EG3576

COMMUNICATIONS ENGINEERING I - COMMUNICATIONS FOR CONTROL

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HTTP://WWW.ERG.ABDN.AC.UK/~GORRY/EG3576/

V81 (JAN 2025)

INTRODUCTION TO THE COURSE

Module 0.0

COURSE AIMS

- To present the fundamentals of **serial communications** and use to control real-world equipment.
- To gain an understanding of serial data techniques using **asynchronous and synchronous** transmission and related software algorithms.
- To become familiar with the operation of **key protocols** (e.g. DMX-512, RDM, CAN).
- To introduce a professional oscillosope and use this to **measure the signal** at the bus interfaces.

The course roadmap is on-line at:

https://erg.abdn.ac.uk/users/gorry/eg3576/

Communications Engineering I: Modules

0.0 Overview
- 0.1 Scopes
- 0.2 Long Distance Communications

1.0 Asynchronous Serial Transmission
- 1.1 Asynchronous Transmission
- 1.2 UART
- 1.3 EIA-232

2.0 Communications Links
- 2.1 Asynchronous Serial Frames
- 2.2 NMEA GPS Frames
- 2.3 Transmission Theory

3.0 EIA-485 Differential Transmission
- 3.1 Differential Transmission
- 3.2 EIA-485 Cable Bus

4.0 DMX 512 Physical Layer
- 4.1 DMX 512 Overview
- 4.2 Bus Terminatiion
- 4.3 Bus Transceivers

5.0 DMX 512 Frames
- 5.1 Frames of Slots
- 5.2 Addressing and Receivers
- 5.3 DMX Receiver Hardware
- 5.4 DMX Receiver Software
- 5.3 Digital Control

6.0 DMX 512 Control
- 6.1 Controlling Power
- 6.2 System Architecture
- 6.3 Multiple Slots
- 6.4 LEDs
- 6.5 Start Codes

7.0 Control Networks
- 7.1 Repeaters
- 7.2 Ethernet

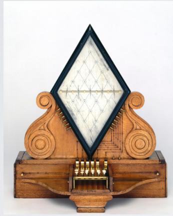
8.0 RDM

9.0 CAN
- 9.1 CAN Physical Layer
- 9.2 CAN Arbitration

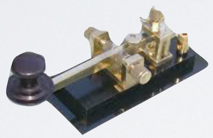
LONG DISTANCE SERIAL COMMS

Module 0

SERIAL CABLE COMMUNICATIONS



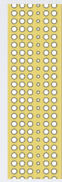
1837



... - - - .

1844

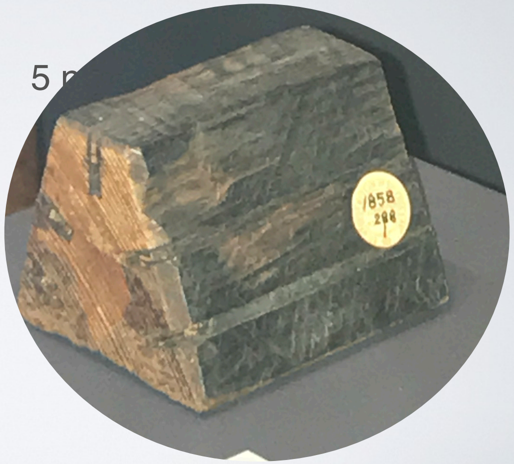
1865

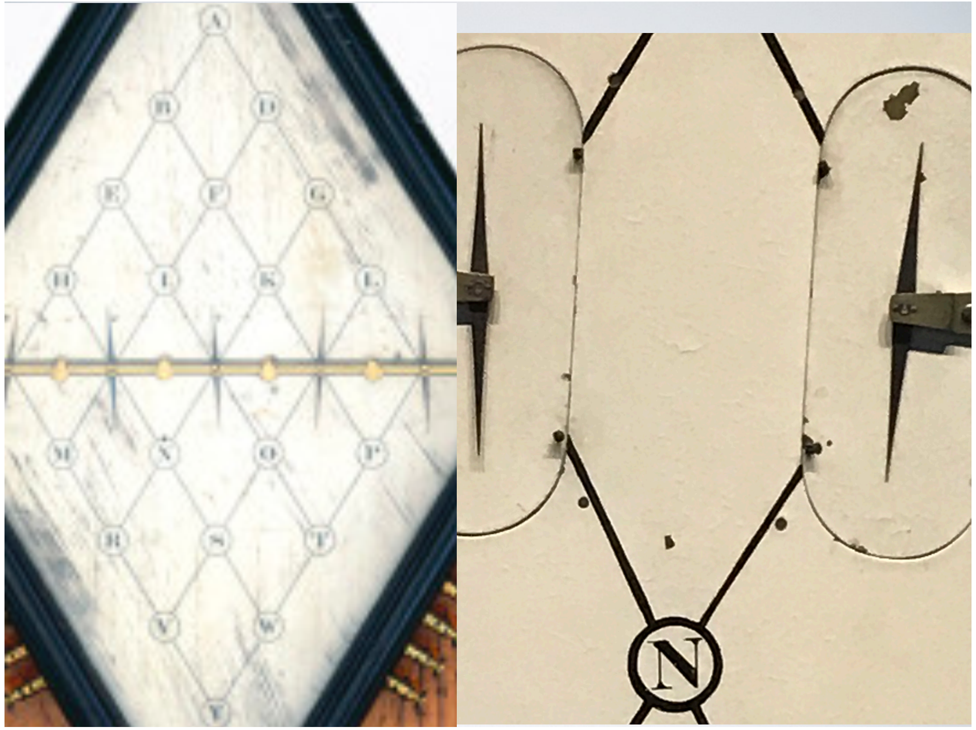


1874

1837: COOKE AND WHEATSTONE TELEGRAPH

5 n

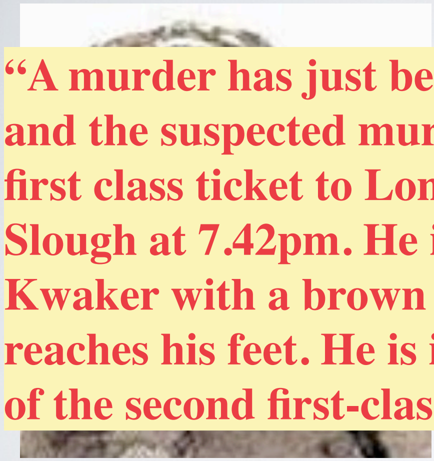


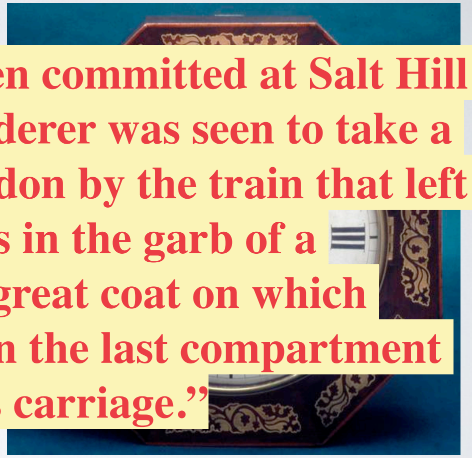


1845: COMMERCIAL SUCCESS

Railway Time

1845: COMMERCIAL SUCCESS





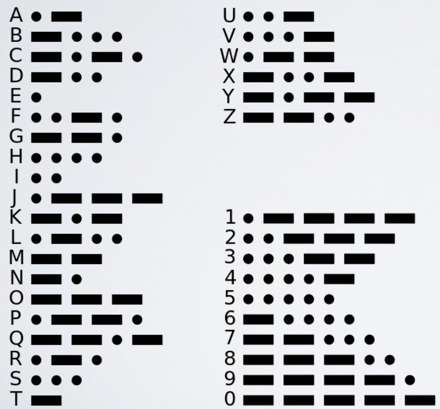
"A murder has just been committed at Salt Hill and the suspected murderer was seen to take a first class ticket to London by the train that left Slough at 7.42pm. He is in the garb of a Kwaker with a brown great coat on which reaches his feet. He is in the last compartment of the second first-class carriage."

John Tawell

https://www.btp.police.uk/police-forces/british-transport-police/areas/about-us/about-us/our-history/crime-history/murder-of-sarah-hart/

1844: MORSE CODE

SERIAL COMMUNICATIONS



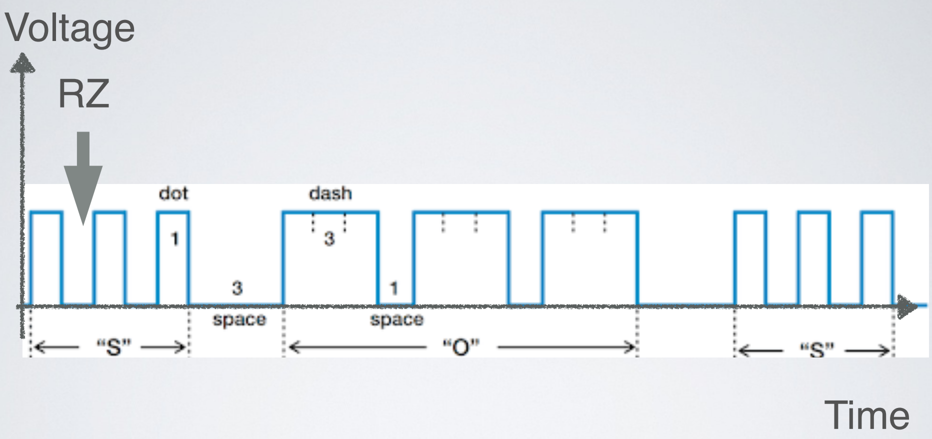
3 symbols, dot, dash, space

One wire or radio channel

Letters and numbers are serialised into a single stream

MORSE WAVEFORM

RETURN TO ZERO



Each symbol (baud) is sent at the same level, seperated by a return to zero.

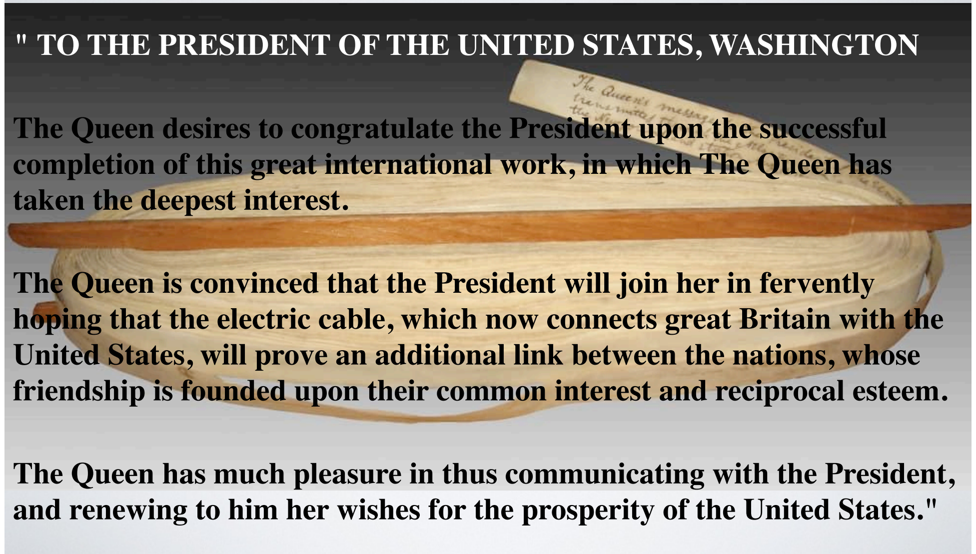
THE MORSE KEY

--. --- .-. .-. -.--

G O R R Y

1857: ATLANTIC TELEGRAPH

16 AUG 1858: FIRST MESSAGE



" TO THE PRESIDENT OF THE UNITED STATES, WASHINGTON

The Queen desires to congratulate the President upon the successful completion of this great international work, in which The Queen has taken the deepest interest.

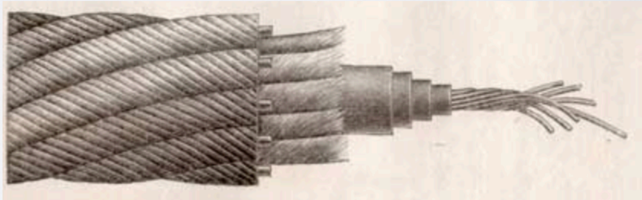
The Queen is convinced that the President will join her in fervently hoping that the electric cable, which now connects great Britain with the United States, will prove an additional link between the nations, whose friendship is founded upon their common interest and reciprocal esteem.

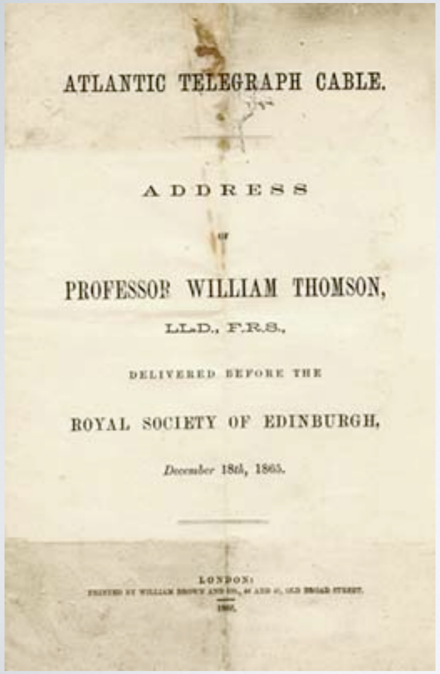
The Queen has much pleasure in thus communicating with the President, and renewing to him her wishes for the prosperity of the United States."

OH DEAR!

1865:
ATLANTIC TELEGRAPH

1 telegraph channel !!!!





ATLANTIC TELEGRAPH CABLE.

ADDRESS

OF

PROFESSOR WILLIAM THOMSON,

LL.D., F.R.S.,

DELIVERED BEFORE THE

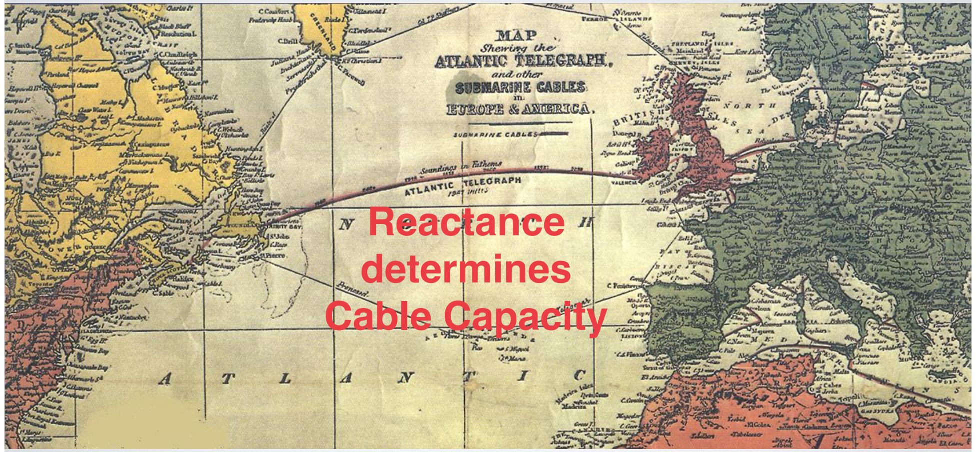
ROYAL SOCIETY OF EDINBURGH,

December 18th, 1865.

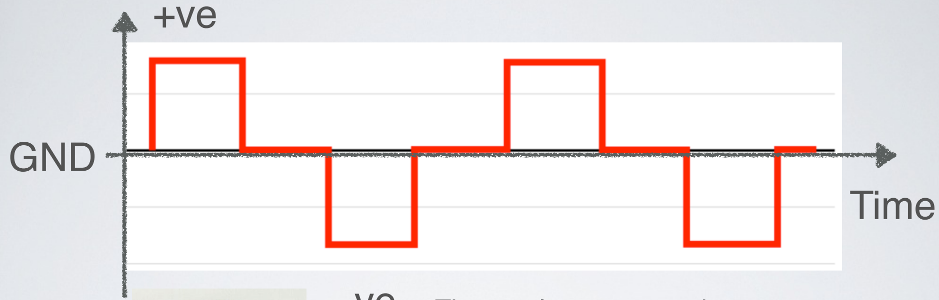
LONDON:

1857 1858 1865

SENDING FASTER....



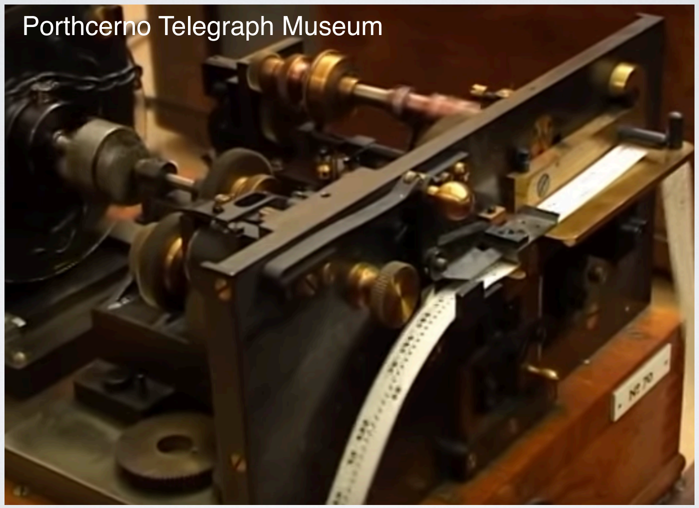
1860: BIPLOAR SIGNAL



- Three values: +, –, and zero
- Equal-sized pulses for + and -
- No net DC signal
- Capacitance of cable much less important

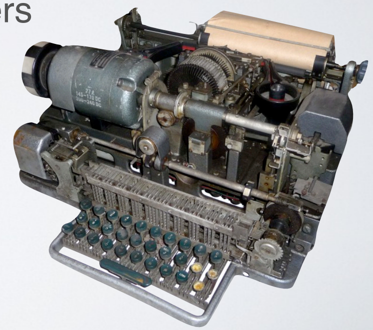
"A bipolar transmission telegraph signal" refers to a telegraph signal that uses both positive and negative voltage polarities to represent information"

BIPOLAR MORSE SIGNALLING



1900 -1950

Automatic teleprinters



1874: EMILE BAUDOT

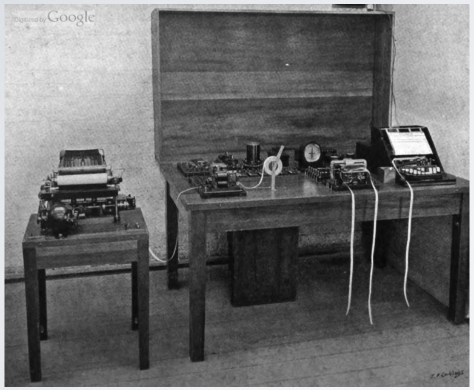
Designed a fixed-sized code
A "Baud" is the name for the symbol sent on a cable.

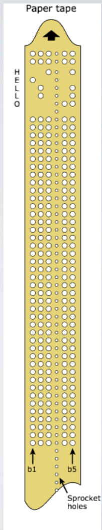
1874: 5-BIT BAUDOT CODE

00000	00000	Null
00100	00100	Space
10111	11101	Q
10011	11001	W
00001	10000	E
01010	01010	R
10000	00001	T

All characters represented by a 5-bit value
5-bits represent (2^31)-1 different characters = 31.

1905: MURRAY PRINTING TELEGRAPH

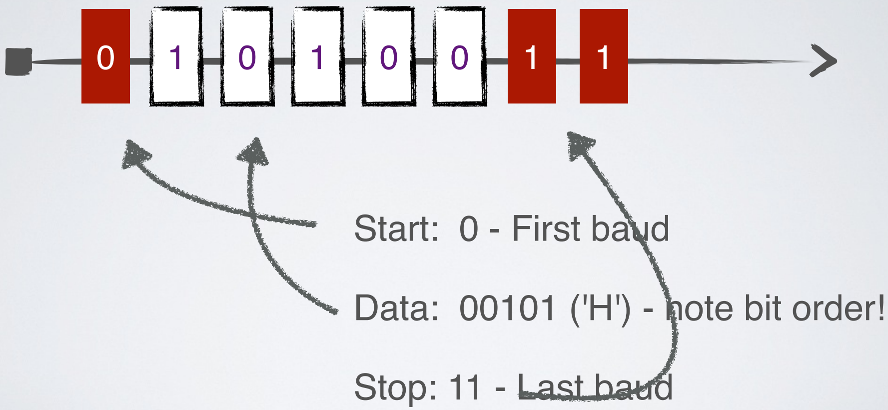




A start-stop system using 5-bit codes

START AND STOP BAUDS

Murray's start-stop system using 5-bit codes



1908: STANDARD ITA-1 CODE

2^5 = 32 values

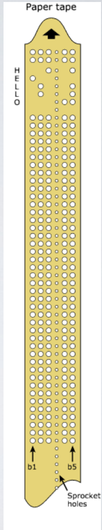
26 Letters

4 Control Chars
- Null (0)
- Space
- Carriage Return
- Line Feed

2 Shift Chars
- Number Shift*
- Letters Shift*
  - *26 Numbers

*26x2

Telex paper tape



COMPARISON

Suppose we were to send the message "SOS" using the Cooke and Wheatstone Telegraph, Morse Code and theTelex Code - how long (measured in bauds) would this take?

A Cooke and Wheatstone sends 3 letters in 6 bauds

Assume 1 baud between morse bauds, and 3 between letters, a dot is 1 baud, a dash is 3 bauds:

SOS in morse is then ... --- ... = 8+14+8 = 30 bauds

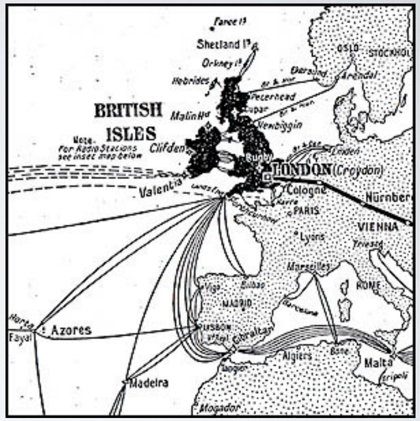
Assume ITA-1 code, with 1 start and 2 stop bauds:

SOS in this asynchronous format takes 8 x 3 = 24 bauds

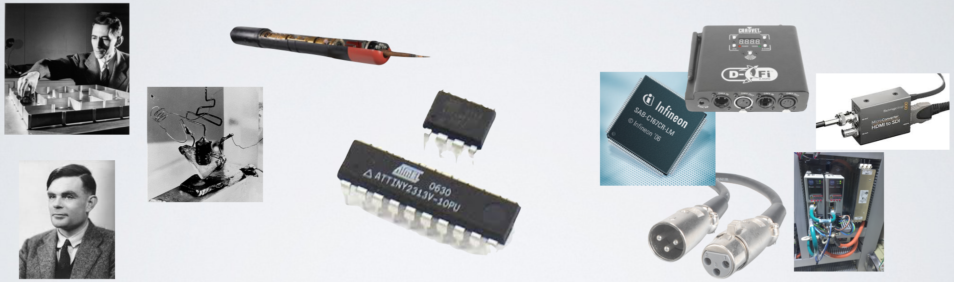
CREED MK3 TELEPRINTER

USED THROUGHOUT UK BY THE GPO FOR SENDING/ RECEIVING TELEGRAMS

1939: PORTHCERNO, CORNWALL

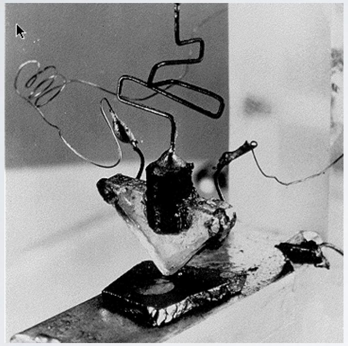


MULTIPLEXING AND COMMUNICATIONS BUSSES



1948 1955 1965 1980s 1990s 2020

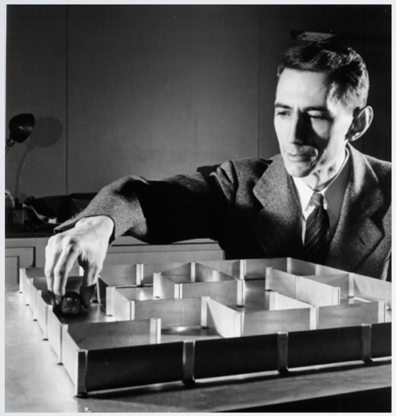
1947: FIRST TRANSISTOR



John Bardeen, William Shockley and Walter Brattain

1948: CLAUDE SHANNON

INFORMATION THEORY

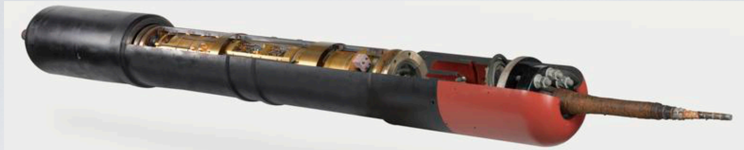


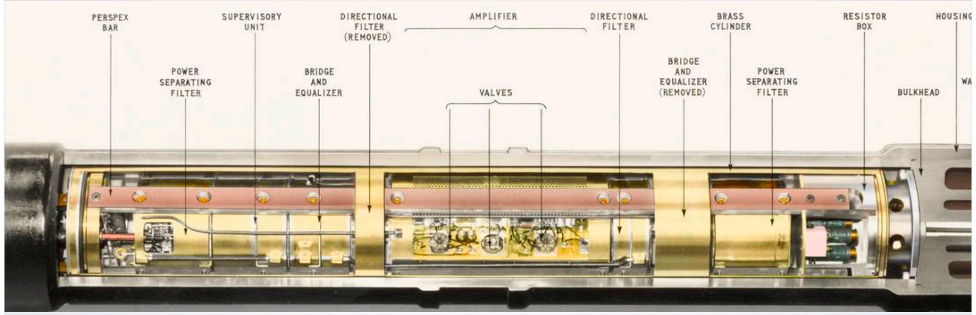
The Shannon–Hartley theorem states the maximum rate at which information can be transmitted over a communications channel of a specified bandwidth

