EEEN20060 Communication Systems

Physical Layer - Introduction

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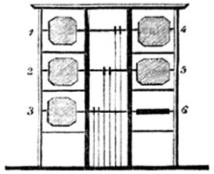
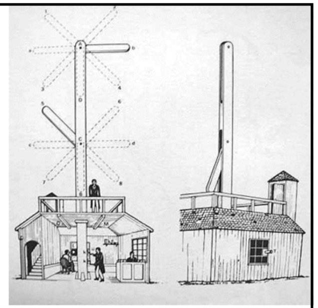
Early Communication Systems

1795, linked London to Portsmouth, 108 km in 15 minutes





- Telegraph Systems
  - designed to send messages – text
  - various codes used to represent letters
- Early systems optical
  - flags or shapes on tall structure or hill
  - viewed from far away
  - message re-transmitted as necessary (note!)

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Electric Telegraph

- Electromagnetic Telegraph
  - Cooke & Wheatstone, 1837
  - 5 needles, deflect left or right in combinations
  - 5 wires, each with two directions of current (or none)
  - 6th wire as return path for current, or use earth

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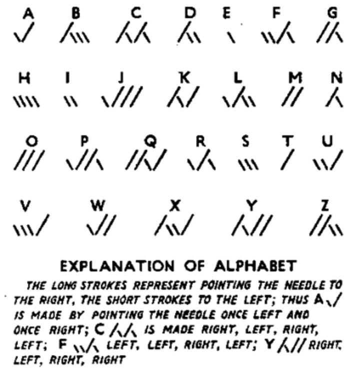
One-Wire Telegraph



- One needle
  - use sequence of left and right deflections to represent letters
  - one wire, two directions of current, earth return
  - machine can send or receive, one at a time

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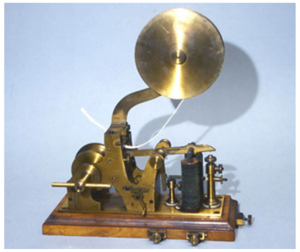
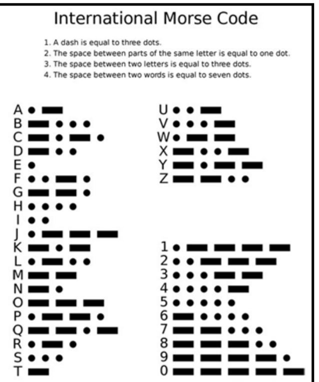
Recording Telegraph





- Samuel Morse
  - and others, 1844
  - simplified signals – current on or off
  - different *durations* for elements of code
  - electromagnet pulls marking device onto moving paper tape to record the message

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Longer Distances

- Weaker signals
  - longer wires, higher resistance, more leakage
  - not enough current to operate receiver
- Use relay(s) along the way
  - detect signal while still strong enough
  - use to control switch to send new signal…
    - using battery at relay location
- Undersea cables more difficult
  - finally achieved transatlantic cable in 1866

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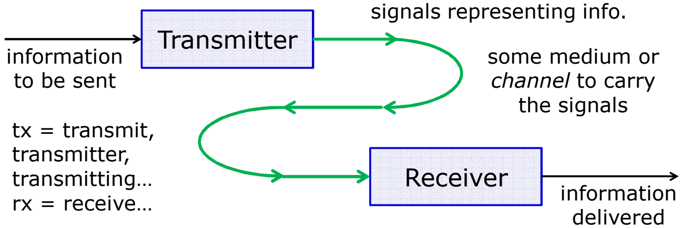
Physical Layer – Basic Requirement



- Want to shift information from A to B
  - reasonably reliably
  - may also want to shift info from B to A
- Must have some physical medium
  - some path to carry signals from A to B
  - called *channel* in Communication Theory

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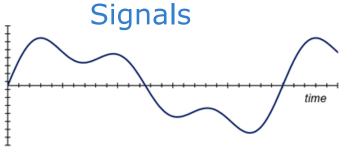
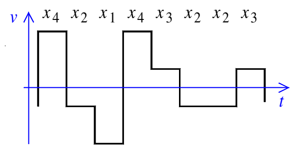
Signals





