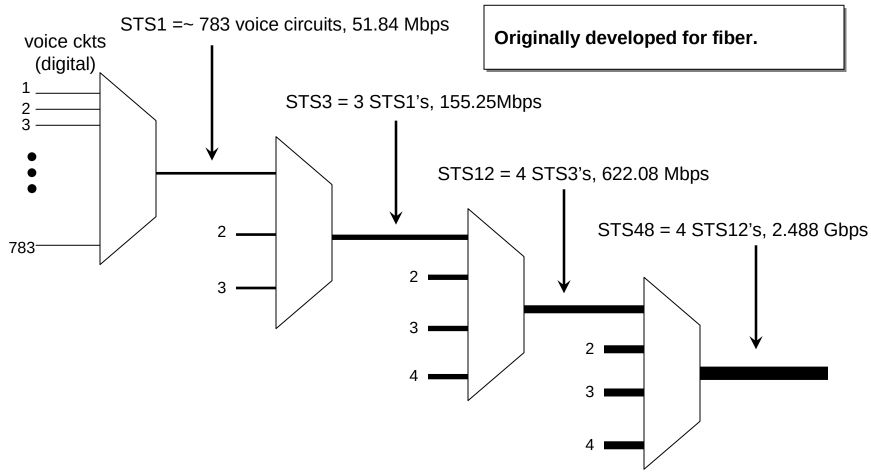

How do we carry several data streams on one link?

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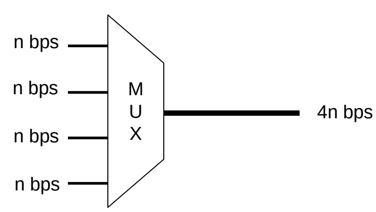
Multiplexing



- Transport multiple data streams simultaneously over a single link
- Must divide the link's bandwidth between the data streams
- Receiver must be easily able to separate the data streams again ("demux")
- Two primary approaches:
  - Time-Division Multiplexing (TDM)
  - Frequency-Division Multiplexing (FDM)

TDM - fixed slot

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Link bandwidth is divided up "timewise" among the datastreams

"Fixed slot" TDM (4 slots)

Data from datastream #1	Data from datastream #2	Data from datastream #3	Data from datastream #4	Next data from #1	• • •
Time slot	Time slot	Time slot	Time slot	Time slot	

- Timeslot length is fixed and known to receiver.
- Receiver must know where each slot begins
  - Method 1: Synchronized clocks (must be re-synched frequently)
  - Method 2: Special synch markers transmitted at beginning of slots (bandwidth lost to overhead)

A problem with fixed-slot TDM

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- A particular datastream may not have any data send at its timeslot time or may have only a small amount
- In this case the timeslot is unused and bandwidth is wasted

TDM - unslotted

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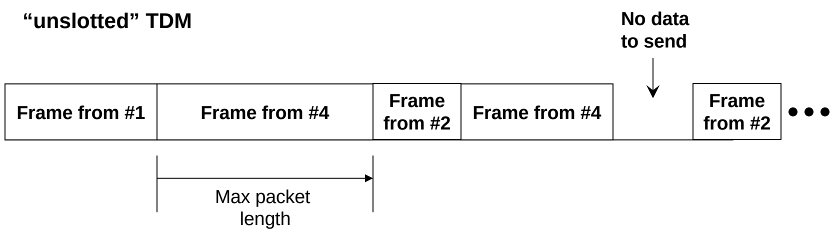

- Data sent over link as needed (data "frames" or "packets")
- Max frame length usually limited to help ensure fairness
- Since frames are variable length and order, they must carry additional overhead info:
  - Where they start and end (markers, length counts, etc)
  - Which datastream they belong to

FDM

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Different datastreams transmitted using different sets of frequencies

For instance:

data stream	"0"	"1"
1	1.0Khz	1.1Khz
2	1.2Khz	1.3Khz
3	1.4Khz	1.5Khz
4	1.6Khz	1.7Khz

- The different datastreams are truly sent simultaneously
- but each one gets only "one-nth" of the link bandwidth

Turning analog signals into digital (sampling)

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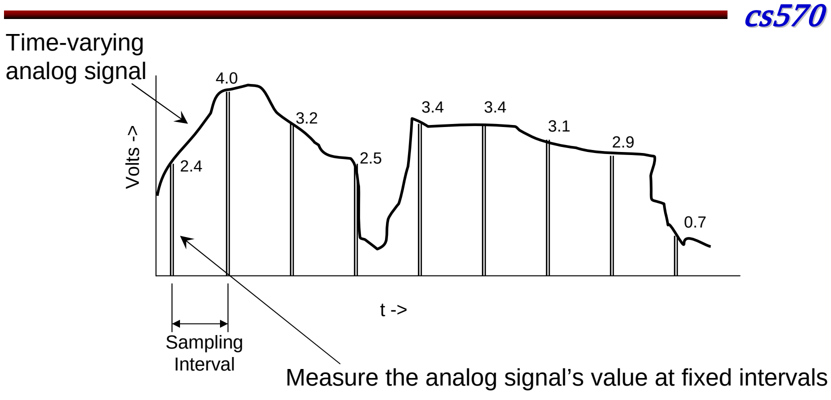

Digitized version: 2.4, 4.0, 3.2, 2.5, 3.4, 3.4, 3.1, 2.9, 0.7

How fast do we need to sample?