Claude Shannon introduced the term Binary Digit - “bit”

GALLANACH BAY,
SOUND OF KERRERA NEAR OBAN

1955: TAT-1 REPEATER





Using low-loss coaxial cable, signal could be sent 69 km

Signal repeated every 69 km using 51 repeaters

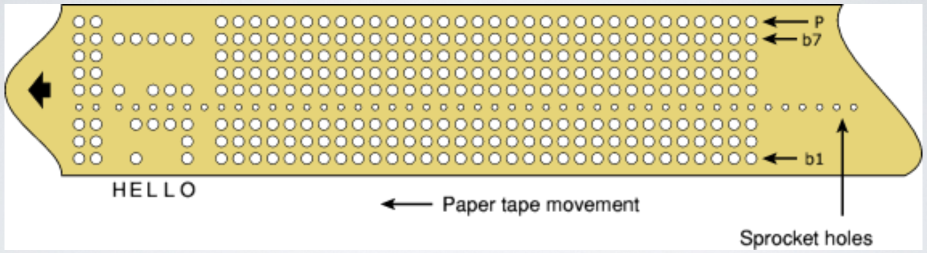
- Photos: Science Museum Lond

1960: COMPUTERS

PDP-8

1963: 7 BIT ASCII

AMERICAN STANDARD CODE FOR INFORMATION

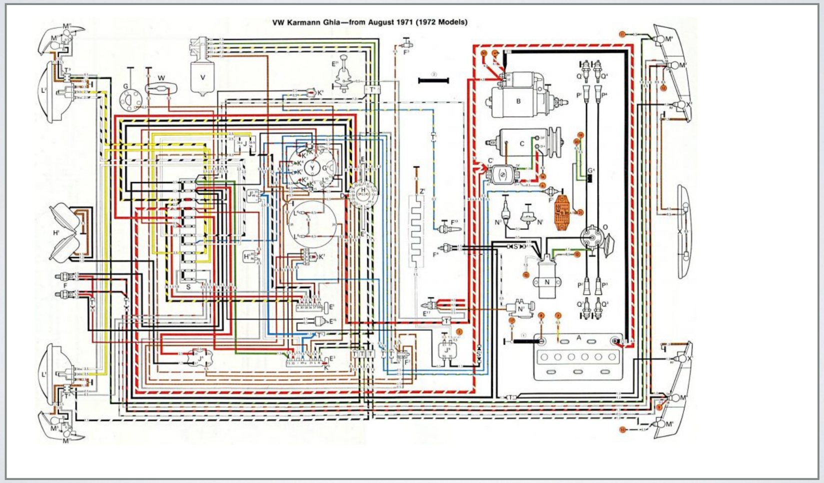


A 7-bit code (1 bit “spare” - used in UNICODE)

1976: PIC MICROCONTROLLERS
1985 NMEA SPECIFICATION
1986: DIGITAL MULTIPLEX (DMX)
1996: AVR (AND LATER ARDUINO, 2006)

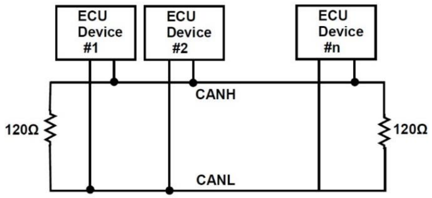
2021: RDM

1972: WIRING DIAGRAM VW BEETLE



1986: MULTIPOINT CONTROL

CONTROLLER AREA NETWORK (CAN)

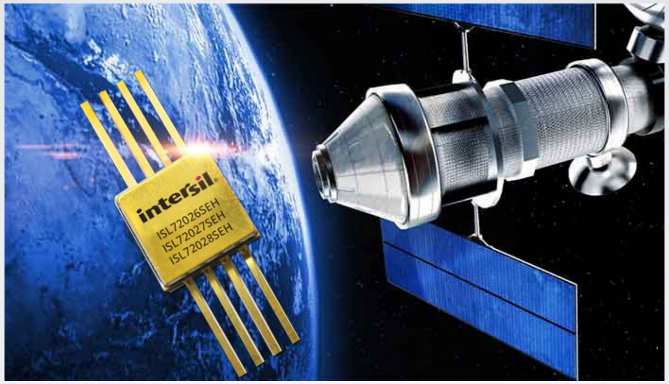


Before CAN …
there could be miles of cable in a car

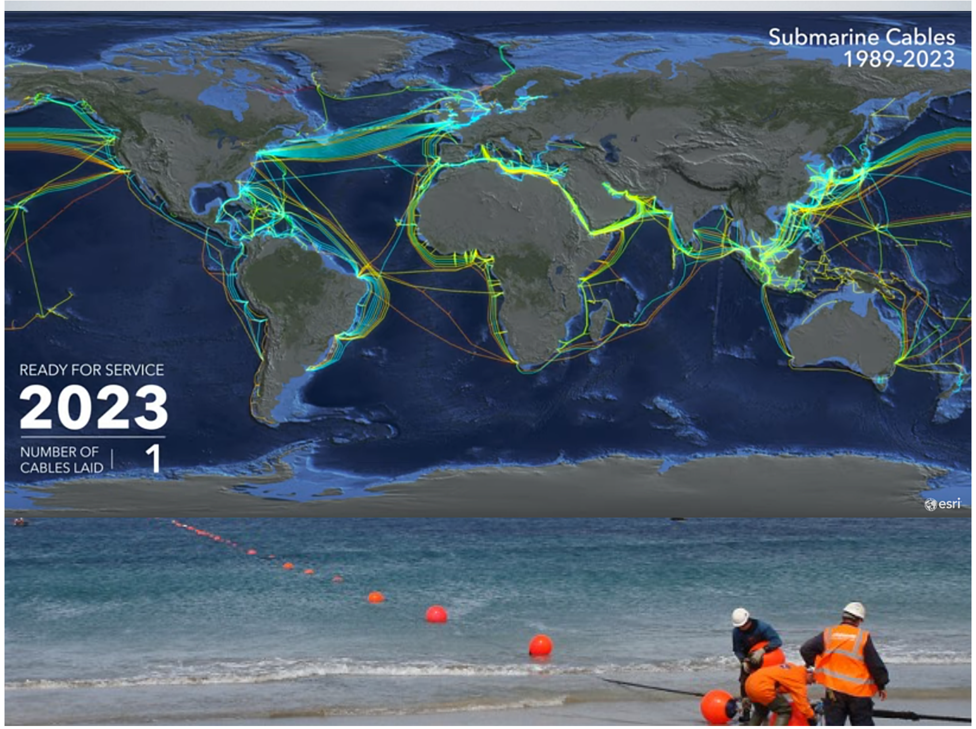
1991: CAN-2

2012: CAN-FD

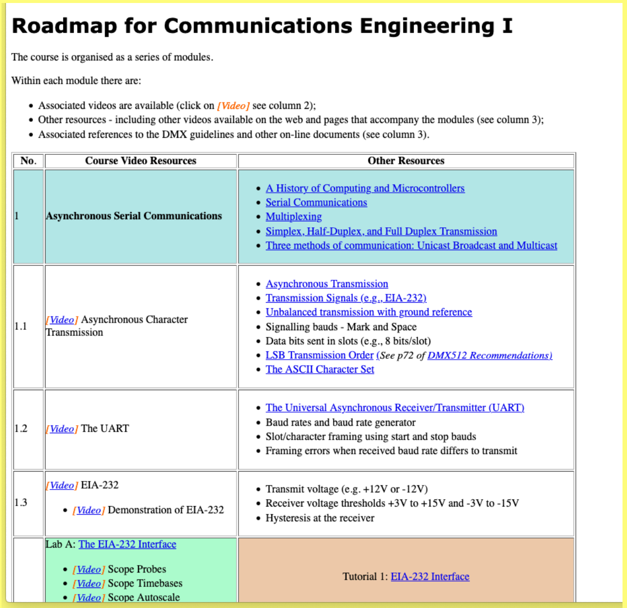
2015: CAN IN SPACEFLIGHT



ECSS-E-ST-50-15C (May 1, 2015)



Course Roadmap



Roadmap for Communications Engineering I

The course is organised as a series of modules.

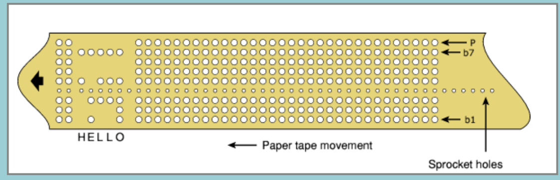
Within each module there are:

- Associated videos are available (click on *[Video]* see column 2);
- Other resources - including other videos available on the web and pages that accompany the modules (see column 3);
- Associated references to the DMX guidelines and other on-line documents (see column 3).

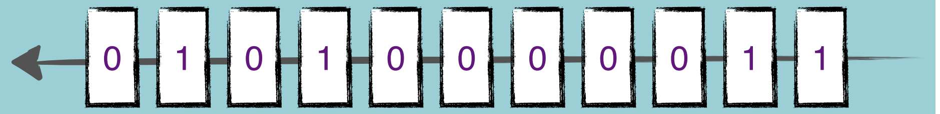
No.	Course Video Resources	Other Resources
1	**Asynchronous Serial Communications**	• A History of Computing and Microcontrollers • Serial Communications • Multiplexing • Simplex, Half-Duplex, and Full Duplex Transmission • Three methods of communication: Unicast Broadcast and Multicast
1.1	*[Video]* Asynchronous Character Transmission	• Asynchronous Transmission • Transmission Signals (e.g., EIA-232) • Unbalanced transmission with ground reference • Signalling bauds - Mark and Space • Data bits sent in slots (e.g., 8 bits/slot) • LSB Transmission Order *(See p72 of DMX512 Recommendations)* • The ASCII Character Set
1.2	*[Video]* The UART	• The Universal Asynchronous Receiver/Transmitter (UART) • Baud rates and baud rate generator • Slot/character framing using start and stop bauds • Framing errors when received baud rate differs to transmit
1.3	*[Video]* EIA-232 • *[Video]* Demonstration of EIA-232	• Transmit voltage (e.g. +12V or -12V) • Receiver voltage thresholds +3V to +15V and -3V to -15V • Hysteresis at the receiver
	Lab A: The EIA-232 Interface • *[Video]* Scope Probes • *[Video]* Scope Timebases • *[Video]* Scope Autoscale	Tutorial 1: EIA-232 Interface

ASYNCHRONOUS SERIAL TRANSMISSION

Module 1.0

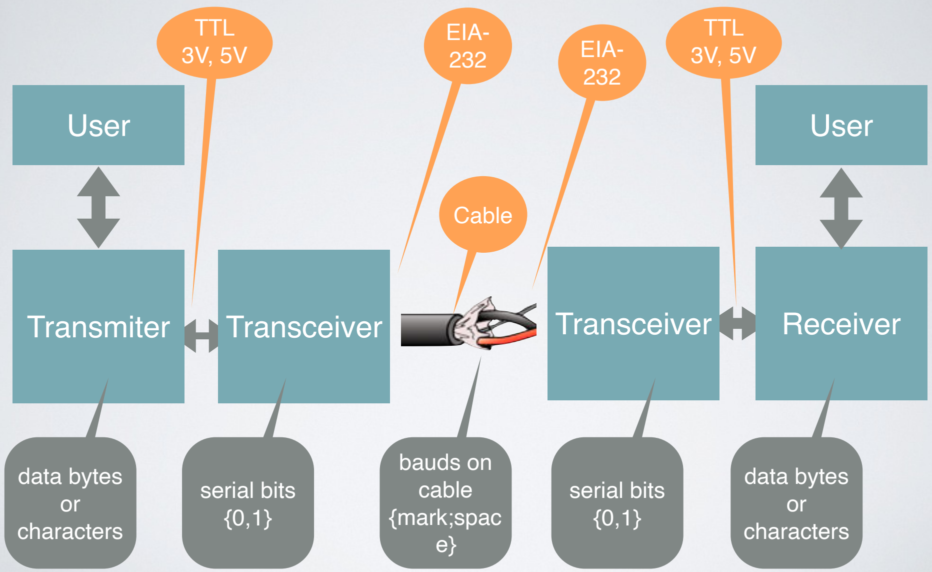


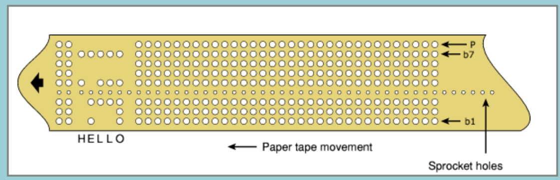
CHARACTER TRANSMISSION



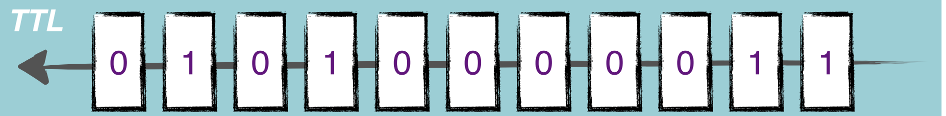
Module 1.1

TRANSMISSION SYSTEM





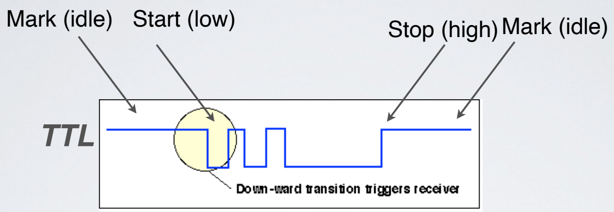
ASYNCHRONOUS CHARACTER TRANSMIT



Module 1.1

ASYNCHRONOUS SLOTS

Data set in a slot. Let's look at how one slot is sent...



Arbitrary idle gap between slots, uses Mark level (*high*)

Each slot starts with one start baud (*low*)

The bits in a byte/slot are sent LSB first (bit order reversal)

Each slot ends with two stop bauds (*high*)

Shows only "A" signal

ASCYNCHRONOUS SLOT (CHARACTER) FRAMING

Data is organised in bytes/slots and then serialised to bits

Sender and receiver both know the rate of transmission

- Each has a digital clock set to the same nominal baud rate
- This clock determines the duration of each baud
- The clock signal is NOT sent to the receiver

BAUD* - A physical transition on a cable

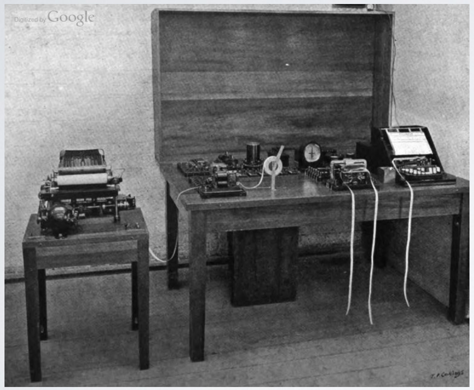
If one bit is sent in each baud, then the ***baud rate*** and ***bit rate*** would be the same.

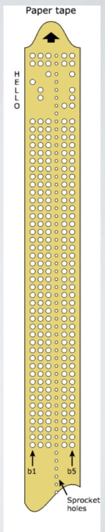
This is **not** the case for asynchronous transmission!

Using asynchronous transmission 8 bits are sent in 11 bauds.

** named after JME Baudot*

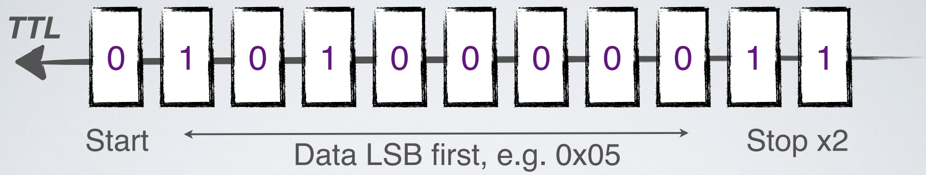
MURRAY PRINTING TELEGRAPH (1905)





A start-stop system using 5-bit codes

ASYNCHRONOUS SLOTS



$f = \frac{1}{T}$ and $T = \frac{1}{f}$

Example 1: Low speed (e.g. 4800 baud) clock

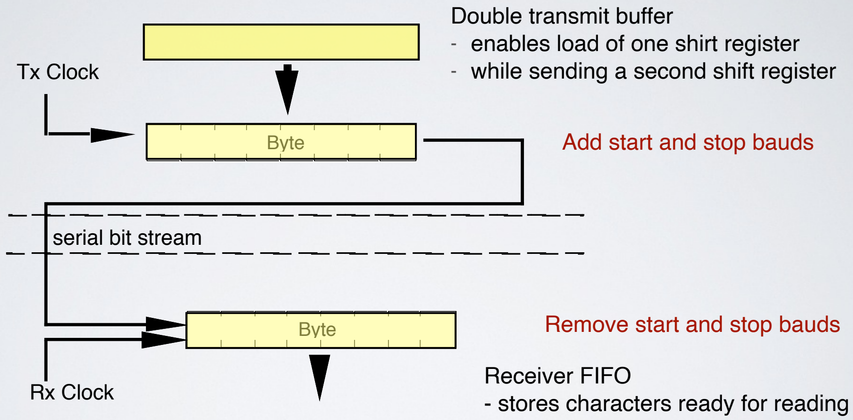
0.21 mS pulses (1/4.8 kbaud) with 8 data bits/frame

Example 2: DMX-512 sender and receiver use a 250 k baud clock

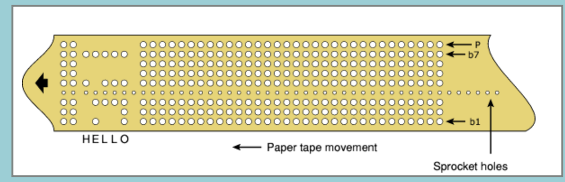
4μS pulses (1/250 kbaud) with 8 data bits/slot

Total slot duration is therefore 44 μS

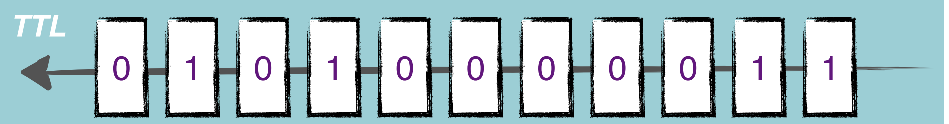
SERIAL COMMUNICATIONS



Uses two shift registers (both clocks must be the same)
- Note that bytes are sent l.s.b. first!



ASYNCHRONOUS CHARACTERS



Module 1.1

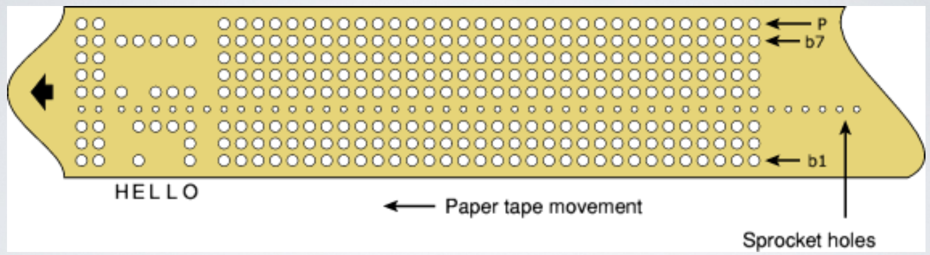
SERIAL BYTE STREAM

Multiple bytes are sent as a series of successive slots:

| 7654321 | 7654321 | 7654321 | 7654321 |

Strings can be sent by encoding each character as a byte

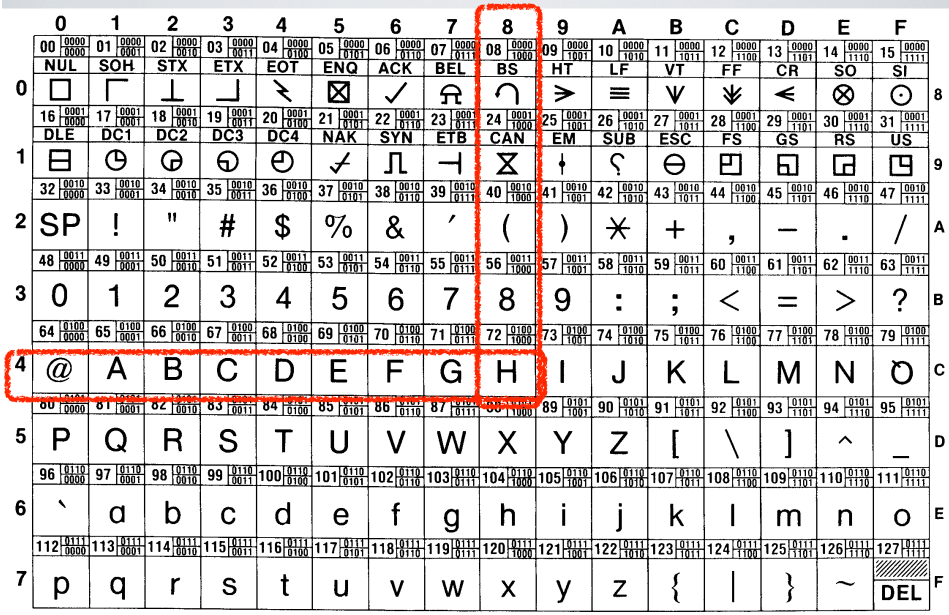
8 BIT TRANSMISSION: ASCII (1963)



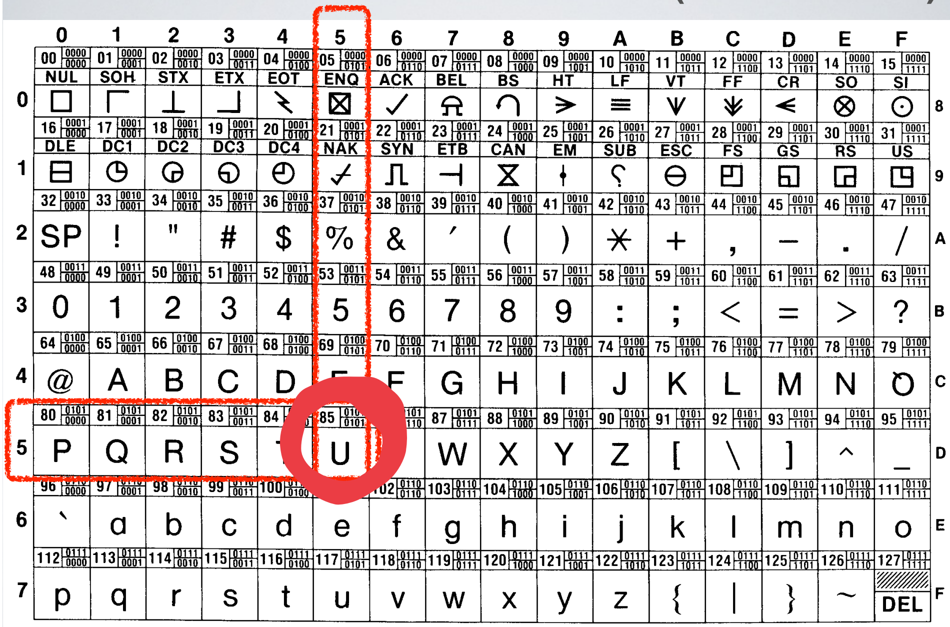
A 7-bit code (1 bit "spare")

ASCIII

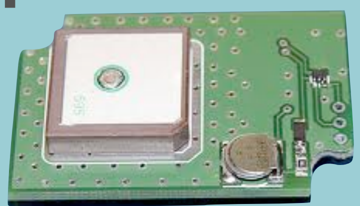
0x48, 72 in decimal= 'H'



DECODING HEX 55 (DEC 72)



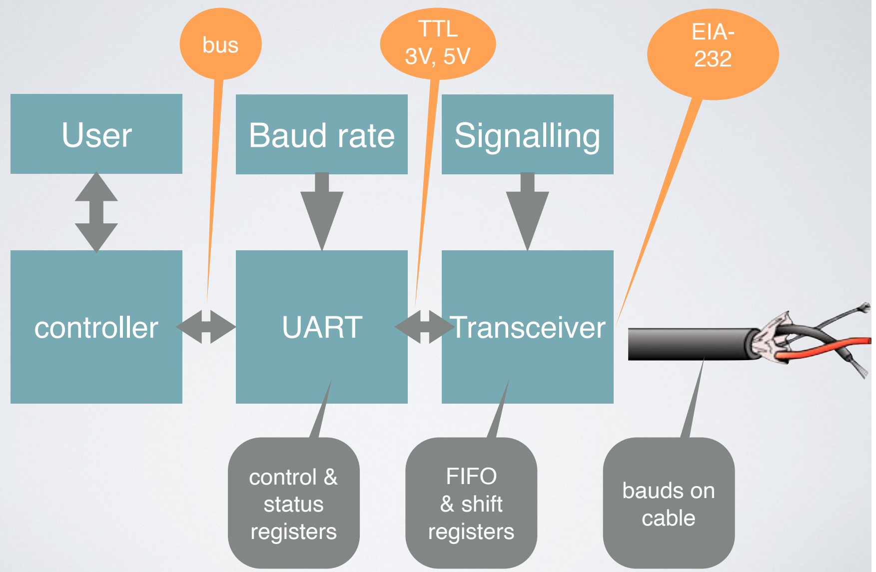
UART



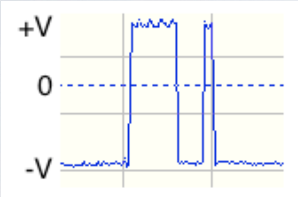
Universal
Asynchronous
Receiver
Transmitter