- Analogue signals – continuous range of values
  - continuous in time also
  - easy to represent info. from analogue world
    - sound waves, light intensity, temperature…
- Digital signals – finite discrete set of values
  - discrete in time also
  - must have info. as symbols from finite set
    - different electrical signal represents each symbol
  - symbols transmitted one after another
    - so signals change at discrete points in time
  - simplest case is binary – only 2 symbols

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Coding

H	I	space	T	H	E	R	E
10100	00110	00100	10000	10100	00001	01010	00001

- Example – info. is text – min. 27 symbols
  - not easy to send 27 different electrical signals
  - difficult to distinguish signals at receiver…
- Can change representation – re-code
  - use a smaller (or larger) set of signals
  - to suit the characteristics of the channel
- Example – text, 27 symbols
  - map each symbol to group of 5 binary symbols
  - transmit binary symbols (usually in sequence)
  - reverse mapping at receiver…

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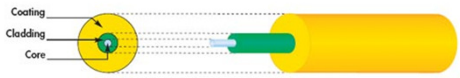
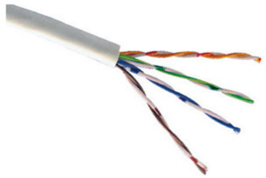
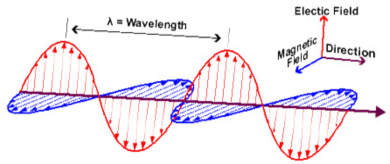
Channels







- Signals travel through physical channel
  - voltage/current travelling on wires in a cable
    - can also view as electromagnetic wave…
  - light waves travelling along glass fibre
  - light waves travelling in free space
  - radio waves travelling in free space

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Problems on the Channel

Transmitter —channel→ Receiver

- Signal is attenuated (weakened) along channel
  - receiver only gets a fraction of the tx power
- Signal is delayed along the channel
  - finite speed of propagation
    - radio waves 3×10^8 m/s, cable ~ 2×10^8 m/s
- Signal is *distorted* by the channel
  - different frequency components in the signal
    - attenuated by different factors
    - delayed by different times
  - these differences change the shape of the signal

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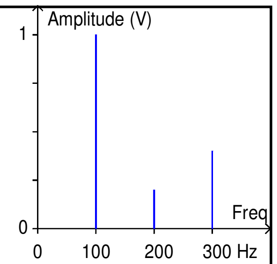
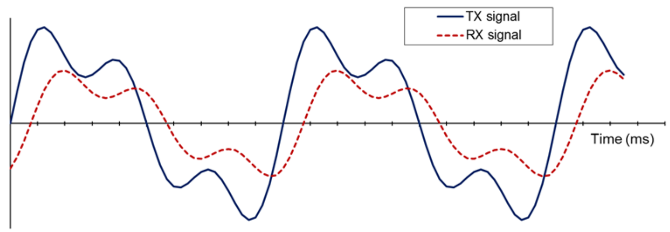
Analogue Signal Example

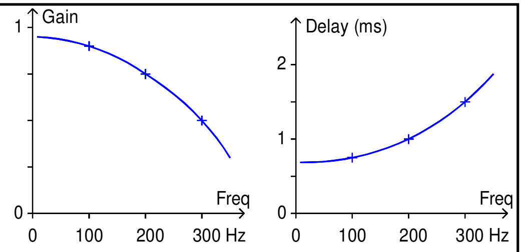


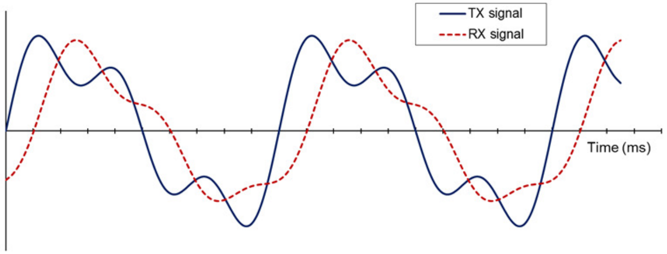
- Signal has 3 components
  - 100, 200, 300 Hz
  - 1, 0.2, 0.4 V amplitude
- Graphs show no distortion
  - all frequencies scaled 0.55
  - all frequencies delayed 0.75 ms