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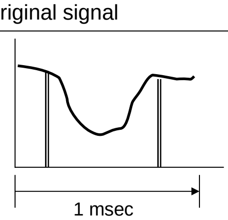
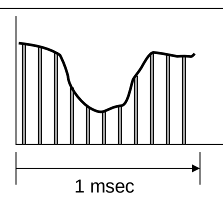
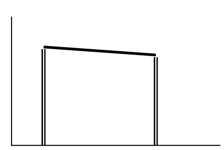
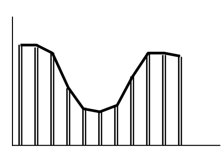
	If we sample too infrequently, we won't be able to reproduce the original signal	But the more frequently we sample, the more bandwidth it takes to transmit the digital data
Sampled Signal		
Bandwidth Needed to Transmit	At 1 byte/sample, 16 Kbps	At 1 byte/sample, **176 Kbps**
Reproduced Signal at Receiving end		

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Nyquist's Theorem gives the optimum sampling rate for any signal

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- We know that any time-varying signal can be represented as a set of frequencies
- Nyquist's theorem says:
  - The optimum sampling rate is twice the highest frequency in the signal you are sampling (this is the "Nyquist rate")
  - Also, if you have a binary data link with frequency bandwidth H, the max data rate is 2H bps.
- Surprisingly, sampling faster than the Nyquist rate yields <u>no</u> additional fidelity

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An application of the Nyquist rate

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- A standard voice-grade PSTN line will transmit up to H=4Khz.
- So the Nyquist rate is 2 x 40 = 8Khz (8000 samples / sec)
- If samples are 1 byte each, we need 8 x 8000 = 64 Kbps
- Implications:
  - The standard sampling interval for voice is 1/8000 = 125 usec
  - Can't reliably transmit more than 64 Kbps through a voice-grade line

OK, then why doesn't my voice modem provide anywhere close to 64 Kbps?
- Protocol overhead (56 Kbps max)
- Excessive line noise
- Poor-quality wiring

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Data encoding

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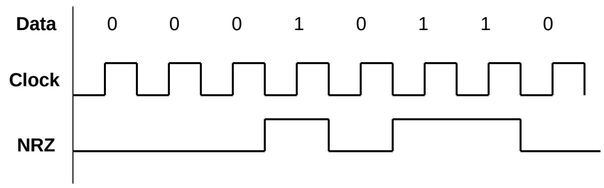
Basic encoding -- Non-Return to Zero (NRZ)



Problem: if there's a long run of 0's or 1's, there's nothing for the receiver to synch to. Receiver may lose synch and sense data at the wrong point in the datastream

Example:
Nodes A and B are connected by a 100Mbps link. A sends a long string of 1's to B using NRZ encoding. B's clock runs 1 second per year slower than A's. If the clocks are synched at the beginning of the series and not synched again, how long will it be until B's clock is exactly one bit period behind A's (that is, until B has "lost" a bit)?

100Mbps => 10^{-8} sec/bit.
B loses 1 sec/year = 1 sec/31.5x10^{6} sec = 3.17x10^{-8} sec/sec.
This means that B will lose a bit period (10^{-8} sec) in **about 0.31 second**.

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A self-clocking code (Manchester Code)

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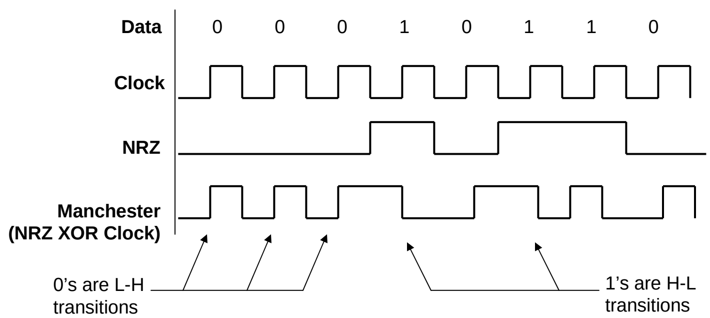

A self-clocking code provides a synthetic "clock" as part of the datastream. The receiver can use this to synch.

In the case of the Manchester code, NRZ is XORed with the sender's clock to provide a clock edge in every bit period.

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