Module 1.2

TRANSMITTER

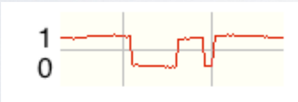


THE TRANSCEIVER EIA-232 SIGNAL LEVELS



EIA-232

O baud - negative voltage (+12V)
1 baud - positive voltage (-12V)
Both voltages referenced to GND

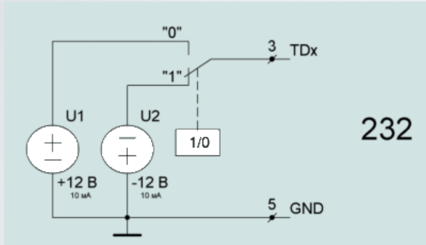


TTL

Digital Interface
0 - baud below threshold
1 - baud above threshold

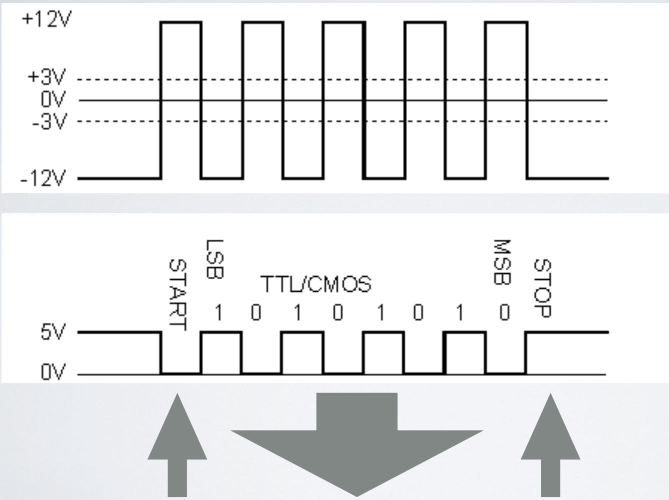
The line driver ***inverts*** the signal and ***changes*** the voltage

MODEL FOR EIA-232



An EIA 232 transmitter switches between a positive and negative voltage depending on the baud value

SERIAL RECEPTION (EIA-232)



Line signal

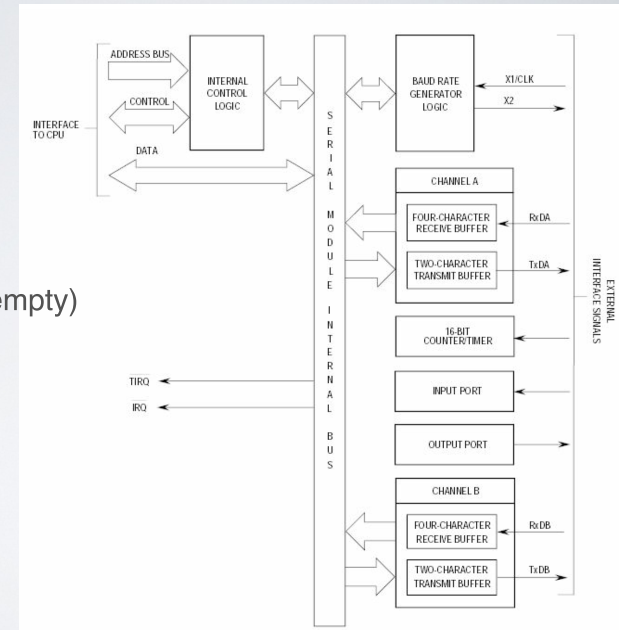
Digital output

START **%0101 0101** **STOP**

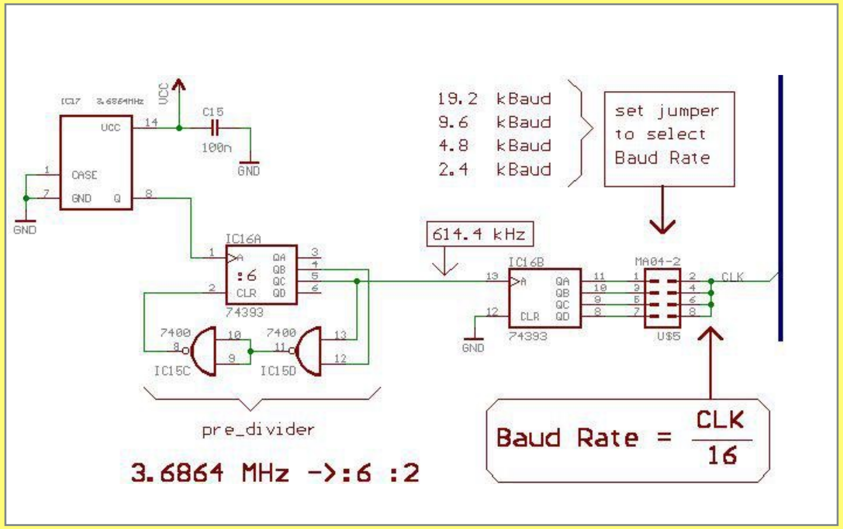
0x55

Universal Synchronous/Asynchronous Receiver Transmitter

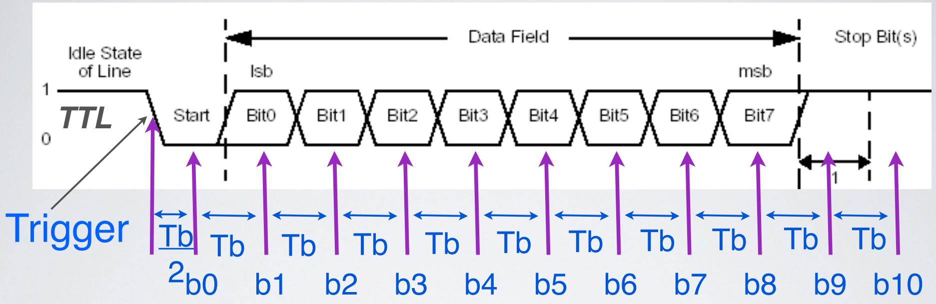
- **Tx/Rx:**
  - Data-in register
  - Data-out register
  - FIFO's
- **Status register**:
  - Tx byte sent (Tx_empty)
  - Rx byte ready
  - Rx overrun
  - Framing error
-



BAUD RATE GENERATORS



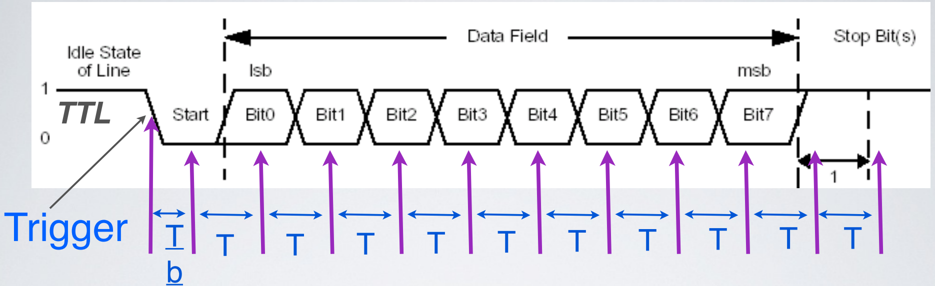
RECEIVER TIMING



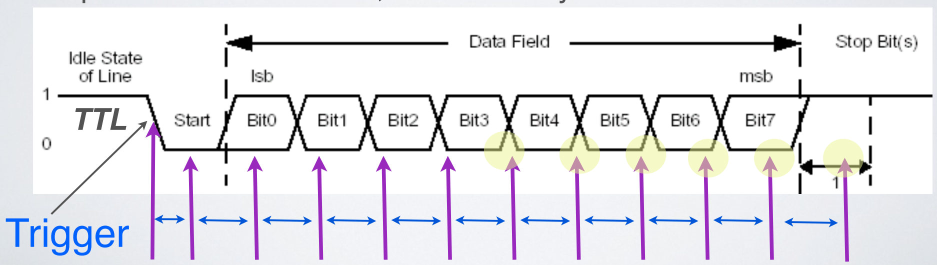
Tb= 1/ baud rate
0.2 mS for 4800 bps
0.1 mS for 9600 bps
4 μS for 250 kbps

b0 (start) must be “0”; b9, b10 must be “1” -- any other value is an error
Some systems use “parity” by enforcing a check on the last bit before the stop bit (usually uses 9 data bits)

RECEIVER MIS-TIMING

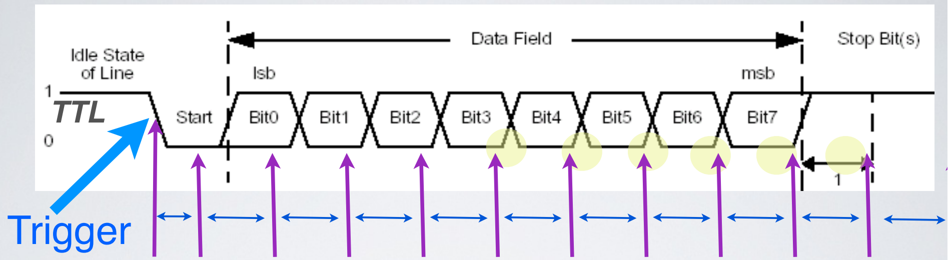


If the period is 5% too small, then this may still work



If the period is significantly too small, then this will fail

RECEIVER MIS-TIMING



If the period is too large, then this will also fail

SUMMARY: ASYNCHRONOUS TRANSMISSION

Benefits

One common standard (widely supported)

Simple UART implementation (no clock recovery, no DPLL)

Drawbacks

Lower efficiency: 3/11 of capacity used for framing

Poor error detection, bytes/slots may be “lost”

Rate limited by clock stability and cable quality, distance, etc.

SCOPES

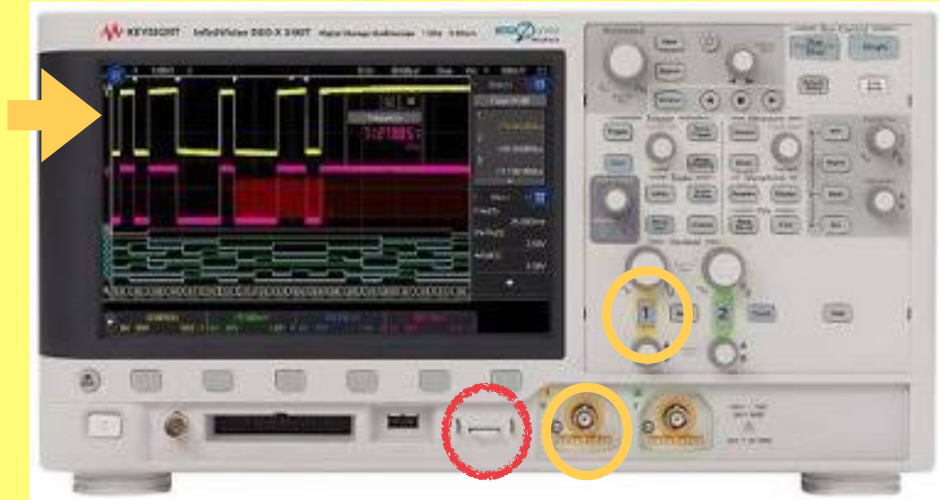
10 GBPS 6G LINK


- Prototype 6G subTHz link on display at the 6G Symposium, University of Surrey, May 2023.

KEYSIGHT UXR1104B

PROBES

PROBES



PROBE TIPS

: Check the probe - especially for measurements >20MHz
: Check the coupling mode
: Check the ground connection
: Check the scope channel display matches the probe type!

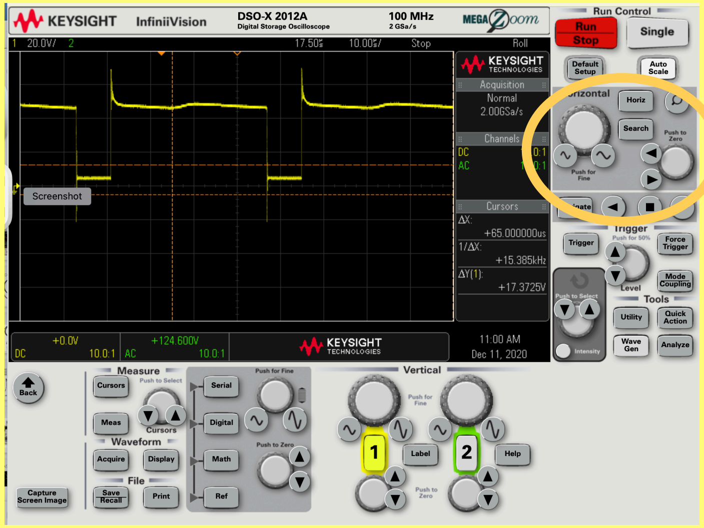
1:10 Impedance Ratio

1:1 Impedance Ratio

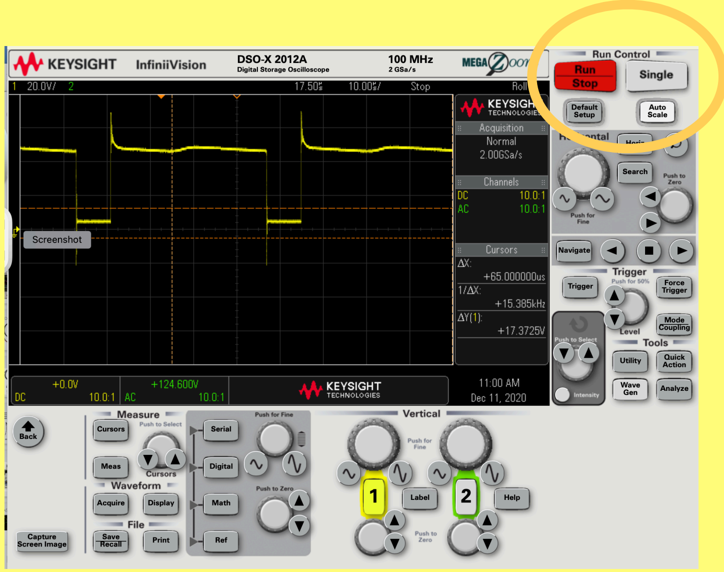
PROBE TIPS

Press the channel button
Connect the probe to the bar (ground) an test terminal
Calibrate the probe (check the attenuation/impedence)
This should show a square wave
Select Current or Voltage

TIMEBASE FREQUENCY



SINGLE TRIGGER



CURRENT PROBE

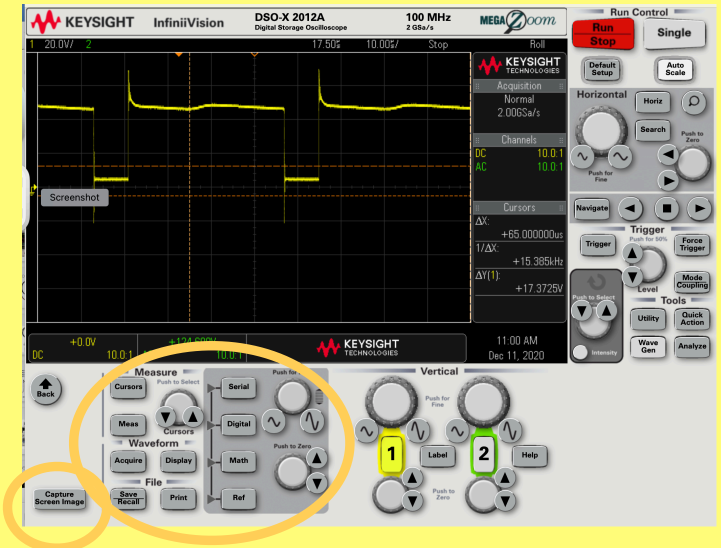
Turn OFF the probe when not in use!!!

For more information about different probes see also: www.keysight.com/find/probes

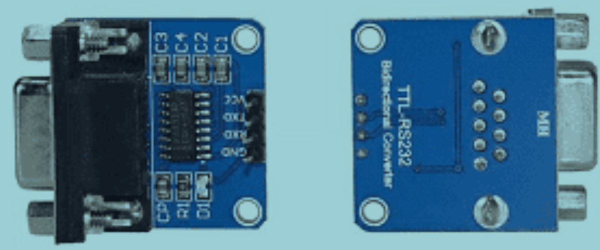
SAVE TO USB

- Save files in PNG format (there are many formats!)
  - Find a USB drive that works (or borrow one)
- Carefully note what the file contains
- Check you backup the files to a PC or Storage

WEB-INTERFACE

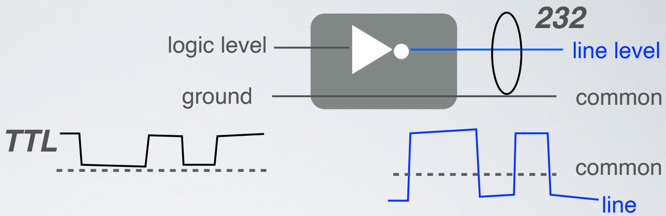


EIA-232 TRANSCEIVER



Module 1.3

EIA-232 TRANSMITTER



A line transceiver converts logical level signals to bauds

Each baud is sent as a level relative to the common (ground)

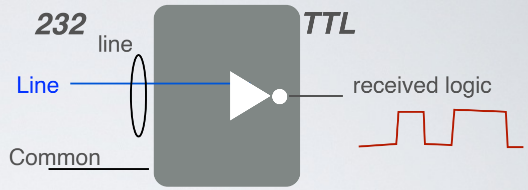
A '0' is sent as **+12V** (**relative to ground**)

A '1' is sent as **-12V** (**relative to ground**)

The cable can be screened at the sender to reduce interference

Can reliably drive cables unto 15 metres at 20 kbps or 150m at 9600 bps

EIA-232 RECEIVER



Receiver

Input Impedance 12K Ohms

Ground connected at the receiver

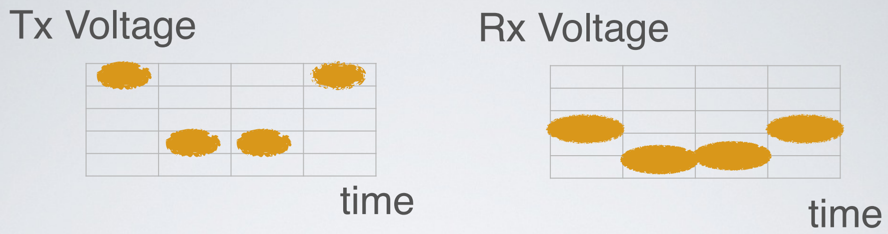
Receiver detects data by reference to the common signal*

Logic 0 when received voltage is between **+3V and +15V**

Logic 1 when received voltage is between **-3V and -15V**

** An EIA-423 5V transmitter would also drive a receiver over shorter lengths of cable*

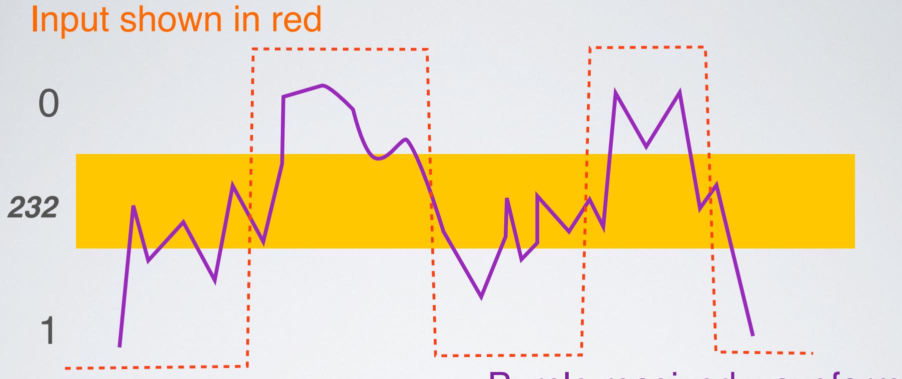
BINARY COMMUNICATIONS



For binary communications

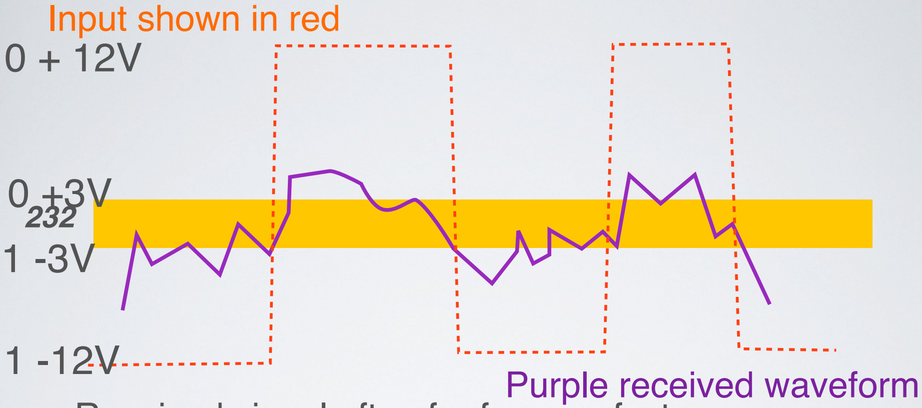
- Receiver needs ***sufficient voltage*** to differentiate a 1 and 0 baud
  - Cable attenuation (resistance/metre) reduces received signal
  - If a 0 is detected when 1 was sent, or vice versa, there is an ***Error***

SIGNAL AT THE SENDER



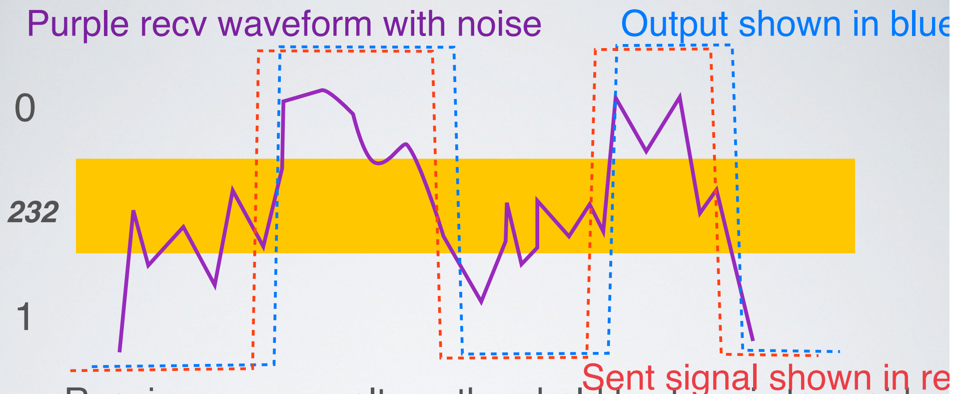
- Signals might be perfect when sent (red)
  - Cable, Receiver and Noise add to distort the waveform
  - Interference from other signals add to the received signal

SIGNAL AT THE RECEIVER



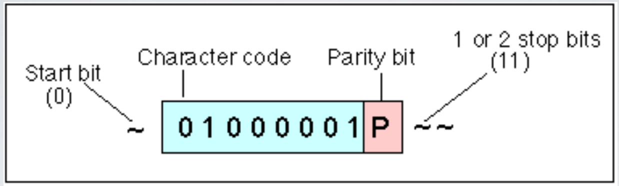
- Received signal often far from perfect
  - Attenuation from the cable - increases with distance
- A large (24V) transmit voltage swing
  - Needed for enough signal at the end of a long cable!

RECEIVER HYSTERESIS



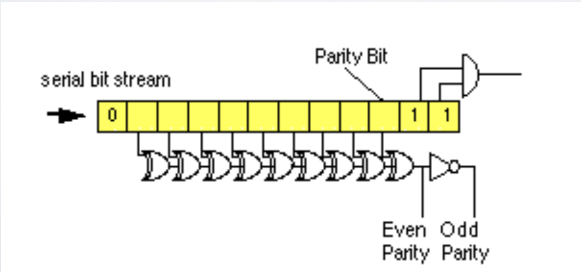
- Receiver uses a voltage threshold hysteresis to avoid oscillation in the output when the signal varies.
  - A signal must cross ***upper*** threshold to count as a 0
  - A signal must cross ***lower*** threshold to count as a 1
  - Prevents rapid transition but causes timing ***jitter***

CHARACTER PARITY



Parity baud **sent** as XOR of 8 data bauds

Even and Odd party have been defined...