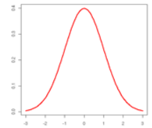
Distortion Example

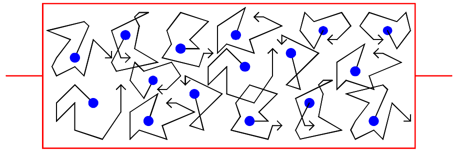
note signal shape has changed





Noise





- Thermal noise
  - due to random motion of electrons in resistors (or any resistive circuit elements)
  - random voltage, zero mean, Gaussian pdf
  - covers (almost) all frequencies - *white noise*
  - effect depends on bandwidth of system
  - rms voltage: $V_{rms} = \sqrt{4kTRB}$
    - R = resistance (Ω)
    - T = absolute temperature (K)
    - B = bandwidth of measurement (Hz)
    - k = Boltzmann's constant ≈ 1.38×10^{-23} J/K

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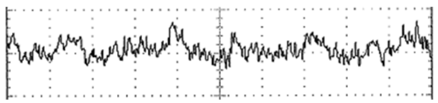
Noise

$V_{rms} = \sqrt{4kTRB}$



- Thermal noise example
  - resistor 100 kΩ, at room temperature, 290 K
  - measurement BW 1 MHz, V_{rms} ~ 40 μV
- Small noise voltages
  - significant for small signals, wide BW
- Shot noise $I_{rms} = \sqrt{2qI_{DC}B}$
  - occurs in electronic devices when current flows
  - due to quantised nature of charge
  - random noise current, Gaussian pdf, white
  - e.g. diode at 10 mA, BW 1 MHz, I_{rms} ~ 57 nA
  - but if flows through 1 kΩ, V_{rms} ~ 57 μV

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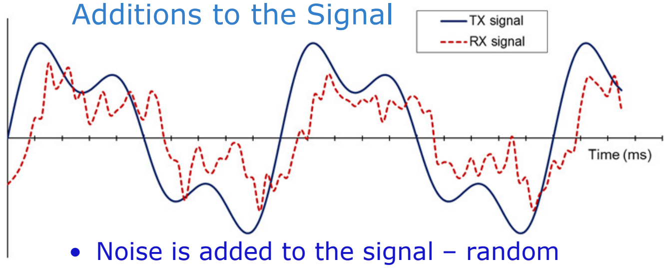
Additions to the Signal



- Noise is added to the signal – random
  - thermal noise from resistance of conductors
  - thermal noise and shot noise from electronics in receiver – usually dominant
- Interference may be added to the signal
  - unwanted, but not really random
  - often leakage from another system
  - in cable, *crosstalk* from another pair of wires

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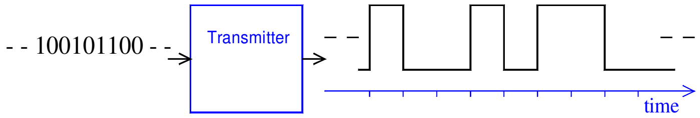
Main Channel Parameters