CHARACTER PARITY

0	1	2	3	4	5	6	7	EVEN
1	1	1	0	0	0	1	0	0
0	0	0	1	0	0	1	0	0
1	0	0	1	0	0	1	0	1
1	0	0	1	0	0	1	0	0

Parity baud **sent** as XOR of 8 data bauds

Number of 1 bits + parity always an even number of 1's

Parity **checked** as XOR of 8 data bauds = Parity baud

If parity is incorrect, byte is marked as an error (red above)

CHARACTER PARITY

```
     Sent          Received
H  S010010011SS  S010010011SS
e  S011001010SS  S011011010SS
l  S011011000SS  S0110110000S
l  S011011000SS  S011111001SS
o  S011011110SS  S011011110SS
```

```
H S010010011SS S010010011SS H Valid 'H'
e S011001010SS S011011010SS ¿ Parity Error
l S011011000SS S0110110000S ¿ Invalid
l S011011000SS S011111001SS v Valid 'l'
o S011011110SS S011011110SS o Valid 'o'
```

EIA-423 TRANSMISSION

EIA-423 is an update to EIA-232 for use in an office

Small signals allow higher speeds of 100 kbps

> **Signal relative to ground (+4 to +6V and -4 to -6V)**
> The signal has a 10V swing (compared to 24V for EIA-232)
> Receiver uses a +3V threshold

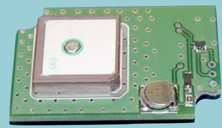
Open-ended cable length also ***increased to 1200m***

This is not an industrial interface
- because it is sensitive to noise and interference

COMMUNICATIONS LINKS

Module 2.0

ASYNCH SERIAL FRAMES



GPS NMEA Protocol

Plug & Play ... and very easy to program

EIA-232 interface (up to about 15m)

Low-speed asynchronous bus at 4800 bps

Uses ASCII framed messages

Module 2.1

GPS RECEPTION

- **NMEA standard (National Marine Electronics Association)**
  - A combined electrical and data specification for communication between marine electronic devices
  - Example uses: echo sounder, sonars, anemometer, gyrocompass, autopilot, GPS receivers and other instruments
- **Uses a simplex (unidirectional link)**
  - Sender transmits frames of ASCII characters using a serial link.
  - One sender, but could be one or multiple receivers
-

GPS DATA FORMAT

- Interface: EIA-232/EIA-423 or TTL
  - Serial format, 4800 baud, 8-bits, 1-stop-baud, no parity
  - More on this in the next set of slides...
- Simple frame: starts with a fixed well-known marker sequence
  - $GPsxx ,,,,
  - Values are represented inASCII
  - Separated by commas
  - Format of the values is determined by “xxx”

FRAME SYNCH

Data is grouped into **frames**

This allows a receiver to make sense of received data

A method is needed to align to the start of each frame

A sequence may be sent within the data of a frame in a ***Frame Alignment Word*** -typically at the start of each frame.

This could also be a ***distinct signal*** at the physical layer.

NMEA DATA FRAMES

- *GGA —Global Positioning System Fixed Data*
  `$GPGGA,161229.487,3723.2475,N,12158.3416,W,1,07,1`
  `9.0,M, , , ,0000*18`
- *GLL—Geographic Position - Latitude/Longitude*
  `$GPGLL,3723.2475,N,12158.3416,W,161229.487,A,A*41`
- *GSA—GNSS DOP and Active Satellites*
  `$GPGSA,A,3,07,02,26,27,09,04,15, , , , ,`
  `,1.8,1.0,1.5*33`

NMEA FRAME SYNCH

One simple frame: uses a fixed well-known marker field in the first 3 bytes of each frame:

```
$GP.....

$GP.....

$GP.....
```

Any unexpected values result in the entire frame being discarded, and the receiver has to hunt for synchronisation.

FRAME ALIGNMENT

First stage, search for the $GP pattern….

```
19,4807.038,N,01131.000,E1,08,0.9,545.4
,M,46.9,M,,?$GPGGA,123519,4807.038,N011
31.000,E,1,08,0.9,545.4,M,46.9,M,,?$GPG
GA,123519,4807.038,N,01131.000,E,1,08,0
.9,545.4,M,46.9,M,,?$GPGGA,123519,4807.
038,N,01131.000,E,1,08,0.9,545.4,M,46.9
,M,,?$GPGGA,123519,4807.038,N,01131.000
,E,1,08,0.9,545.4,M,46.9,M,,?
```

TRANSMISSION ERROR

What happens when bits are corrupted by noise?

```
19,4807.038,N,01131.000,E1,08,0.9,545.4
,M,46.9,M,,?$GPGGA,123519,4807.038,N011
31.000,E,1,08,0.9,545.4,M,46.9,M,,?$GPG
GA,123519,4807.038,N,01131.000,E,1,08,0
.9,545.4,M,46.9,M,,?$GPGGA,123519,4807.
038,N,01131.000,E,1,08,0.9,745.4,M,46.9
,M,,?$GPGGA,123519,4807.038,N,01131.000
,E,1,08,0.9,545.4,M,46.9,M,,?
```

Error, needs to be detected

CHARACTER PARITY

0	1	2	3	4	5	6	7	EVEN
1	1	1	0	0	0	1	0	0
0	0	0	1	0	0	1	0	0
1	0	0	1	0	0	1	0	1
1	0	0	1	0	0	1	0	0

Parity baud **sent** as XOR of 8 data bauds

Number of 1 bits + parity always an even number of 1's

Parity **checked** as XOR of 8 data bauds = Parity baud

If parity is incorrect, byte is marked as an error (red above)

INTEGRITY CHECK AT END

- Sample:
  $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,***47**

Final byte in a frame can contain a binary number to check frame inetgrity
(here written here as * and two hex digits)

Cumulative XOR of all bytes between the $ to the *.
(also known as longitudinal parity)

```
var checksum = 0;
for(var i = 0; i < stringToCalculateTheChecksumOver.length; i++) {
  checksum = checksum ^
    stringToCalculateTheChecksumOver.charCodeAt(i);
}
```

Checks whether the frame may have been corrupted

LONGITUDINAL PARITY

Receivers compare transmitted parity in the message with a value re-calculated at the receiver.

- Longitudinal parity for $GP
  - sent parity "00110011"
  - received "00110011"
- Sent=Received parity - ***OK***!

$	G	P	PARITY
0	0	0	0
0	1	1	0
1	0	0	1
0	0	1	1
0	0	0	0
1	1	0	0
0	1	0	1
0	1	0	1

LONGITUDINAL PARITY

- Longitudinal parity for $GP
  - sent parity “00110011”
  - received “00111011”
- Sent ≠ Received
  - One ***error*** detected!

$	0	P	PARITY
0	0	0	0
0	1	1	0
1	0	0	1
0	0	1	1
0	1	0	0
1	1	0	0
0	1	0	1
0	1	0	1

LONGITUDINAL PARITY

- Longitudinal parity for $GP
  - sent parity “00110011”
  - received “001110001”
- Sent ≠ Received
  - Multiple errors detected!

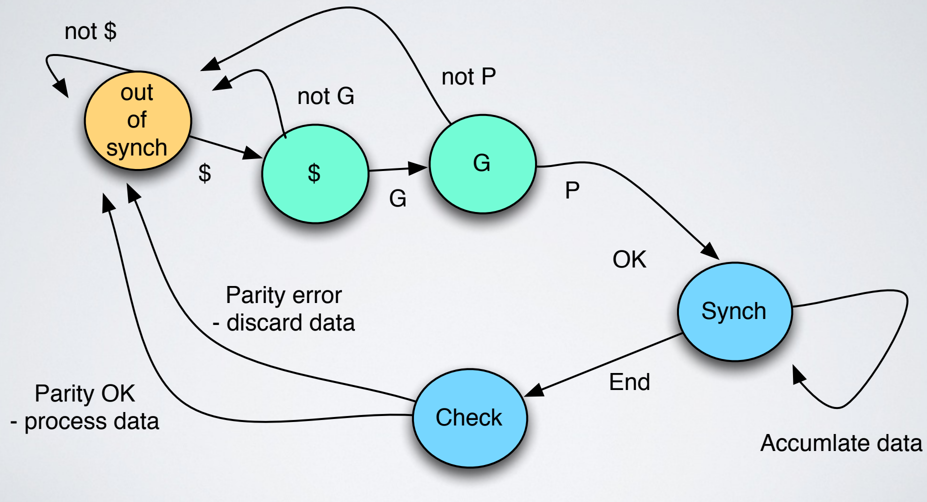
$	0	P	PARITY
0	0	0	0
0	1	1	0
1	0	0	1
0	0	1	1
0	1	0	0
1	1	0	0
1	1	0	1
0	1	0	1

LONGITUDINAL PARITY

- Longitudinal parity for $GP
  - sent value “00110011”
  - received “00110011”
- Even errors ***NOT*** detected!

$	0	P	PARITY
0	0	0	0
0	1	1	0
1	0	0	1
0	0	1	1
1	1	0	0
1	1	0	0
0	1	0	1
0	1	0	1

RECEIVER STATE



Note any error also causes return to the out-of-synch state

IMPROVING FRAME ALIGNMENT

NMEA GPS sends a ***continuous stream*** of updated messages

Framing relies on a unique '$' character not intentionally appearing in data.

Corrupted data is discarded, there is no retransmission - - receiver simply waits for next updated message.

Doing better:

Could be ***robust*** to corruption of frame alignment word - i.e. a corruption does not cause immediate loss of synchronisation.

Most NMEA systems use ***differential transmission*** (see next module)

LABS

A: EIA-232

B: ASYNCHRONOUS COMMS

Lab Notes

EIA-485 DIFFERENTIAL ASYNCHRONOUS SERIAL EQUIPMENT BUS

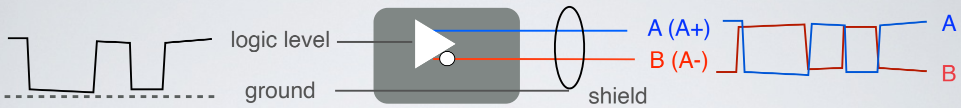
Module 3.0

DIFFERENTIAL TRANSMISSION

INTERFACE

Module 3.1

EIA-485 TRANSMITER



A line transceiver converts **logical level signals to line levels**

The output sends the signal using two conductors A and B*

The difference between A and B is ***always*** 5V

The cable shield/screen is grounded only at the sender

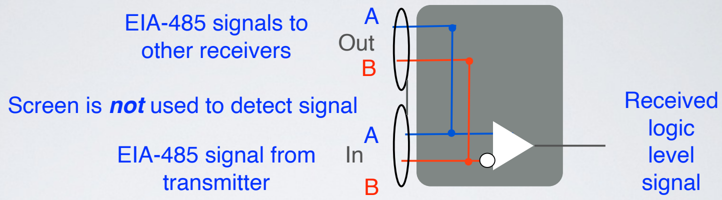
Each baud is sent by setting the level of A and B:

The B signal is an inverted A signal (there is no average dc voltage)

Reliably drives cables unto 1000 metres at 250 kbps

** The B signal is also known as "A-"*

EIA-485 RECEIVER



A receiver detects data by the ***difference*** between the two conductors

This uses a 200mV Differential threshold detector

Logic 0 a difference between (A+ & A-) < 200mV

Logic 1 a difference between(A+ & A-) > 200mV

The A,B signals are not referenced to the cable screen

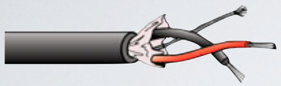
Can be in the range + 12V, -7V relative to the receiver ground

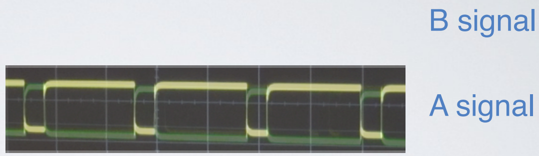
DIFFERENTIAL TRANSMISSION

CABLE

Module 3.1

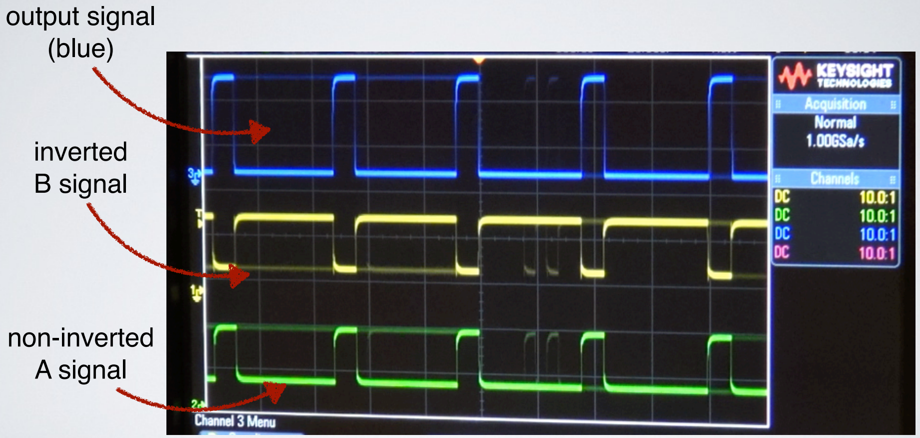
EIA-485 TRANSMISSION



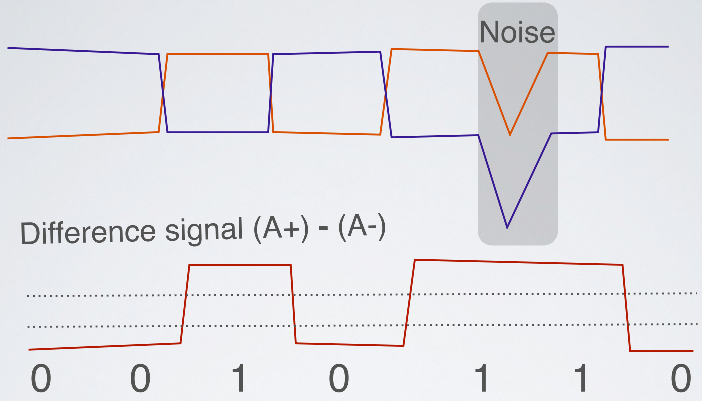


Balanced cable improves noise immunity
Differential signal, 200mV receive threshold

LINE SIGNALS & TRANSCEIVER OUTPUT



DIFFERENTIAL

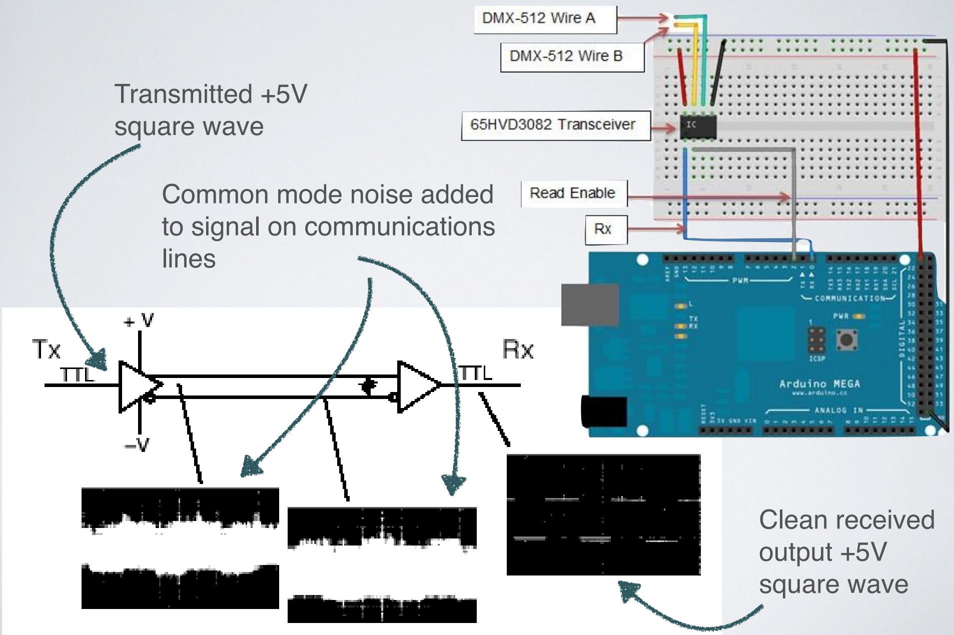


Common-mode noise impacts both conductors equally

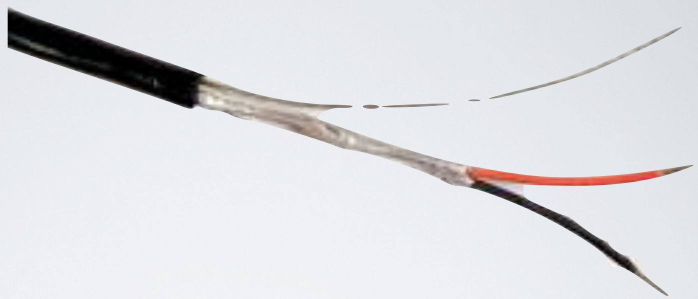
There is no net difference form common-mode noise

Significant increase in noise immunity

SIMPLE TRANSCEIVER



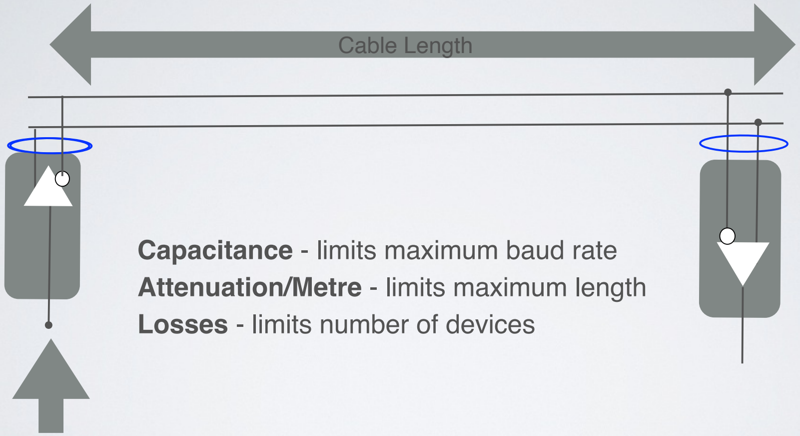
EIA-485 CABLE



2 stranded conductors twisted along the length forming a “pair”
Impedance between the pair: 100-120 Ohms
Conductive shield around the twisted pair (ground) - ***see later***
PVC outer protective sleeve

Capacitance between conductors within a shield < 65 pF/m
Capacitance between any conductor and the shield < 115 pF/m

CABLE CHOICE



Capacitance - limits maximum baud rate
Attenuation/Metre - limits maximum length
Losses - limits number of devices

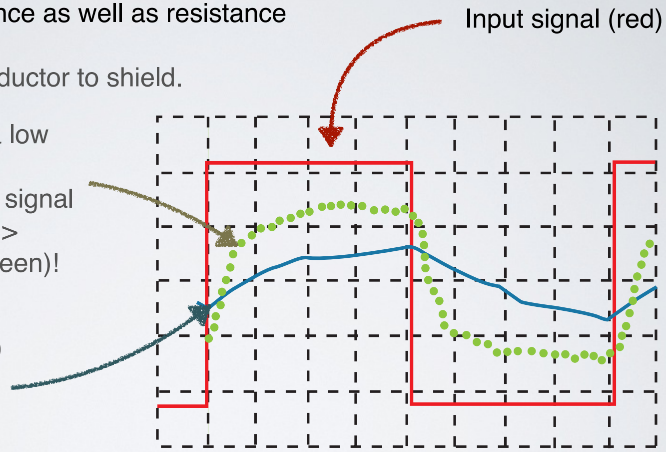
EXAMPLE CABLE

Cable has capacitance as well as resistance

typ. 30-60 pF conductor to shield.

The cable acts as a low pass RC filter.
<1 Mbaud ~ 1 MHz signal
Higher frequencies > MHz attenuated (green)!

higher frequencies e.g. 30 MHz (Blue) are severely attenuated



A signal working at 300kbaud is not distorted.

Maximum rate determined by capacitance & resistance

HOW MUCH SIGNAL IS RECEIVED?

Signal ***transmitted*** at sender 5V

Cable attenuation and loss reduce the signal level (~ 4db/100m)

Minimum signal at ***receiver*** 0.2V

Let's calculate what that means for a practical system with:

300m of cable

32 receivers

CABLE POWER MARGIN*

Signal transmitted at sender 5V

Minimum signal at receiver 0.2V

Power margin in decibels

$= 10 \log (V_{in}/V_{out})^2$

$= 20 \log (V_{in}/V_{out})$

$= 20 \log (5/0.2)$

$= 28$ dB

The receiver signal can be 28dB lower than the sender

*Power margin is measured in dB

CABLE ATTENUATION 24/7 TWISTED PAIR

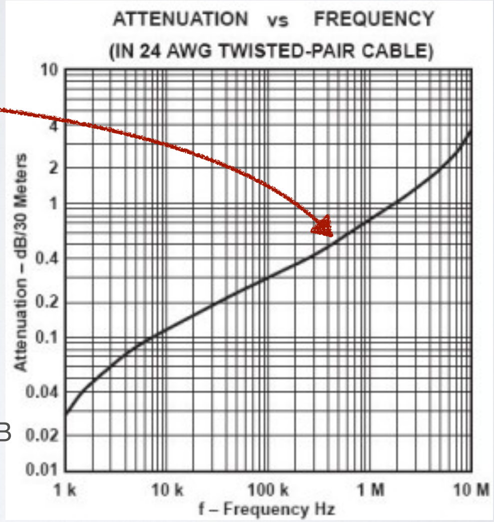
Resistance: 85 Ohm/km

Typical attenuation is:
~2-4dB per 100m
@4dB/100m:
For total cable bus length:
300m = ~12dB

For each receiver:
0.1dB loss per transceiver
0.2dB connector loss
Total loss /receiver 0.3dB
Loss from 32 receivers = 13 dB

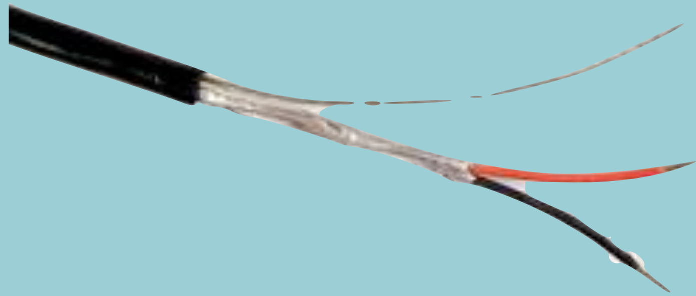
Signal attenuation at end = 25dB

Margin = 3dB



Maximum distance was limited by number of receivers & cable length

BUS TRANSCEIVERS



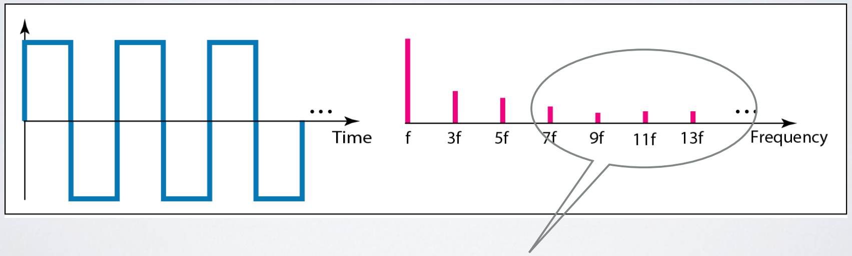
Module 4.3

SIGNALS ON CABLE

A square wave contains frequency harmonics many times baud rate.

For 250 kBaud, highest frequency components arise sending 101010 etc

- Highest rate => 125 kHz square wave
- Components at 375 kHz, etc ….



There is still appreciable energy ***above 2 MHz***

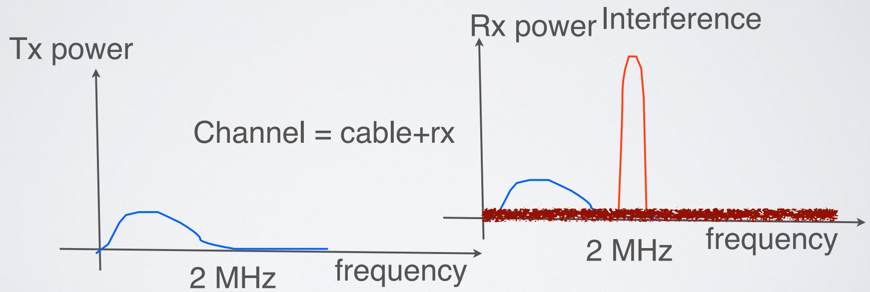
SIGNALS ON CABLE

Signal energy mainly around baud rate (<< 2 MHz)

Signal has components >> 2 MHz

Interference/noise above 2 MHz degrades signal!