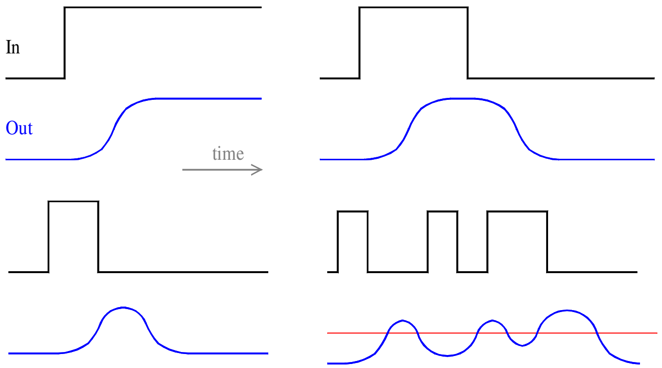
- Bandwidth – *B*
  - range of frequencies that channel can carry
  - for cable, not well defined, no clear limit
    - attenuation increases with frequency
  - design decision:
    - what range of freq. will we use?
    - how much attenuation can we tolerate?
  - for radio, often set by regulation / allocation
- Signal-to-Noise Ratio – SNR, *S/N*
  - ratio of signal power to noise power at receiver
  - analogue system, determines quality of signals
    - music quality, want > 60 dB (ratio 10^6)
    - telephone quality, accept 30 dB or less (ratio 10^3)
  - see later for digital system

Digital Transmission



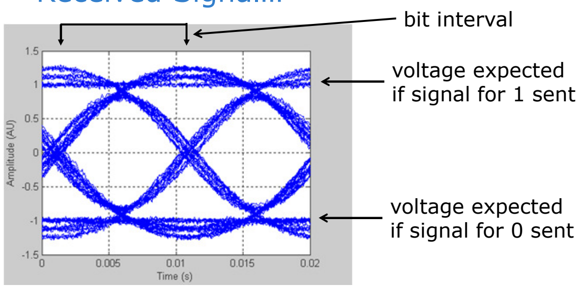
- Assume binary transmission (for now)
- What electrical signals to use?
  - need two – one to represent 1, one for 0
- Want to choose signals that will
  - survive the damage caused by the channel
  - be easy to distinguish at receiver
    - even with distortion, noise, interference
  - fit in available time interval (usually)
  - have reasonable average power

Distortion in Channel



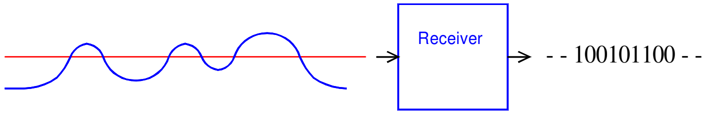
rough sketches, show delay & distortion only…
note received signal shape depends on neighbours …

Received Signal…



- This view called "eye diagram"
  - use oscilloscope to view received signal
  - trigger so that bit intervals line up
  - signals from many intervals overlaid…
  - note signal influenced by neighbouring bits…

What does the Receiver Do?



- Make a decision in each bit interval
  - does this signal represent 1 or 0?
  - actually: is this signal *more likely* to represent…
  - some finite probability of error in this…
- In order to do that
  - need to identify bit intervals
  - must extract timing information from rx signal
    - find where bit intervals begin and end…
  - need changes in the signal – *transitions*

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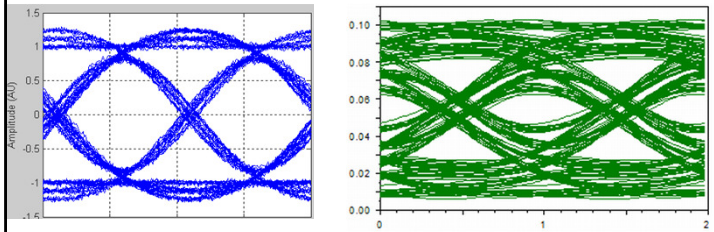
How to Make Decision?