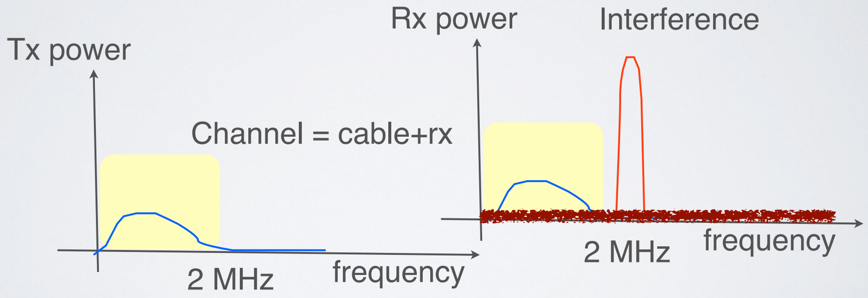
Total noise power = sum off all noise/interference power



FILTERING THE SIGNAL

We could set a receive filter to remove noise at higher frequencies, also helps a lot with eliminating interference

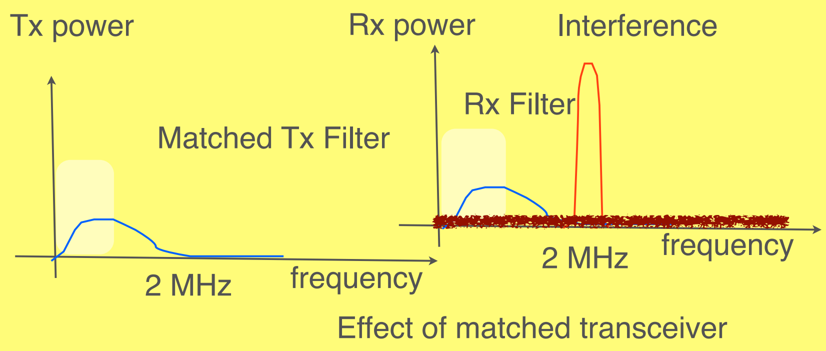
The Rx Signal to Noise Ratio at the receiver is improved



We could split the filter function - half at sender and the receiver

... This results in less radiated signal (don't send what isn't received)

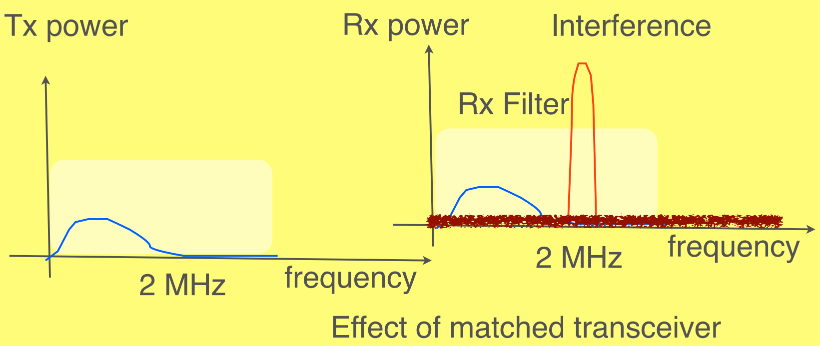
TOO LOW SLEW RATE



A too narrow filter removes some of the wanted signal

- Lowers signal to noise ratio (filters a part of signal in frequency domain)
- In the time domain, this causes some signal energy from an older baud to still be present when the next baud is sent (Inter-symbol-interference).

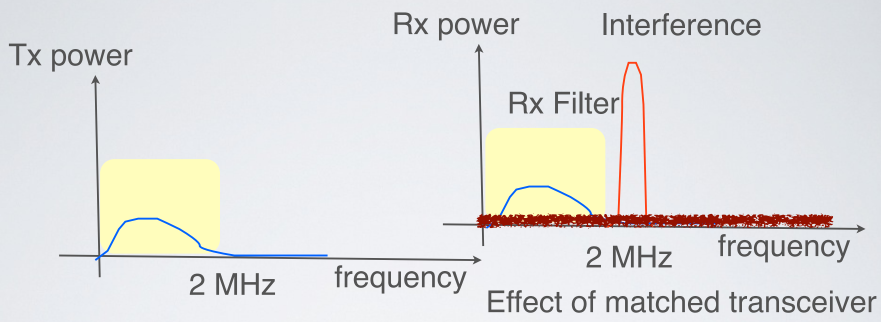
TOO HIGH SLEW RATE



Wideband filter fails to effectively remove interference and noise

- lowers signal to noise ratio

LIMITING SLEW RATE



Line drivers use a low-pass filter, shaping signal at sender ***and*** receiver

- This limits slew rate of the signal, or makes the edges “slower”
  - This also increases rise-time of the signal when a level changes
- Half of the filter function is at the sender and half at the receiver
  - Ensures all transmitted energy falls within the receiver filter

SAMPLE AT THE CENTRE!

A shaped signal rolls-off more gently than a digital signal: it becomes important to sample at the centre of each received baud.

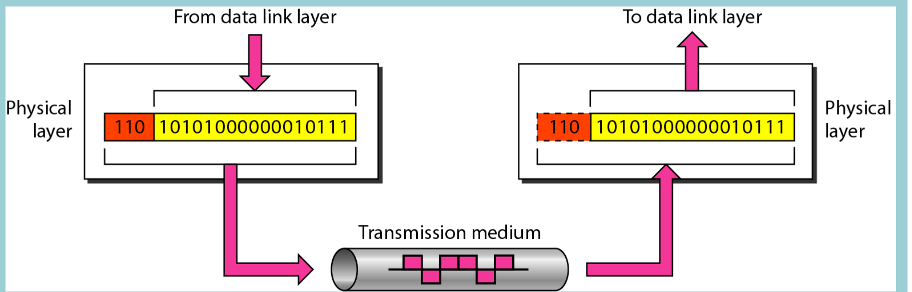
WORKING IN HARSH ENVIRONMENTS

Cable
- Send more **voltage** to compensate for attenuation/meter
- Use ***differential transmission and twisted pair*** cable
- Use foil shi***eld, earthed*** at sender
- ***Termination*** at end of cable to match impedance
- Low ***attenuation***/meter

Connection to cable
- ***DC isolation*** of the bus (removing earth loops)
- Eliminate problems from cable breaks (capacitor to ground, input bias)
- Avoid ***cable stubs***

Receiver
- Limit ***slew rate*** (reduce noise/interference)
- ***Hysteresis*** (to eliminate effect of transient noise)
- ***Sample*** at the centre of each baud

TRANSMISSION THEORY

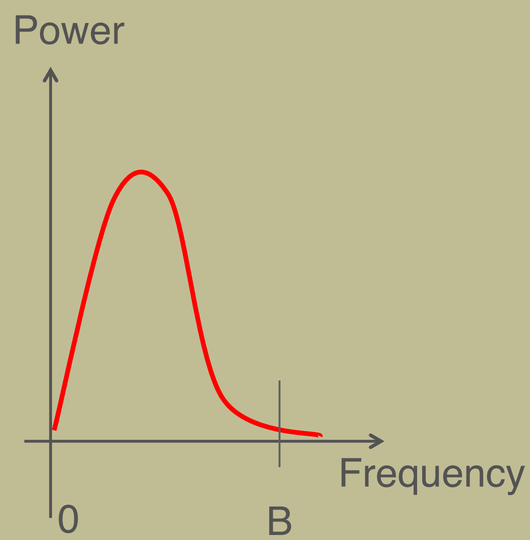


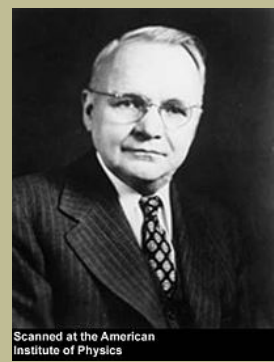
Each bit is sent as a discrete signal (baud) along the wire.

The transmission medium can be considered a “channel”

Module 2.2 (May in some years be presented as a part of Module 1)

IDEAL NOISE-LESS



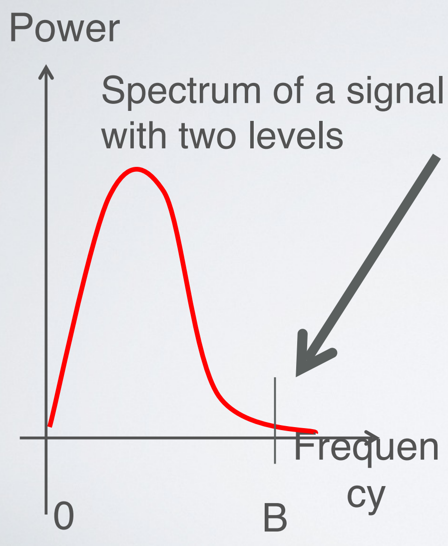


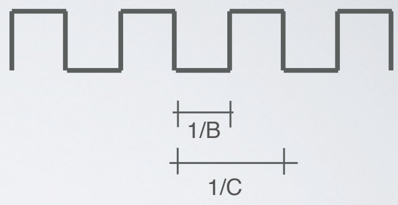
H. Nyquist

NYQUIST FREQUENCY

- Consider an ideal channel (no noise)
  - The sender transmits two levels (“0” or “1”)
- Maximum transmission rate of a signal over a cable with fixed bandwidth
- Transmission capacity (C) is twice bandwidth (B):
  - C = 2 x B

EXPLAINING THE NYQUIST THEOREM



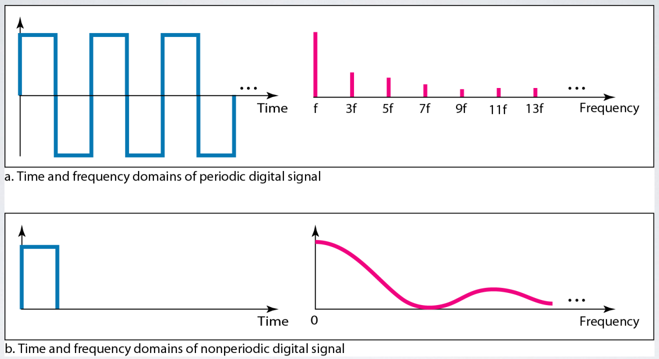


- Largest frequency component of signal is when the signal alternates high/low:

2/B = 1/C

FOURIER DECOMPOSITION

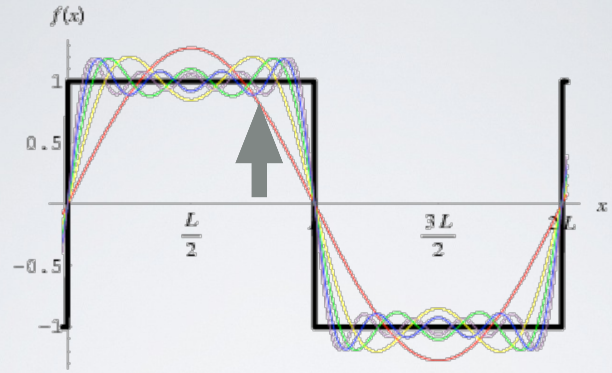
H. Nyquist



A perfect digital signal has an infinite bandwidth….

Note for later:
Real cables have resistance - attenuation/metre
And capacitance/inductance - limiting cable bandwidth

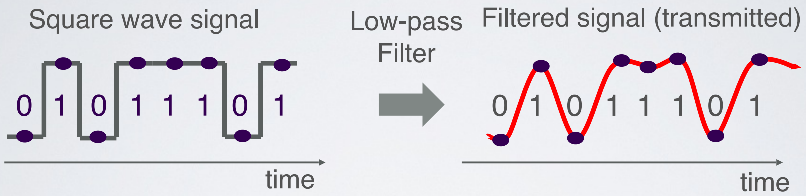
FOURIER DECOMPOSITION



Fourier analysis can decompose a periodic signal into a combination of sine waves with different frequencies, amplitudes, and phases.

FILTERING HIGHER ORDER HARMONICS

H. Nyquist



- Filtering higher order harmonics result in a smoother signal
  - A receiver needs to sample at the centre of a baud to detect the level (0 or 1)
- Nyquist filtering limits the signal spectrum bandwidth(0Hz to B)
  - Nyquist theorem would require the spectrum to be <u>exactly zero</u> when frequency>B

SIGNAL RATE

What is the required bandwidth of a low-pass channel if we need to send 1 Mbps using baseband transmission?

Solution

a. Minimum bandwidth, B = bit rate /2, or 500 kHz.

SIGNAL BANDWIDTH

- What is the required bandwidth of a low-pass channel if we need to send 1 Mbps using baseband transmission?

- Solution

  The answer depends on receiver.

  a. The minimum bandwidth, is B = bit rate /2, or 500 kHz.

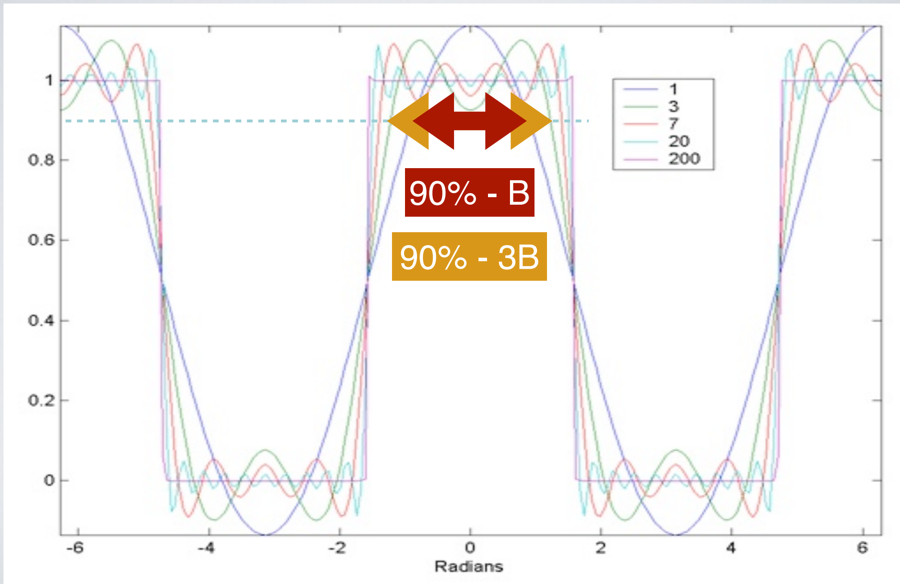
  b. A more "square" waveform eases receiver timing ..

  e.g. to include the first and the third harmonic harmonics with B = 3 × 500 kHz = 1.5 MHz.

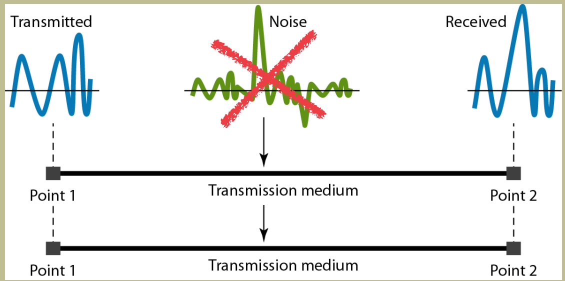
  The first, third, and fifth harmonics would be:

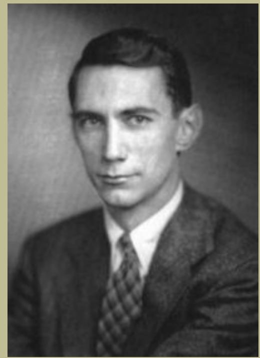
  B = 5 × 500 kHz = 2.5 MHz.

SAMPLING POINT



A REAL "CHANNEL"

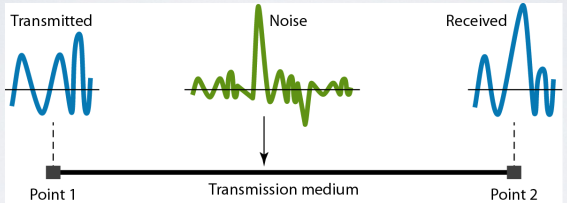




C. E. Shannon

NOISE

Real channels have limits…

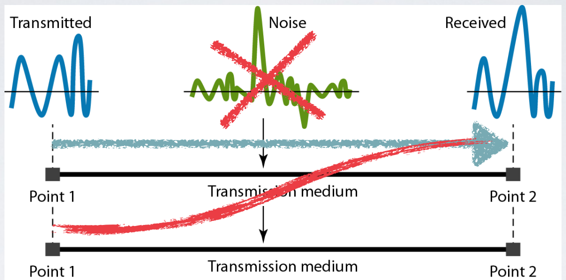


There is no such thing as a noiseless channel!!

INTERFERENCE

Industrial environments can be hostile - our signal is not alone

Noise+Interference

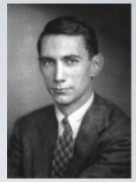


Other signals can also be received*, increasing the noise floor

Far-end cross talk is a measure of the received unwanted signal

* Later in the course we'll see that similar signals can have the same frequency spectrum and are particularly disruptive

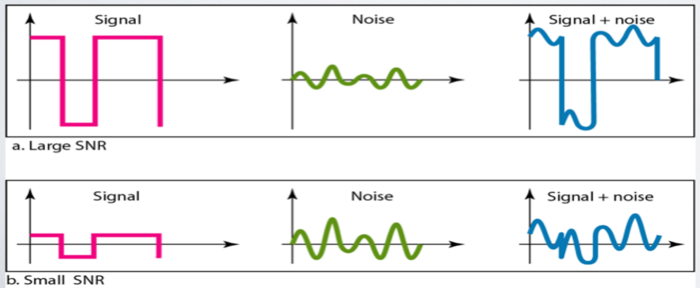
A REAL "CHANNEL"



C. E. Shannon

- Noise and interference make small signals difficult to detect
- The important factor is the signal to noise ratio (SNR).

$$SNR = \frac{\text{Power signal}}{\text{Power noise}}$$



High SNR

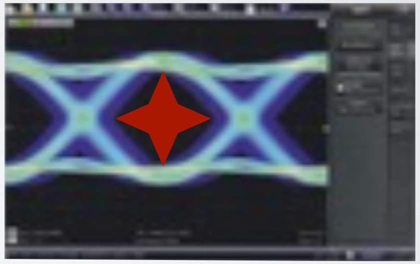
Low SNR

A REAL WAVEFORM (EYE DIAGRAM)

One way to view the signal is an eye diagram

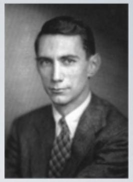
- Scope triggered at a particular point (start of a baud)
- Each trigger, scope resets the X-axis
- It does not erase the display (persists for multiple scans)

High SNR
(e.g., at sender)



Lower SNR
(e.g., at receiver)

SHANNON CAPACITY



C. E. Shannon

- For a noisy channel, the Shannon capacity gives a theoretical limit of the usable bitrate of a channel with a bandwidth B and a signal-to-noise-ratio SNR.

C = B x log2(1 + SNR)

- Any attempt to transmit faster than the Shannon limit will result in unrecoverable transmission errors

THEORETICAL CAPACITY OF A TELEPHONE LINE

- A telephone line has a nominal bandwidth of 3000 Hz and the signal-to-noise ratio is 3000 (69.5 dB).
- What is the channel capacity?
- Using Shannon formula, the highest rate is:

C = 3000 x log2(1 + 3000) = 34.7 kbps.

- If we wish to send faster than, we can either increase the ***bandwidth of the line*** or ***improve signal-to-noise ratio.***

THERE IS A MINIMUM SNR

- Consider an extremely noisy channel with a signal-to-noise ratio of almost zero. i.e. noise so strong that the signal is faint.
  - The signal-to-noise-ratio is very small SNR<<1
- Capacity of a channel tends to zero regardless of the bandwidth:

$$C = B \log_2(1 + \mathrm{SNR}) = B \log_2(1+0) = B \log_2 1 = B \times 0 = 0$$

EIA-485 EQUIPMENT

Process Field Bus, used mainly in industrial plants (EN 50170).

Field Bus, used for industrial automation.

***CAN Bus**, used for control networks in cars, lifts, etc*

Building automation/management

Common lab/machine room instrumentation bus.

SIMPLEX EQUIPMENT BUS: DMX-512 PHYSICAL LAYER

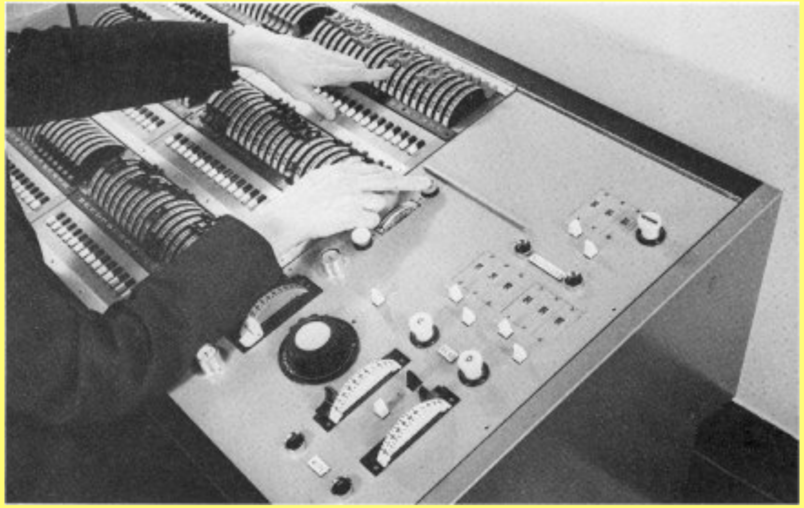
Module 4.0

DMX READING

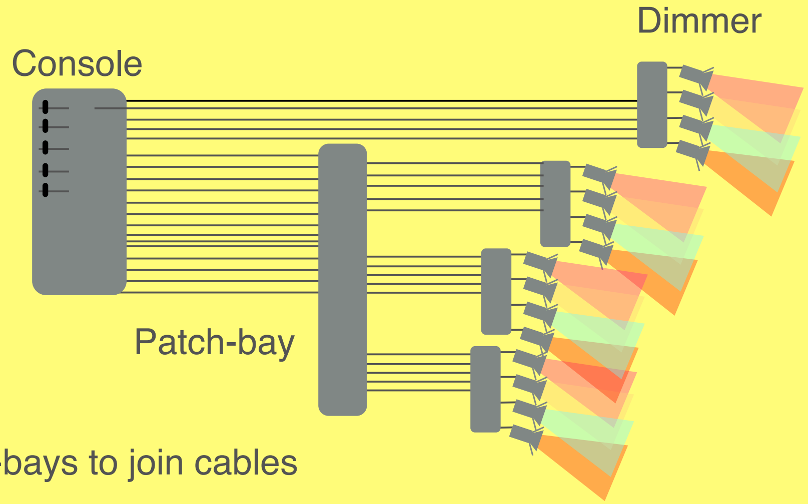
- "Recommended Practice for DMX 512: A Guide For users and Installers", Adam Bennette, (PLASA) *
- “Control Freak - A real world guide to DMX-512 and Remote Device Management”, Wayne Howell, 2010
- ANSI E1.11, Asynchronous Serial Digital Data Transmission Standard for Controlling Lighting Equipment and Accessories, USITT DMX512-A, American National Standards Institute, 1990 (PLASA) *
- ANSI E1.20, Remote Device Management, over USITT DMX 512 Networks, 2003 (PLASA) *

* Free download at tsp.plasa.org

ELECTRICAL DIMMING -



MESSY CABLING



Patch-bays to join cables

LOTS of cable - Lots of connections

DIGITAL MULTIPLEX (DMX)

The DMX-512 standard (actually USITT DMX-512 - 1990)

- Published by U.S.I.T.T. and now maintained by ESTA
- Designed to be easily implemented by microcontrollers

Single simple cable

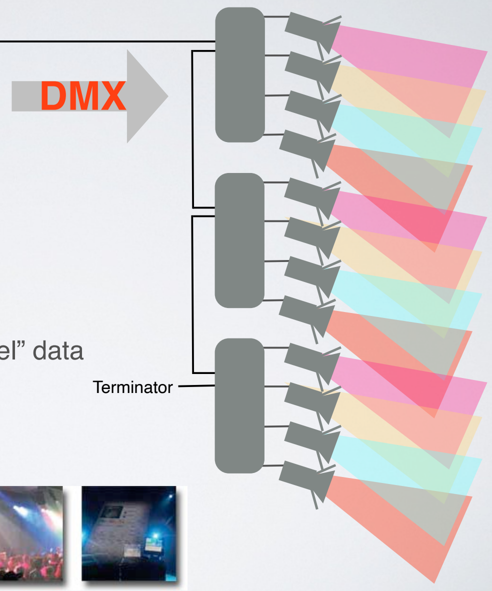
- Assembles channel slots into a 513 slot frame
- One cable is less bulky, cheaper, and less cumbersome
- For long distances, repeaters only need to amplify 2 signals

Standard allows control of a wide variety of equipment:

- PAR cans, moving head lamps, stage equipment, smoke machines, scanners, dimmers, fans, motors, etc.

Equipment may be controlled by more than one channel

DMX BUS

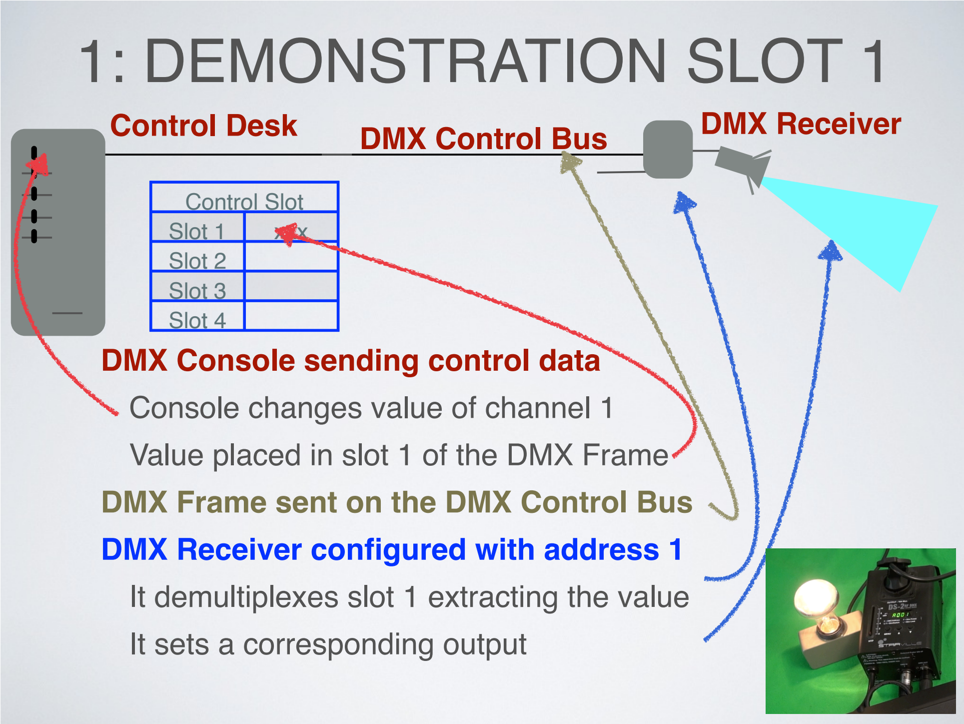


A serial transmission bus

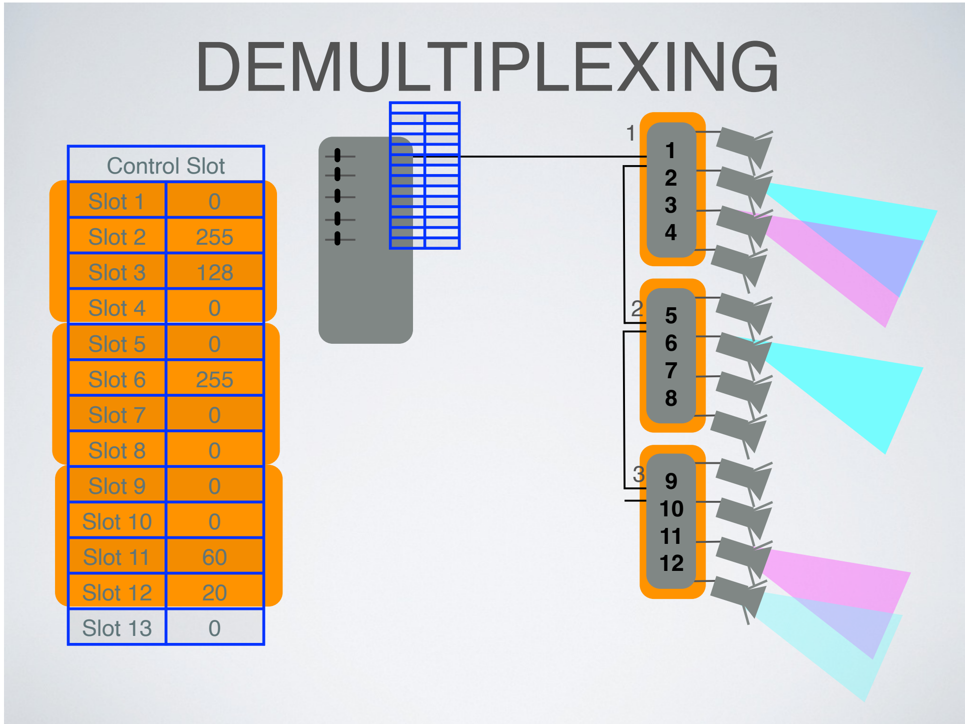
All equipment sees all frames

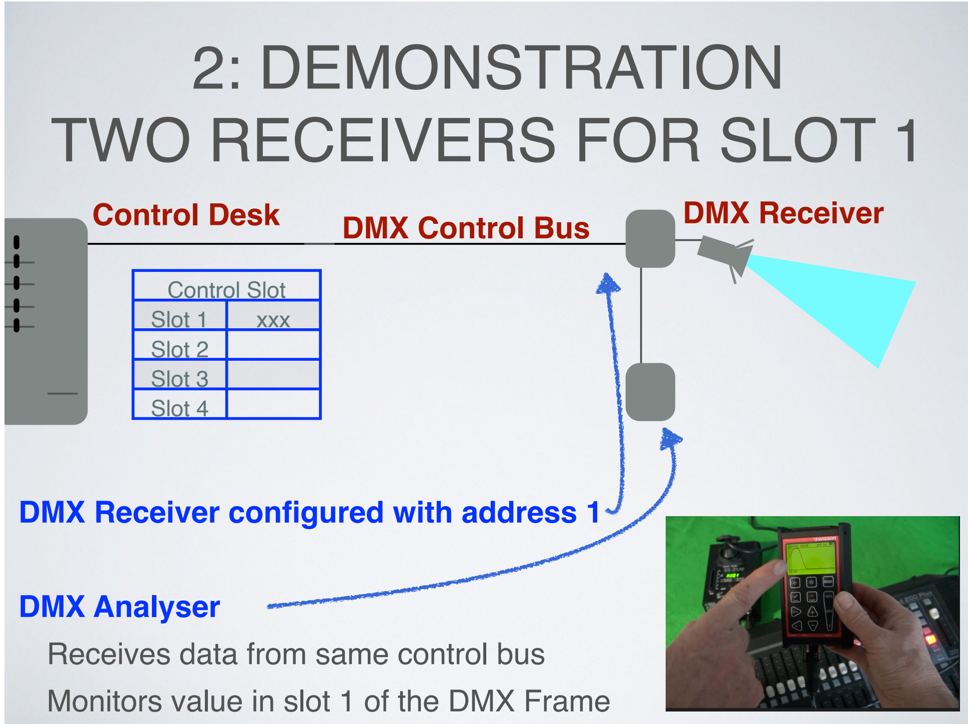
Equipment extracts “own channel” data

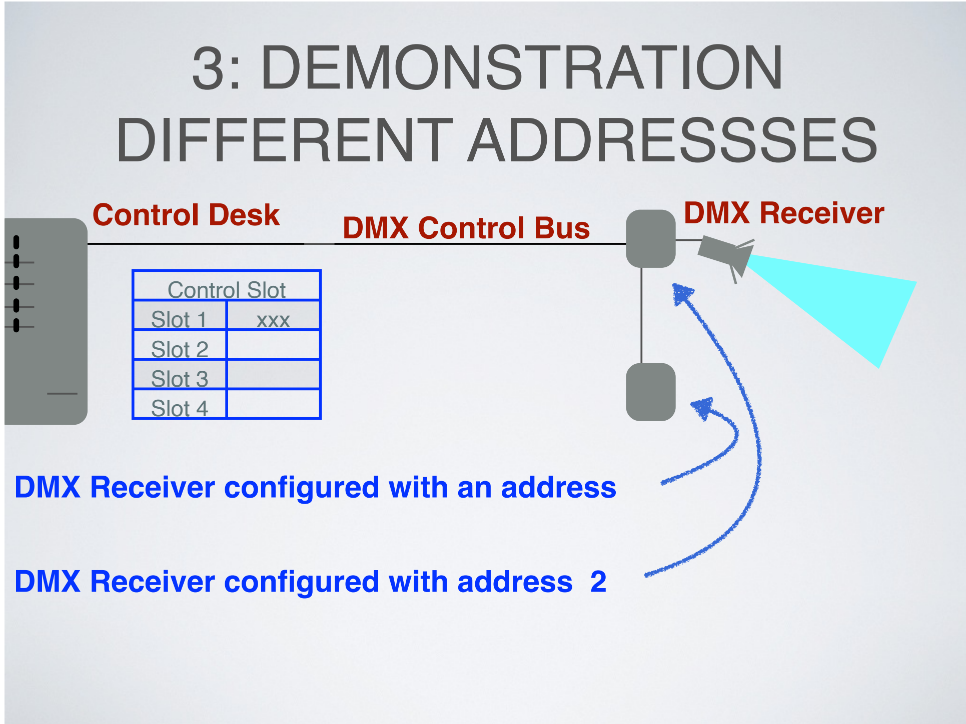
Bus terminated at end

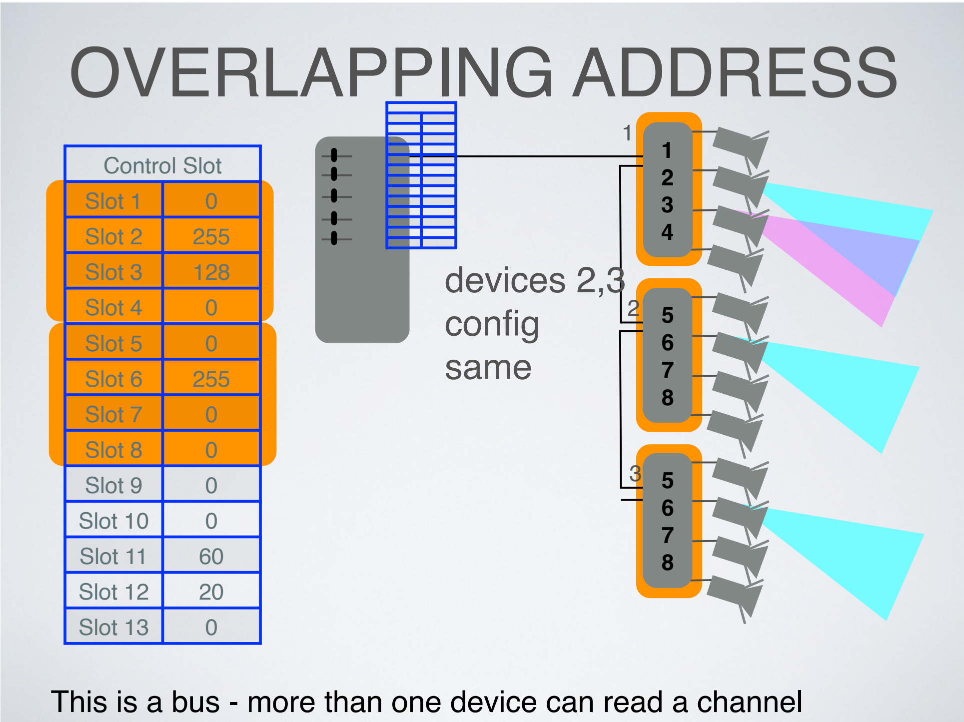

1: DEMONSTRATION SLOT 1
Control Desk
DMX Control Bus
DMX Receiver
Control Slot
Slot 1
xx
Slot 2
Slot 3
Slot 4
DMX Console sending control data
Console changes value of channel 1
Value placed in slot 1 of the DMX Frame
DMX Frame sent on the DMX Control Bus
DMX Receiver configured with address 1
It demultiplexes slot 1 extracting the value
It sets a corresponding output

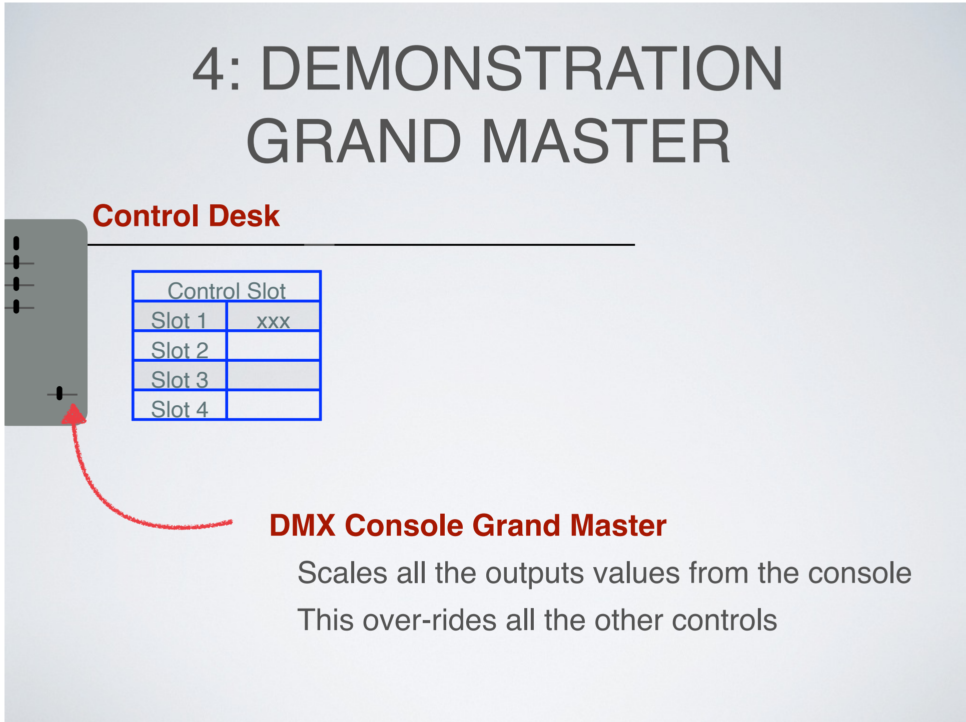

EUROVISION 2013
1243 Lighting fixtures
800 moving lights
50 km power cable
40 km control, video and audio cable


DEMULTIPLEXING
Control Slot
Slot 1 0
Slot 2 255
Slot 3 128
Slot 4 0
Slot 5 0
Slot 6 255
Slot 7 0
Slot 8 0
Slot 9 0
Slot 10 0
Slot 11 60
Slot 12 20
Slot 13 0
1 2 3
1 2 3 4
5 6 7 8
9 10 11 12

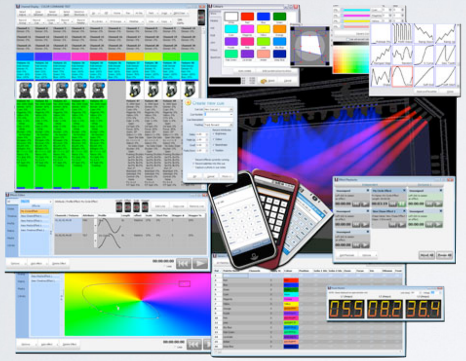

2: DEMONSTRATION
TWO RECEIVERS FOR SLOT 1
Control Desk
DMX Control Bus
DMX Receiver
Control Slot
Slot 1 xxx
Slot 2
Slot 3
Slot 4
DMX Receiver configured with address 1
DMX Analyser
Receives data from same control bus
Monitors value in slot 1 of the DMX Frame


3: DEMONSTRATION
DIFFERENT ADDRESSSES
Control Desk
DMX Control Bus
DMX Receiver
Control Slot
Slot 1 xxx
Slot 2
Slot 3
Slot 4
DMX Receiver configured with an address
DMX Receiver configured with address 2


OVERLAPPING ADDRESS
Control Slot
Slot 1 0
Slot 2 255
Slot 3 128
Slot 4 0
Slot 5 0
Slot 6 255
Slot 7 0
Slot 8 0
Slot 9 0
Slot 10 0
Slot 11 60
Slot 12 20
Slot 13 0
devices 2,3
config
same
1
2
3
1 2 3 4
5 6 7 8
5 6 7 8
This is a bus - more than one device can read a channel


4: DEMONSTRATION
GRAND MASTER
Control Desk
Control Slot
Slot 1 xxx
Slot 2
Slot 3
Slot 4
DMX Console Grand Master
Scales all the outputs values from the console
This over-rides all the other controls

DMX CONSOLES



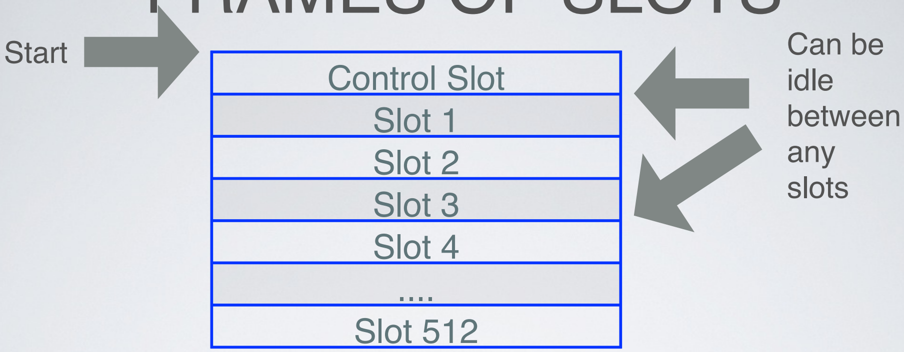
Computer-based

Dedicated Hardware

FRAMES OF SLOTS

Module 5.1

FRAMES OF SLOTS

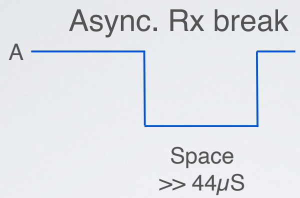


A set of up to 512 slots is assembled to form a frame

Each frame is prefixed by a control “control slot” with a start code

Start of the complete frame must be synchronised with receivers

ASYNCHRONOUS BREAK



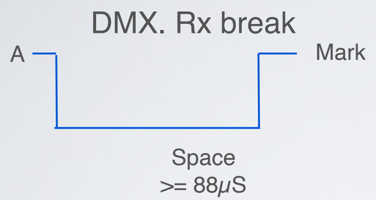
The **start of frame** is delimited by an **asynchronous break**

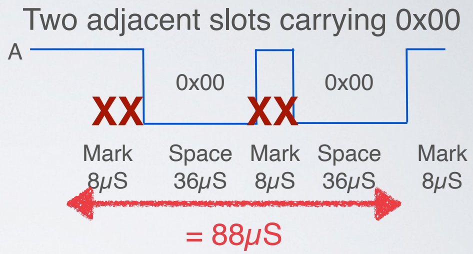
A break is a run of 0s that exceeds the size of one character

- Breaks can be detected at the receiver (in UART Status Register)
- Each break is followed by a ***Mark*** (by definition)

BREAK IN DMX512

At 250 kbps, DMX defines a ***break at the receiver* > 88 µS.**





This is robust to corruption:

Consider for example, two adjacent received slots containing 0x00

Two slots are separated by two stop bauds (mark level)

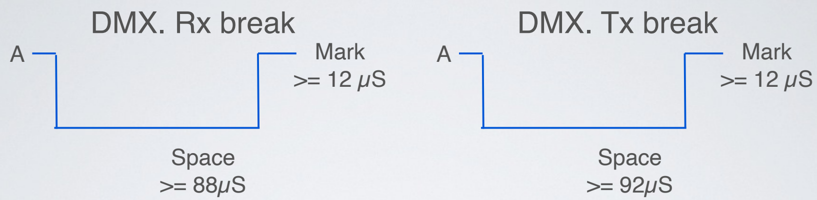
88 µS would need ***4 errors*** to be changed to a break!

At a receiver, a received DMX break causes a UART "error"

This sets a flag in the status register

DMX interprets this as the start of a frame

SEND/RECEIVE BREAK



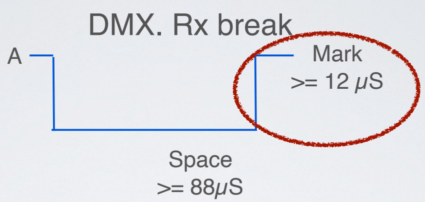
At the receiver, ***a break*** **>** 88 µS of continuous low indicates the start of frame.

The ***break at the sender*** is specified as > 92 µS of continuous low

Why is the break duration specified as larger at the transmitter?

... because a repeater on the path can reduce the received break length.

MARK AFTER BREAK

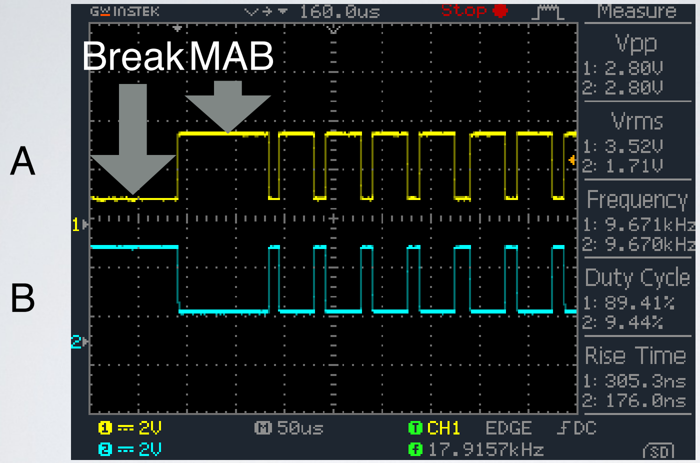


The break is followed by a 12 µS high level (Mark After Break)

The MAB allows time for slow receivers to process break

Minimum at sender: 12µs Minimum at receiver: 8µs

MARK AFTER BREAK



See page 79 of Guidelines

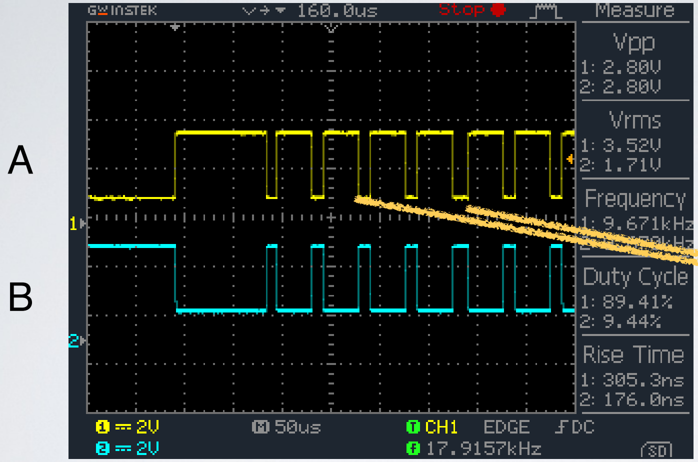
The next low transition indicates the control slot

The control slot carries the **Start Code** value

The most common start code is 0 indicating "data"

Question: What would happen if a receiver took more than 8µs?

MARK AFTER SLOT

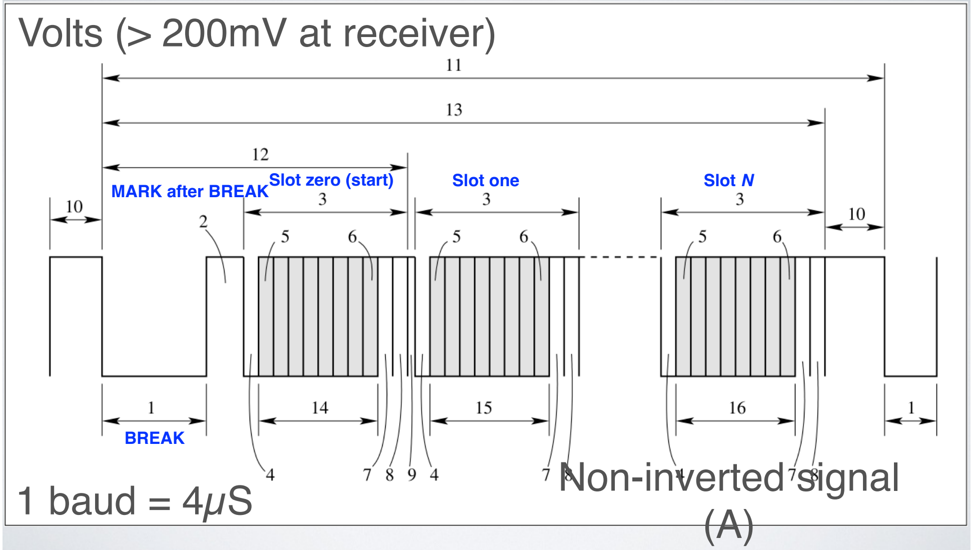


Varying time between slots (see page 82

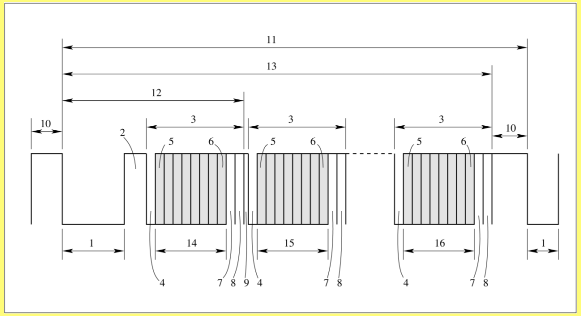
Each slot is 1 byte+1 start+2 stop bauds, and any idle time

The **maximum** possible Mark-between-slot time is one second, if longer, the transmission failed, so the receiver looks for next frame

COMPLETE DMX

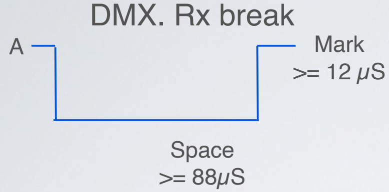


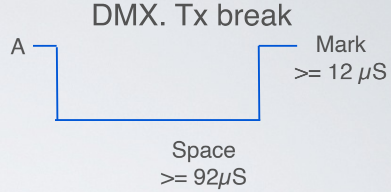
LEGEND



1. SPACE for BREAK
2. MARK after BREAK (MAB)
3. Slot Time
4. START bit
5. LEAST SIGNIFICANT Data BIT (LSB)
6. MOST SIGNIFICANT Data BIT (MSB)
7. STOP Bit
8. STOP bit
9. MARK time between slots
10. MARK before BREAK (MBB)
11. BREAK to BREAK time
12. RESET Sequence (BREAK, MAB, START Code)
13. DMX512 Packet
14. START CODE (SLOT 0 Data)
15. SLOT 1 Data
16. SLOT n DATA (Max. 512)

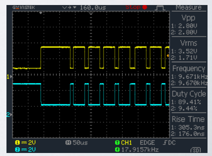
SUMMARY



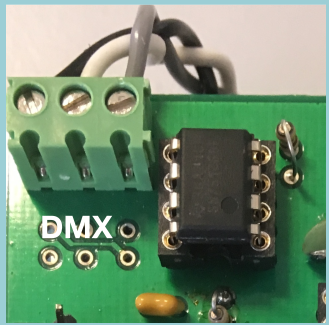


This module has described:

- The asynchronous beak
- How DMX uses a break to indicate the start of frame
- How DMX chose the minimum specified DMX break duration
- The minimum mark after break
- The minimum/maximum time between slots



EIA-485 CONTROL BUS

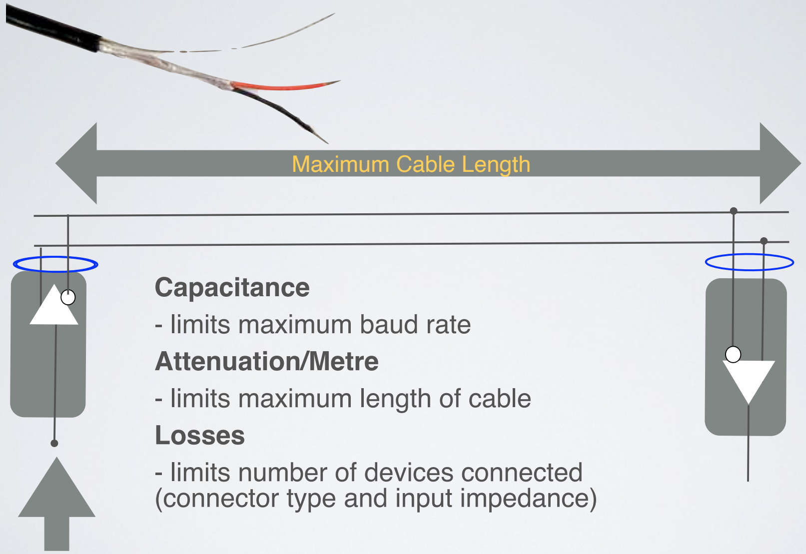


CABLE BUS

E1.27

Module 3.2

MAXIMUM CABLE LENGTH



Capacitance
- limits maximum baud rate

Attenuation/Metre
- limits maximum length of cable

Losses
- limits number of devices connected (connector type and input impedance)

TYPICAL CABLE ATTENUATION 24/7 TP

Resistance: 85 Ohm/km

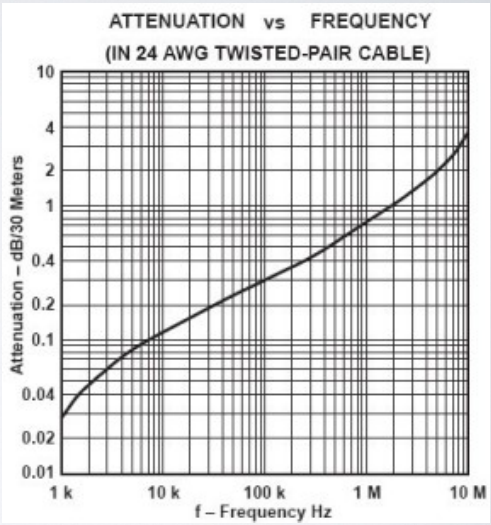
Typical attenuation is:
~2-4dB per 100m

@4dB/100m:
200m = ~8dB
300m = ~12dB

Assume:
0.1dB loss per transceiver
0.2dB connector loss
Total loss /receiver 0.3dB
Loss from **32 receivers** = 13 dB

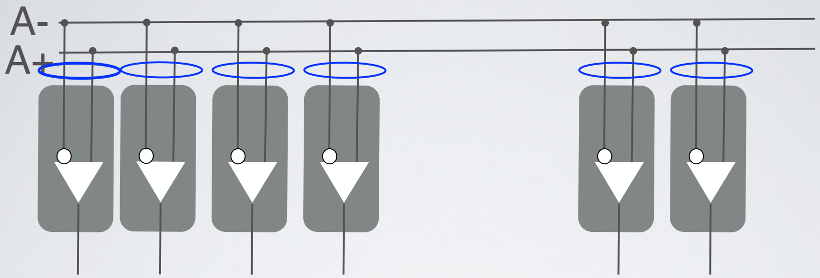
Signal attenuation at end = 25dB

Margin = 3dB



Maximum distance limited by number of receivers & cable length

LOAD FROM 32 RECEIVERS



Each standard EIA-485 rec has an input impedance of 12K.

32 receivers placed in parallel present a combined load of 376 ohms.

Max load is a lot more than cable impedance!

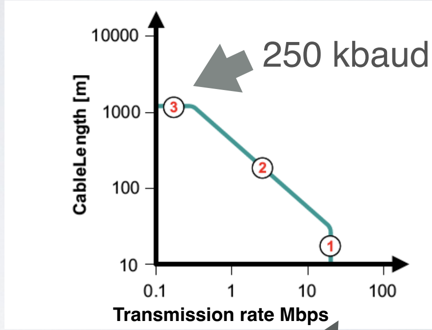
RESISTANCE IN PARALLEL

- Basic reminder:
  - R in parallel with r =1/((R^{-1})+(r^{-1}))
  - Two resistances of resistance R in parallel = R/2
  - Four resistances of resistance R in parallel = R/4
  - Eight resistances of resistance R in parallel = R/8
  - .... 32 in parallel = R/32

CABLE LENGTH

Signal strength, one receiver

= signal*attenuation/distance



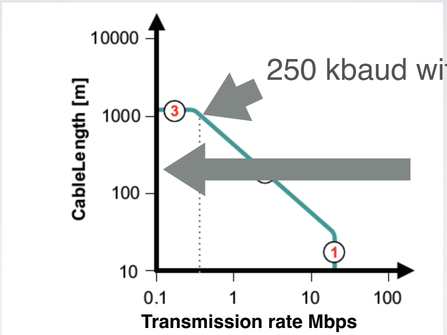
Max transmission baud rate depends on cable length

For very short distance ~10-40 Mbps

For moderate distances rate x length <10^7 (attenuation/metre)

For long distances, 250kbps, but cable attenuation dominates

32 RECEIVERS



300m is a Safe distance for

32 receivers

~ 300m with 32 “standard” receivers

32 receivers at 250 kbps limits bus LENTH to 300m

DOES 250 KBAUD WORK AT 1KM?

We know:

EIA-485 allows 32 Receivers at 300m

Differential transmission can be used at much greater distances

Cable attenuation depends on cable length (loss/meter x distance)

Cable attenuation for typical cables is 4dB/100m
- Determined largely by gauge (diameter) of the wire

Thicker conductors could be used in the twisted pair wires
- Lower resistance per metre (e.g., 3dB/100m)
This would use more copper, and result in more cost
And a larger diameter of cable (more awkward to install)

DOES 250 KBAUD WORK AT 1KM?

Start by looking at the signal at transmitter:

Power Margin (with no cable loss)
$= 10 \, Log_{10}[((V_{tx})^2/(V_{rx})^2]$ dB
$= 10 \, Log_{10}[(5x5)/(0.02 \times 0.02)]$ dB
= 38 dB

i.e. at the transmitter, signal is 38 dB above the receiver threshold

Next, think about the signal at receiver:

The signal at the receiver is not only reduced by cable attenuation
Signal is also lost at connectors, receiver input impedeance, etc

We need a positive margin to take care of noise, and interference

DOES 250 KBAUD WORK AT 1KM?

1. Consider 300m & standard gauge conductors with 32 receivers
Loss @4dB/100m:
Cable attenuation @ 300m = ~12 dB
Receiver loss ~0.3 dB => Total loss for 32 receivers = 10.4 dB
Total loss = 12+10.4 = 22.4 dB
Signal margin at receiver = 38 - 22.4 dB = **15.6 dB**
Positive margin sufficient to operate with noise/interference

2. Consider now 1000m & standard gauge conductors
Loss @4dB/100m (same as in 1)
Cable attenuation @ 1000m = 40 dB
Receiver loss ~0.3 dB => Total loss for 32 receivers = 10.4 dB
Total loss = 30 + 10.4 = 50.4 dB
Signal margin at receiver = 38 - 50.4 dB = **-12.4 dB**
Negative margin - insufficient to reliably work !!!

Let's look at what we can change...

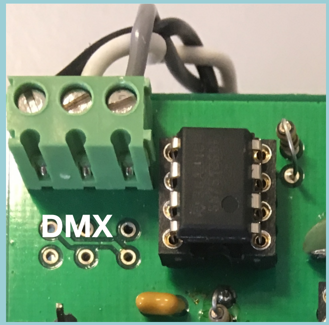
DOES 250 KBAUD WORK AT 1KM?

3. Consider larger gauge conductor (lower resistance/m)
Loss @3dB/100m (depends on cable choice)
Cable attenuation @ 1000m = 30 dB
Receiver loss ~0.3dB => Total loss for 32 receivers = 10.4 dB
Total loss = 40.4 dB
Signal margin at receiver = 38 - 40.4 dB = **-2.4 dB**
Negative margin - insufficient to reliably work !!!

4. What about if we only had one receiver and low loss cable?
Loss @3dB/100m (same as in 3)
Cable attenuation @ 1000m = 30 dB
Receiver loss ~0.3dB => Total for 1 receiver = 0.3 dB
Total loss = 30.3 dB
Signal margin at receiver = 38 - 30.3 dB = **7.7 dB**
Positive margin sufficient to operate with noise/interference

DMX can work over 1000m, if using this low loss cable with 1 receiver

EIA-485 CONTROL BUS



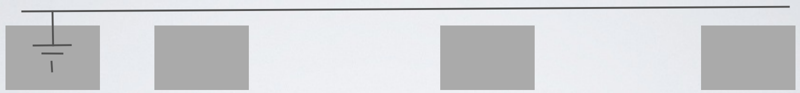
CABLE GROUND/SHIELD

E1.27

Module 3.2

GROUND/SHIELD

Required grounding of the shield



Why is this a bad idea?

GROUND LOOPS

Grounding the cable at each equipment causes problems:

- Equipment might (will) have a different ground potential
- A current will flow along the cable, and that disrupts communications

Only the output line at transmitter (controller) is grounded.

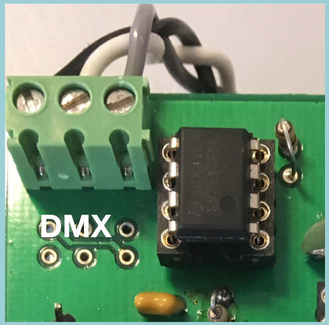
- The connectors must ***not*** be grounded at the receiver.
- The ***Shield*** does need to be connected through in and out connectors.

Earth Rod

AVOIDING GROUND LOOPS

Everything went well - until the whole rig went to full, and the DMX cable vaporised!

EIA-485 CONTROL BUS



RECEIVER HARDWARE

E1.27

Module 3.2

AVOIDING GROUND LOOPS

Balanced lines do not connect the ***chassis grounds*** of different equipment:

Each receiver has TWO ground levels:

1) Local earth for electrical safety.

2) The communications bus shield

Each receiver ***decouple*** the transceiver through an ***opto-isolator***.

With isolation, the transceiver needs a separate the power supply

All comms circuitry is connected to one earth (at sender)

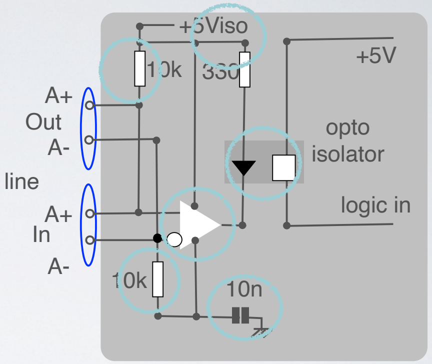
If no sender is driving the bus, the line floats to the level of a transient *

Transients can be many kV, so care is needed in this design.

REAL-WORLD RECEIVER

1. Receiver interface from line driver

2. Opto-isolated transceiver

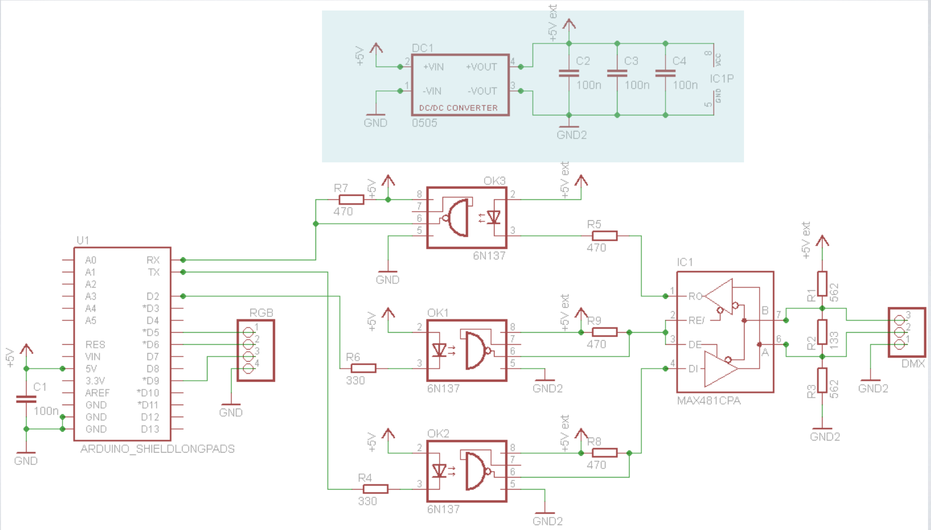


3. Optional: Pull-up/down resistors (50K-100K) protects when cable disconnected

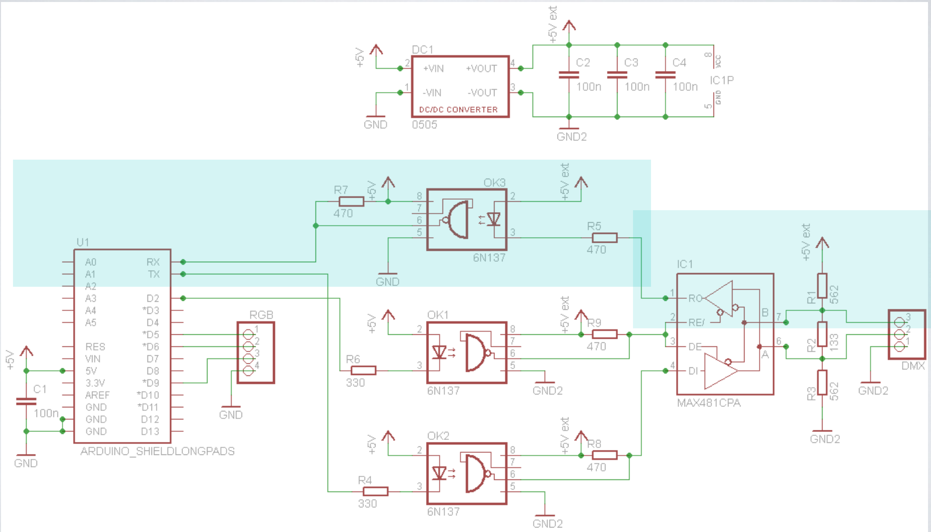
4. DC-DC conversion to isolate transceiver dc (Chasis, +5Viso)

5. Optional: Capacitive coupling to ground 10 nF, 1kV (protects from faults)

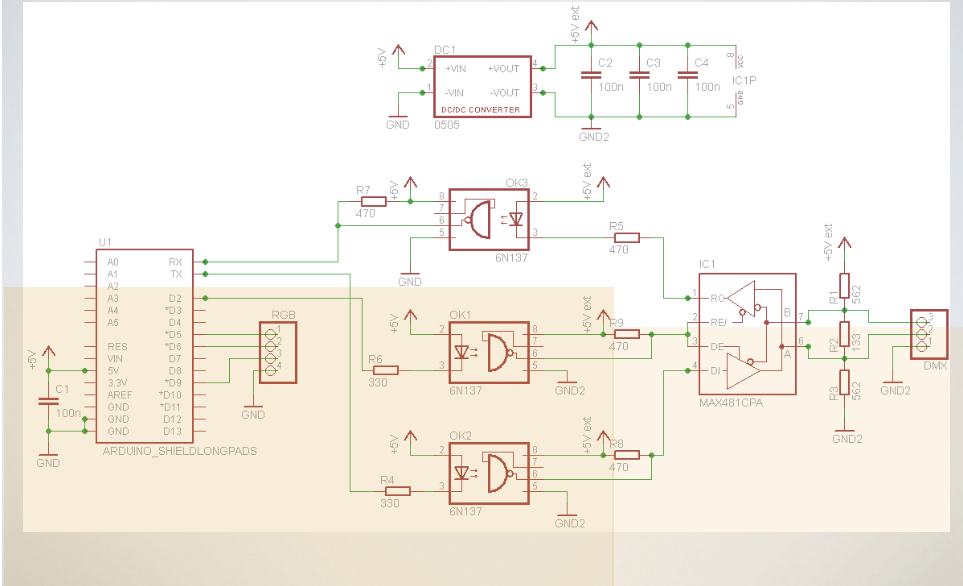
ISOLATED TRANSCEIVER



ISOLATED RECEPTION



ISOLATED TRANSMISSON

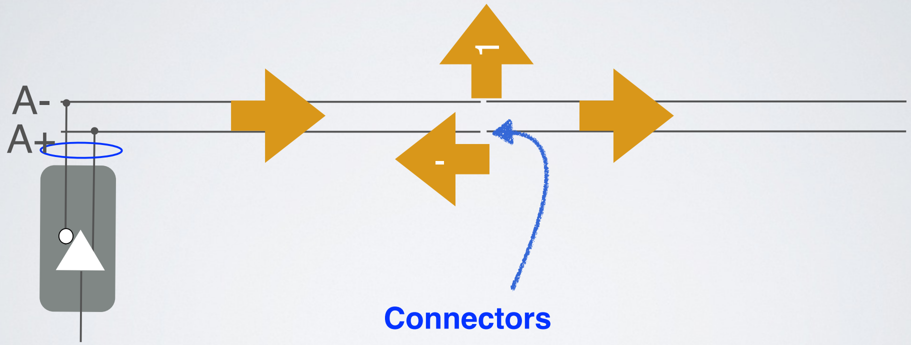


BUS TERMINATION

Module 4.2

SIGNAL PROPAGATION

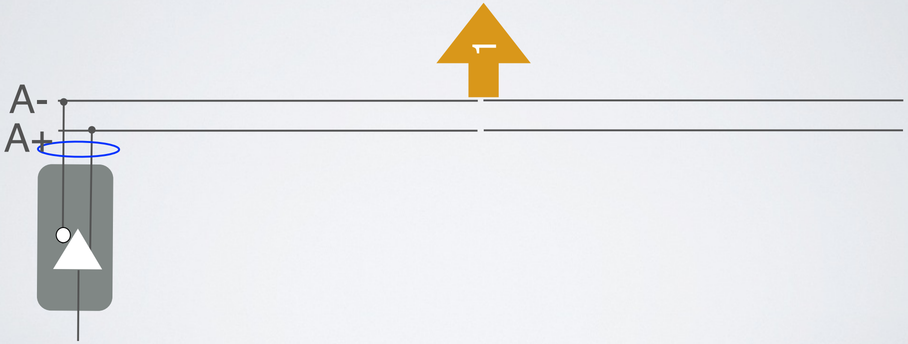
(1) What happens to the signal when we join two cables?



SIGNAL PROPAGATION

(1) What happens when we join two cables? - loss

(2) What happens as the signal travels along the cable?

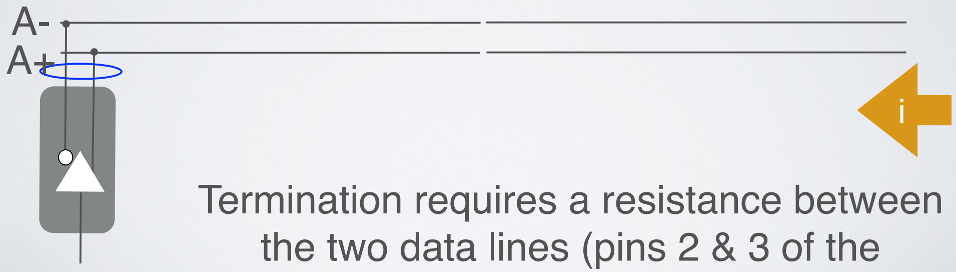


SIGNAL PROPAGATION

(1) What happens when we join two cables? - loss

(2) What happens as the signal travels along the cable?

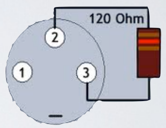
(3) What happens to the signal at the end of the cable?



Termination requires a resistance between the two data lines (pins 2 & 3 of the connector)

TERMINATION

The termination impedance value should match the cable characteristic Impedance.

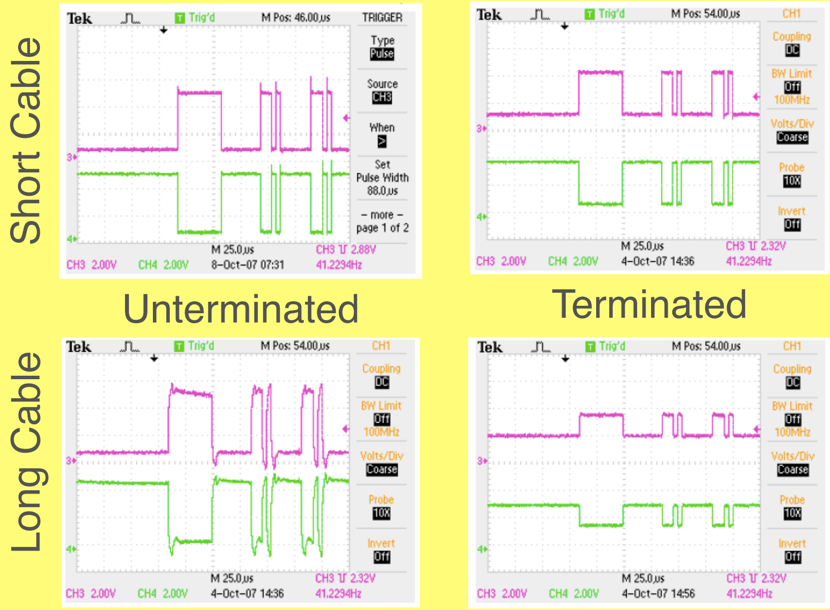


Termination of the cable with the characteristic impedance causes no reflections of the transmitted signal.

When the cable is cut to ***any length*** and ***terminated***, measurements will be identical to values obtained from an infinite length cable.

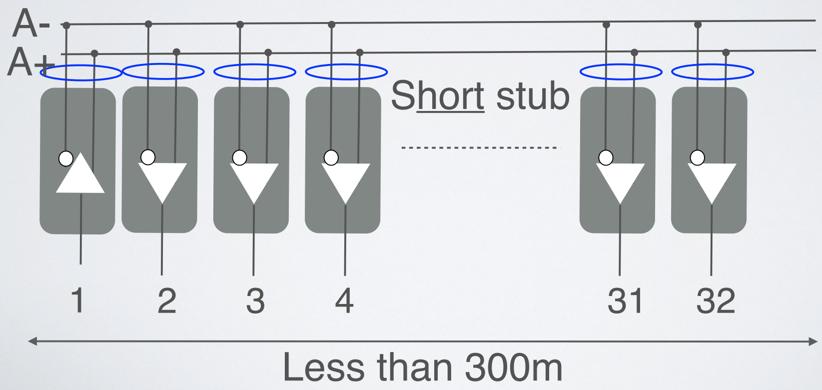
The resistor should be rated at least 0.2W.

EFFECTS OF TERMINATOR



EIA-485 CABLES

Up to 32 receivers can attach directly to cable



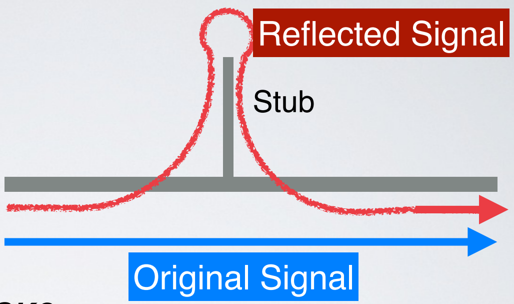
EFFECT OF CABLE STUB

Signal split at stub

Half the signal energy travels along the stub

Reflected at stub end and travels back down stub

Reflection propagates with original signal



How long a stub can be OK?