- Usually set threshold value (voltage)
  - usually half-way between expected values
  - anything above threshold is 1, below is 0
- Need good "eye opening" for reliable decisions
  - random noise added to signal
    - if close to threshold, easy to push over threshold…
  - need good S/N for reliable decisions…

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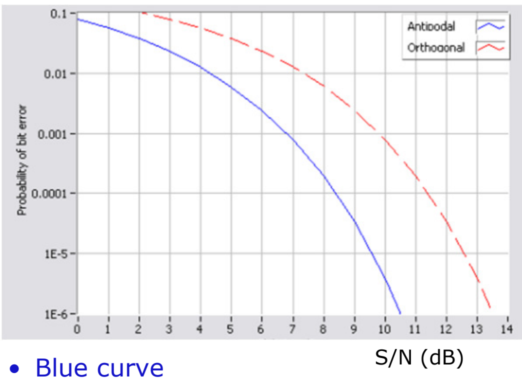
Probability of Error vs. S/N



- Blue curve
  - for simple symmetrical binary signals
  - everything optimum, bit rate = bandwidth

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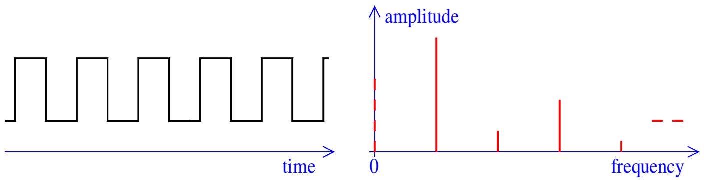
How Fast Can We Transmit?



- Depends on bandwidth available in channel
- Example – bit interval is 1 μs, so 1 Mbit/s
  - could send any sequence of bits
  - including periodic sequence 0101010101…
  - what is the period of repetition of this signal?
  - what is *fundamental frequency* of signal?
    - signal also has *harmonics* – multiples of this freq.
    - may have DC component – average value

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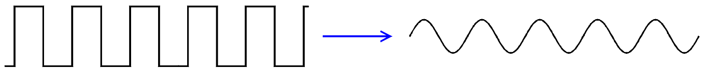
How Fast?



- Channel must pass at least fundamental freq.
  - if not, only DC component gets through
    - no information. . .
  - so need channel bandwidth ≥ ½ bit rate
  - if no harmonics passed, get sinusoidal output…
- So for binary signals, as in example
  - absolute maximum bit rate = 2 × bandwidth
  - theoretical maximum…
  - many practical systems limited to ~1 × bandwidth

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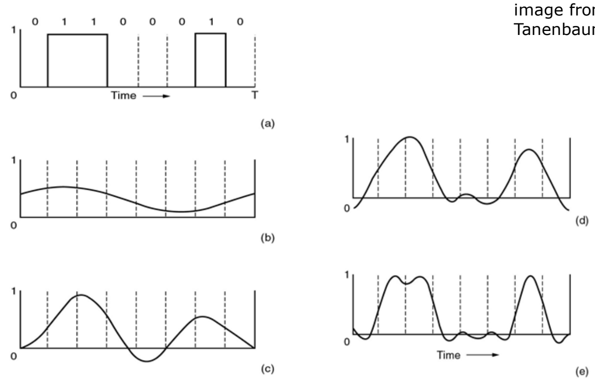
Examples

image from Tanenbaum



- (a) tx signal, (b) to (e) rx signals
- (b) ~minimum bandwidth, (e) ~8 times more

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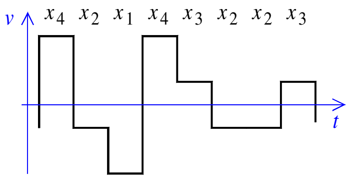
More Complicated Signals



x_1 represents 00
x_2 represents 01
x_3 represents 11
x_4 represents 10

- Channel bandwidth limits *signalling rate*
  - rate at which new signals are sent
  - same as bit rate for binary signals
- Can use larger set of signals – 4 in example
  - now each signal can carry 2 bits
  - in general, for *n* bits, need 2^n different signals
- But harder to distinguish at receiver
  - need better S/N

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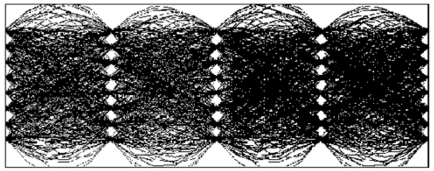
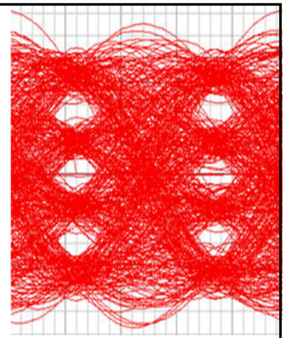
Examples, Design Decision





- Can trade bandwidth for S/N
  - use 2 signals (binary) with low S/N
    - easiest to distinguish in noise
  - need wide bandwidth, only 1 bit per signal
  - use larger set of signals with higher S/N
  - can reduce bandwidth, send fewer signals
    - or use same bandwidth, send bits faster…

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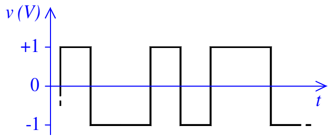
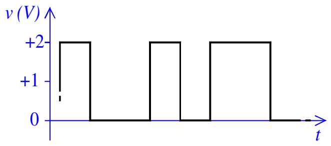
Signal Design





- Want signals
  - robust, easy to distinguish, reasonable power
  - not too many transitions, for low bandwidth
  - plenty of transitions, for timing extraction
  - on some channels, no DC component
    - e.g. wires connected through transformer for safety
- Which of the signals above is better?
  - both will give same opening in eye diagram
    - same probability of error, all else equal

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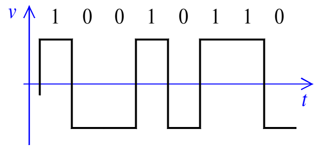
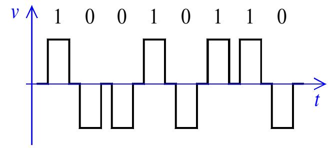
Signal Design





- NRZ = non-return to zero
  - simple, commonly used
  - timing recovery difficult if long strings of 0 or 1
- RZ = return to zero (after each pulse)
  - guaranteed transitions in every interval
  - good for recovering timing information at rx
  - uses more bandwidth
    - but on cable, may not care about bandwidth?

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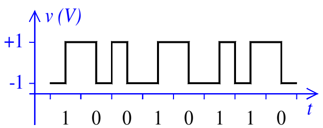
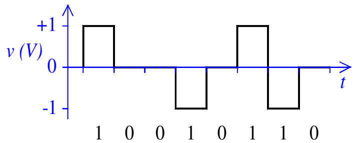
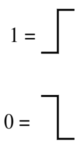
Signal Design







- "Manchester Coding"
  - always transition in centre of bit interval
    - upward transition for 1, downward for 0
  - bandwidth needed ~doubled compared to NRZ
  - if symmetrical as shown, zero DC component
- AMI – Alternate Mark Inversion
  - 3-level signal, 0 → 0 V, 1 → ±1 V alternately
  - zero DC component
  - long sequence of 0 bits → timing problem…

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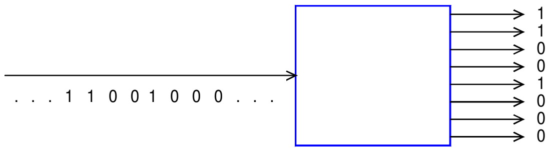
Example: Serial Interface, Serial Port



- Mainly physical layer protocol
  - also supports link layer – delivers groups of bits
  - will be used in lab exercises
- Serial ⇒ one bit after another, on one channel
  - computer works with many bits in parallel
  - hardware converts, also adds extra bits
- Originally used to connect to modem
  - extra signals to control modem

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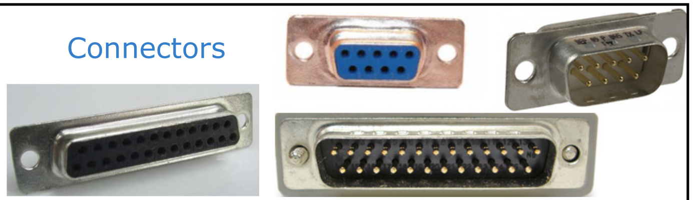
Connectors



- Originally 25-pin D connector
  - many signals rarely used
  - now mostly 9-pin connector (or USB emulation)
- Gender
  - standards specify male connector for DTE
    - Data Terminal Equipment
    - source or destination of data – e.g. computer
  - female connector for DCE
    - Data Communication Equipment
    - used to communicate – e.g. modem

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Main Signals

Signal	Full Name	Direction	Sense	Pin No.
TXD	Transmit Data	Out of DTE	high = 0	3
RXD	Receive Data	Into DTE	high = 0	2
RTS	Request To Send	Out of DTE	high = active	7
CTS	Clear To Send	Into DTE	high = active	8
DTR	Data Terminal Ready	Out of DTE	high = active	4
DSR	Data Set Ready	Into DTE	high = active	6
CD	Carrier Detect	Into DTE	high = active	1
GND	Ground, reference	-	-	5

- RTS/CTS – requests/gives permission to transmit
  - e.g. one-way at a time communication…
- DTR/DSR – DTE/DCE ready for use
- CD – modem is receiving a signal from far end
- pin numbers are for 9-pin connector

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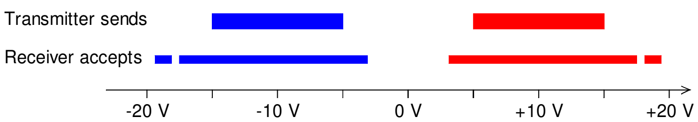
Voltage Levels



- Binary system – voltage either high or low
  - one wire for each signal
  - voltage measured relative to common ground
- At output
  - high voltage in range +5 V to +15 V
  - low voltage in range –5 V to –15 V
- At input
  - must recognise > +3 V as high, < –3 V as low
  - voltages close to zero not valid

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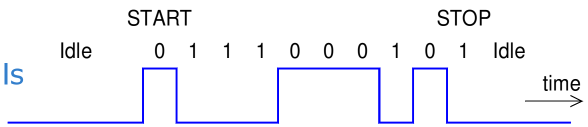
Data Signals



- When idle, data signal remains low (1)
- Each group of bits begins with START bit
  - always 0
- Group of 5 to 8 data bits, sent LSB first
  - least-significant bit, rightmost bit in binary no.
- Followed by STOP bit (sometimes two bits)
  - always 1
- Followed by
  - START bit for next group of bits, if any
  - idle state, if not

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Parity Check Bit

11000101 → 011000101

10100111 → 110100111

- Simple way to detect errors – option here
- Add one extra parity bit to group
  - sent after data bits, before STOP bit
- Two versions:
  - even parity – make number of 1s even
  - odd parity – make number of 1s odd
  - stop bit not included in count
- Can detect one bit error (or odd number)

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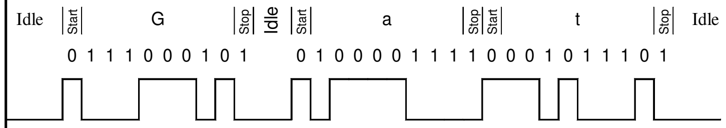
Example



- Sending characters G a t
  - 7-bit data, ASCII code, even parity
- Note upward transition at every START bit
  - either from idle or STOP bit
  - receiver uses this to re-start timing
  - receiver needs to know bit rate
    - but need only be accurate enough to stay in step for one group of bits… (10 bits in this example)
  - standard rates – 300, 600, 1200, 2400, . . . bit/s

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Standards specify:

- Connector and pin assignment
- Voltage levels for 1 and 0
- Grouping of bits, order of transmission
  - would normally be link-layer issue...
- Bit rates – choose from standard set
  - also mechanism for timing recovery at RX
- Optional error detecting mechanism
  - choose odd, even, or no parity
- Standard often called RS-232 (from USA)
  - international standards (from ITU)
    - V.28 specifies voltages, signal characteristics
    - V.24 specifies names and meanings of signals

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