Assume that the reflected signal needs to not be more than 10% delayed relative to the original and that

v= 0.6-0.8 and c= 3 x10^8 m/s

Lstub ≤ (Tr/10) x v x c

Lstub for 250ns Tr (@250kbaud) = 6m

Lstub (@1Mbaud) = 2m

Most buses have several stubs, best to keep all ***SHORT***

EIA-485 SIMPLEX EQUIPMENT BUS: DMX-512 FRAMES

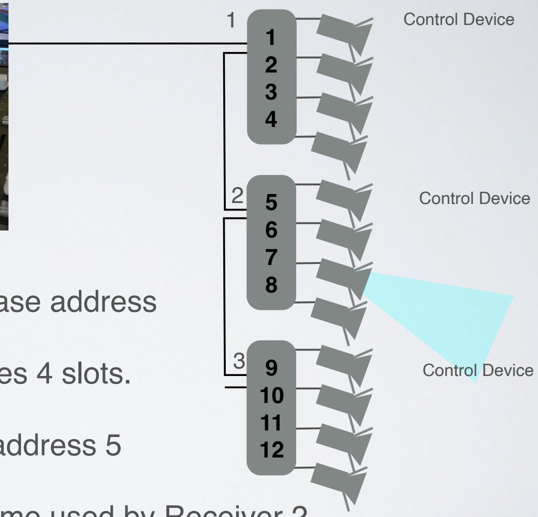
Module 5.0

DMX ADDRESSING AND RECEIVERS

Module 5.2

ADDRESSING A RECEIVER

Control Surface



Each receiver allocated a base address

In this case, the receiver uses 4 slots.

e.g. here, Receiver 2 uses address 5

Hence Slots 5-7 of the frame used by Receiver 2

This receiver uses these 4 slots to control its four outputs

DMX SLOT ADDRESSING

2^0	2^1	2^2	2^3	2^4	2^5	2^6	2^7	2^8

least significant bit first

DMX addresses are often setup using DIP switches:

- Switch setting 100000000, = 1
- Switch setting 101000000, = 5
- Switch setting 111000000, =7

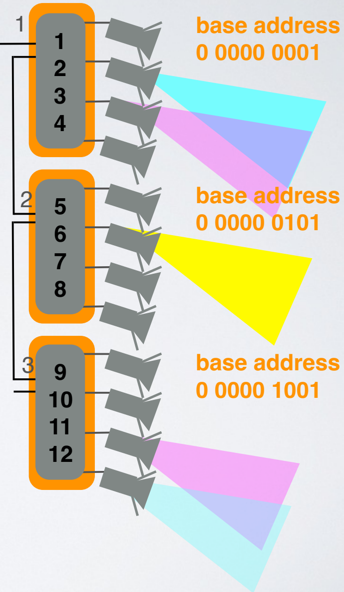
Checks these switch settings for yourself:

A DMX base address of 40 sets 4,6

A DMX base address of 393 sets 1,4,8,9

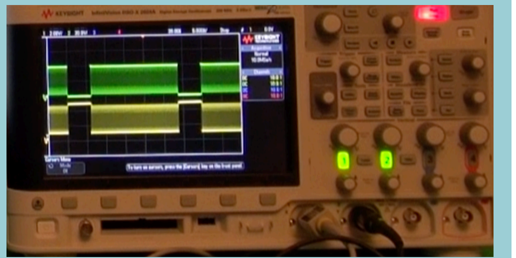
ADDRESSING A FIXTURE

Control Slot	
Slot 1	0
Slot 2	255
Slot 3	128
Slot 4	0
Slot 5	0
Slot 6	255
Slot 7	0
Slot 8	0
Slot 9	0
Slot 10	0
Slot 11	60
Slot 12	20
Slot 13	0



FRAMES OF SLOTS

Control Slot
Slot 1
Slot 2
Slot 3
Slot 4
....
Slot 512



Module 5.1.2
Demo Measuring the Frame Rate

MAXIMUM FRAME RATE

Total frame duration = Break+Mark_after_break+slot*(n+1)

= 92 + 12 + (44 * 513) μS

= 22 676 μS (for full 512 B frame)

Maximum frame rate = 44 frames /sec

Lower rates common for actual operation

e.g. 15 or 30 frame/sec

Allows time between slots

Maximum information transfer rate = 512 x 30 (30 frame/sec)

122.88 kbps (i.e. data bits/second)

SMALLER-SIZED FRAMES

Many applications send 512 B frames, but frames can be smaller.

The receiver knows it has reached the end of frame when it sees the break marking the start of the ***next*** frame.

A smaller frame size allows a higher rate

Small frames are also used for certain types of control slots.

MULTIPLE CHOICE

1) Which of the following is true for DMX?
(a) DMX uses bidirectional transmission
(b) Asynchronous communication sends 3 extra overhead bauds per byte
(c) A sender can pause between each asynchronously sent byte
(d) The stop baud is the same level as for an idle cable

2) Which of these is true for DMX cables?
(a) The cable uses a pair of conductors to send the signal
(b) The cable must be shielded
(c) The cable must be earthed at ***every device*** connected to the bus
(d) The bus must be terminated at ***both ends of the cable***

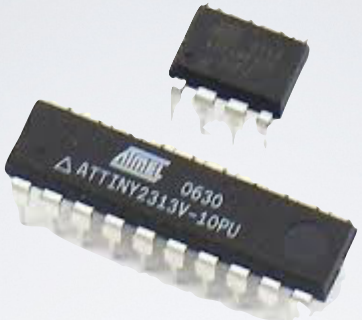
3) Which if these is true of the 120 Ohm EIA-485 bus?
(a) A typical input impedance for a transceiver is 12k Ohms
(b) The maximum number of receivers is determined ***only*** by the cable length
(c) A longer length of cable will deliver acceptable performance with fewer

DMX RECEIVER HARDWARE

Module 5.3

ATMEL* AVR (1997)

8-BIT MICROCONTROLLER



A complete computer on a chip with serial communications

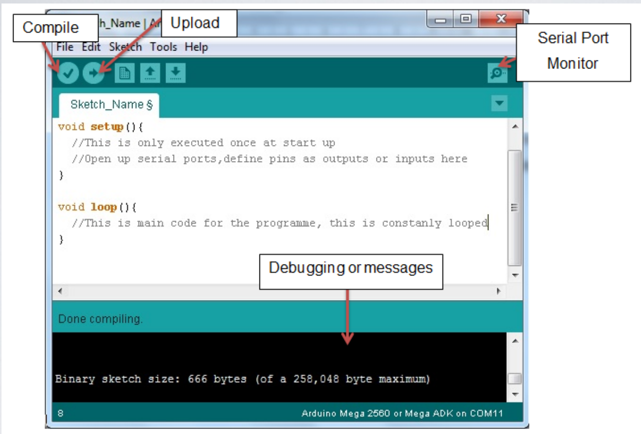
Named after Alf (Egil Bogen) and Vegard (Wollan)

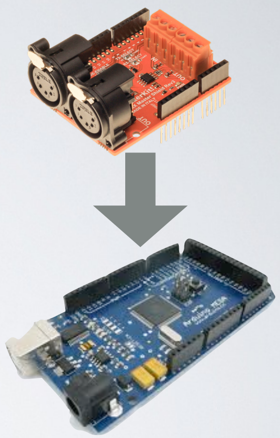
2003: 500 Million sold in first 5 years

2005: Arduino appeared, over 700,000 sold

*ATMEL is now MicroChip

ARDUINO DMX





Total cost about £15-£30, free development tools!

DMX Shields cost ~£20

AT MEGA 8515-16

AMTEL AVR Core

2.7 - 5.5 Volt, 16 MHz (16 MIPS)

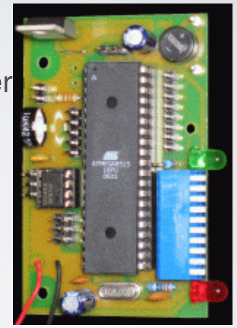
130 instruction RISC processor, 32 register

8 KB program Flash Program Memory

512 B internal SRAM, 512 Byte EEPROM

35 general purpose I/O lines

Serial Programmable USART



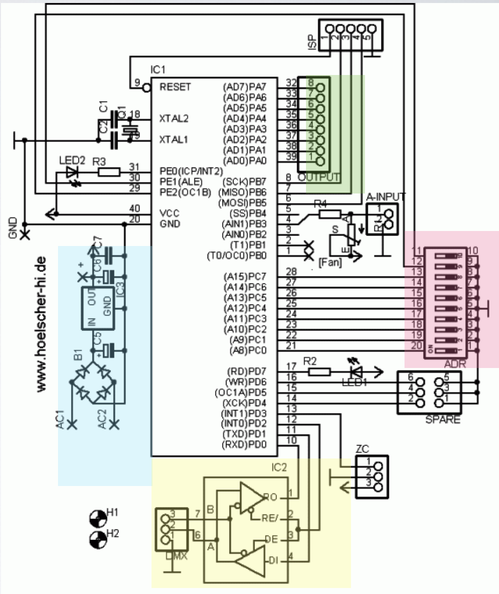
http://www.atmel.com/

Cost about £2-£3, free development tools!

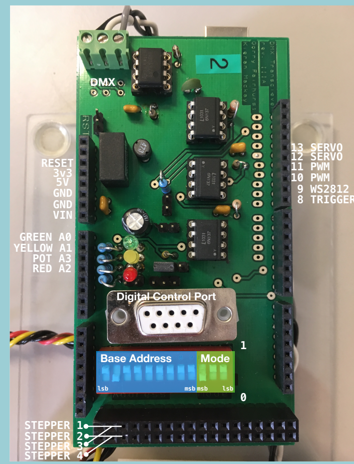
SIMPLE DMX RECEIVER

All with minimal logic!

- AVR 8515 Microcontroller
- 5V Power Supply
- EIA-485 Driver/Receiver
- Parallel input (DIP switch)
- PWM/Level output

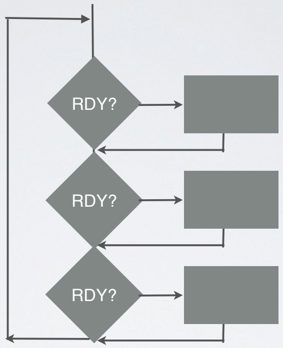


DMX RECEIVER SOFTWARE



Module 5.4

POLLING

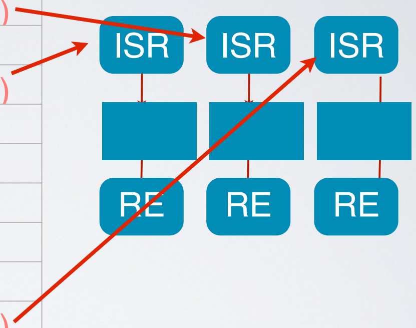


Polling

- Difficulty in responding quickly to input
- Tricky when something more important, longer, etc

INTERRUPT VECTORS

Vector	Location	Value
Reset	$000	
Ext Int 0	$001	(ISR2)
Ext Int 1	$002	
Timer 1	$003	(ISR1)
T1 cmp A	$004	
T1 cmp B	$005	
T1 Oflow	$006	
T0 Oflow	$007	
SPI done	$008	
USART	$008	(ISR3)



Initialise a set of vectors to point to ISRs

Write start address of each routine into corresponding locations

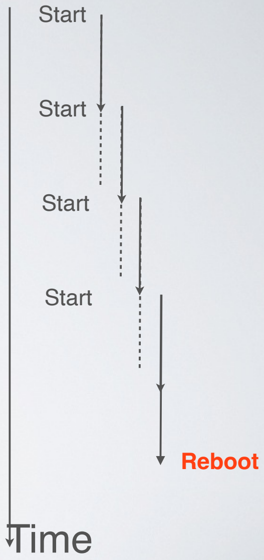
WATCHDOG TIMER

A simple timer that when triggered, counts down to zero and triggers a reset interrupt:

Timer initialised at start.

Periodically reset & restarted by main program.

If the timer ever reaches zero, the program is assumed to have crashed and the watchdog Interrupt service triggers a full reboot.



SOFTWARE DESIGN

- System functions:
  - Initialise hardware - sets I/O pins, clock, USART, Timer, etc.
  - Initialise software - setup vectors, initialise data
  - Monitor user interface
  - Output Status display
  - Receive DMX Signal
  - Output Control waveform
  - Check program is running (watchdog)

DMX RECEIVER STATES

States

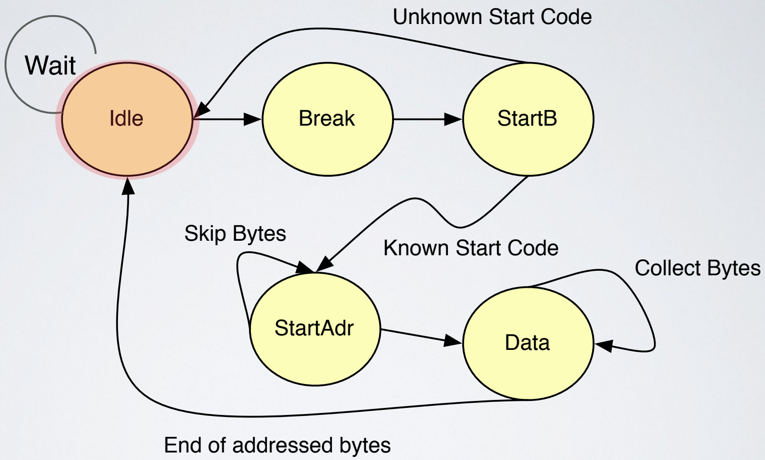
Idle

Break

StartB

StartAdr

Data



Note: All errors also transition to the Idle state

DMX RECEIVER STATES

States

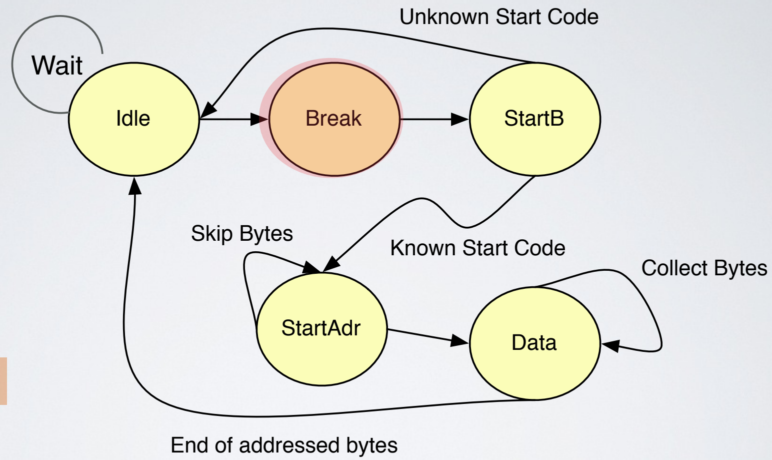
Idle

Break

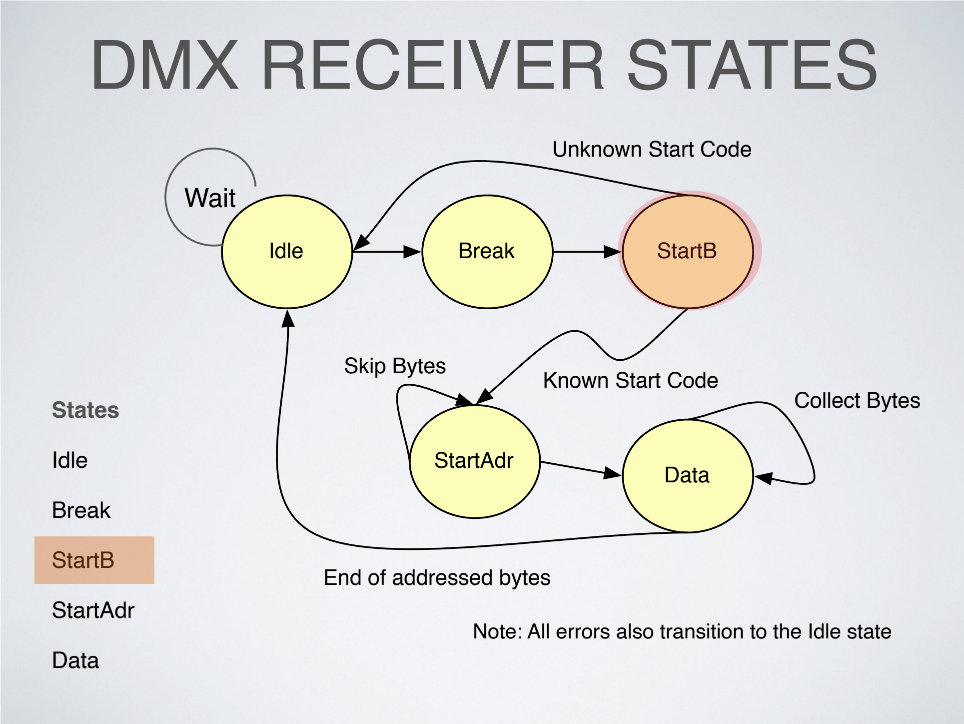
StartB

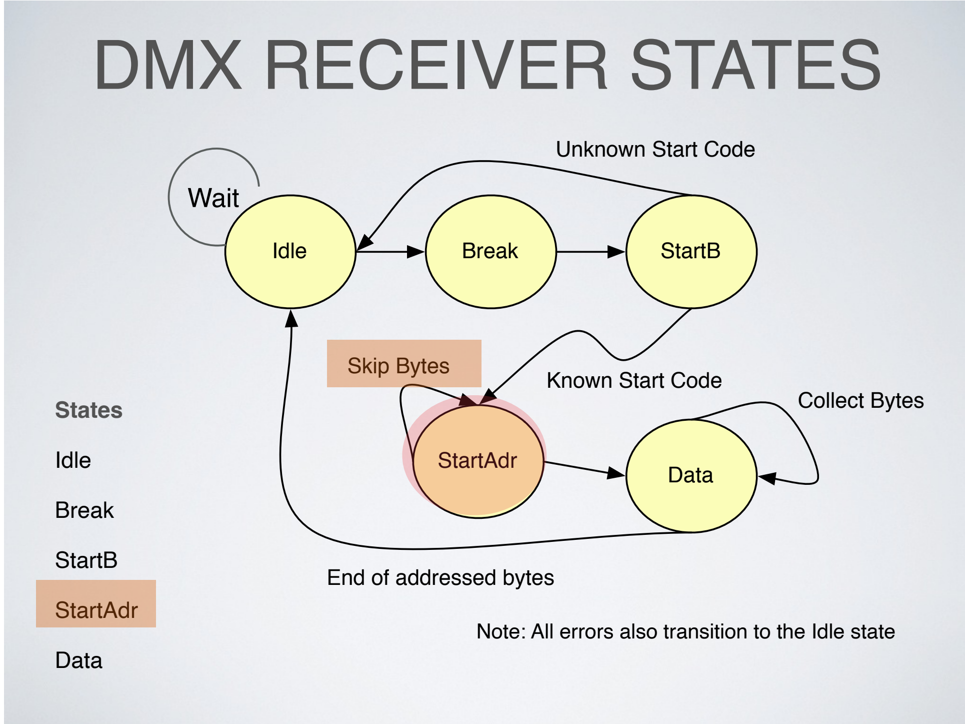
StartAdr

Data



Note: All errors also transition to the Idle state


DMX RECEIVER STATES
Unknown Start Code
Wait
Idle
Break
StartB
Skip Bytes
Known Start Code
Collect Bytes
StartAdr
Data
End of addressed bytes
Note: All errors also transition to the Idle state
States
Idle
Break
StartB
StartAdr
Data


DMX RECEIVER STATES
Unknown Start Code
Wait
Idle
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Skip Bytes
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Note: All errors also transition to the Idle state
States
Idle
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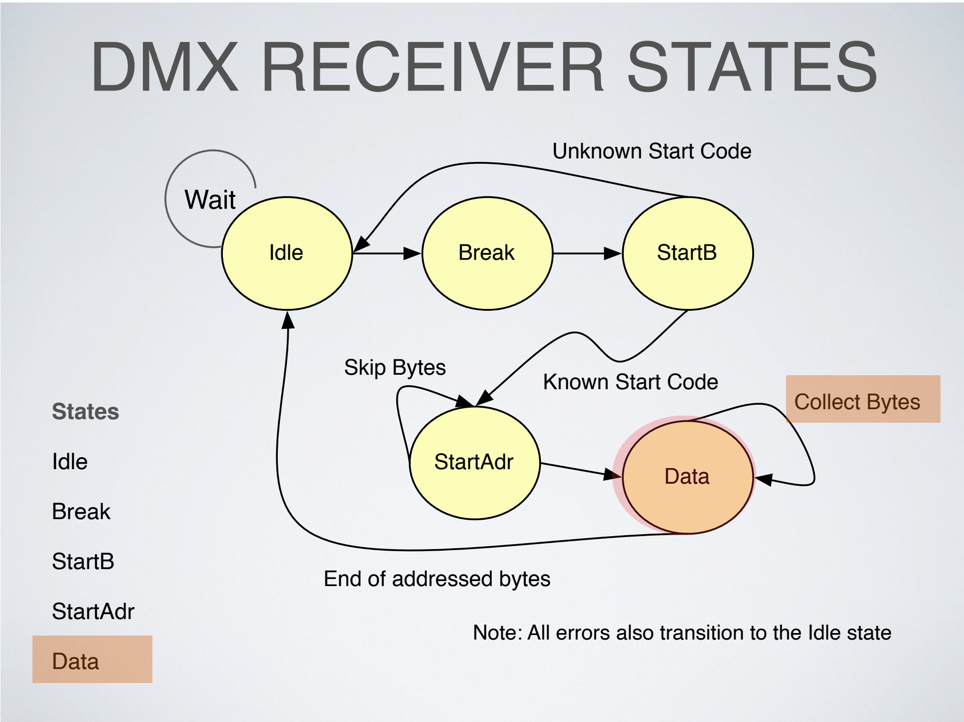
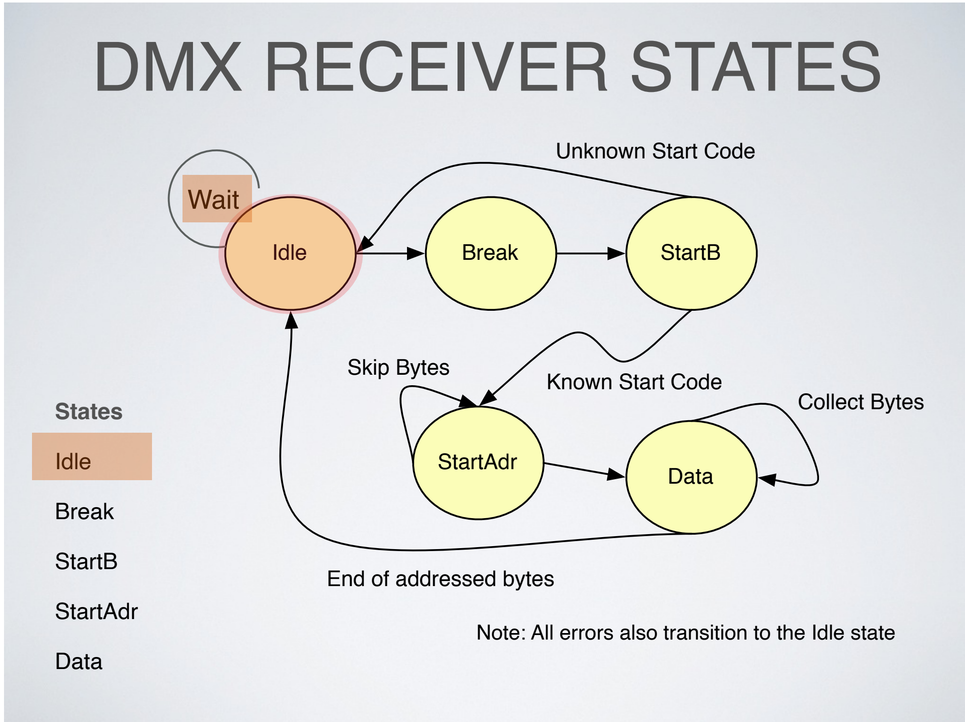
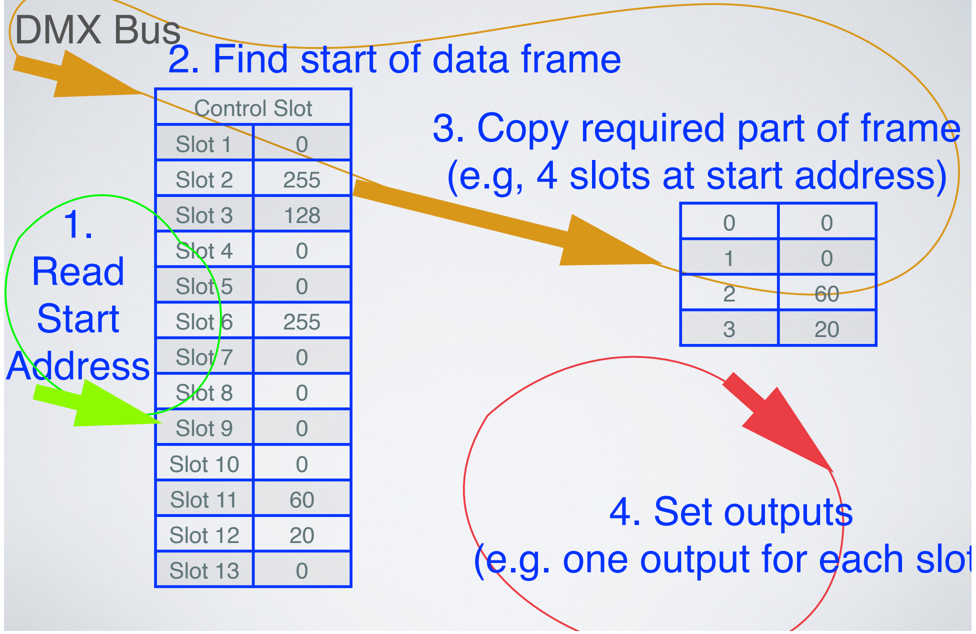
StartB
StartAdr
Data


DMX RECEIVER STATES
Unknown Start Code
Wait
Idle
Break
StartB
Skip Bytes
Known Start Code
Collect Bytes
StartAdr
Data
End of addressed bytes
Note: All errors also transition to the Idle state
States
Idle
Break
StartB
StartAdr
Data


DMX RECEIVER STATES
Unknown Start Code
Wait
Idle
Break
StartB
Skip Bytes
Known Start Code
Collect Bytes
StartAdr
Data
End of addressed bytes
Note: All errors also transition to the Idle state
States
Idle
Break
StartB
StartAdr
Data

DMX - EXAMPLE RX CODE



Control Slot	
Slot 1	0
Slot 2	255
Slot 3	128
Slot 4	0
Slot 5	0
Slot 6	255
Slot 7	0
Slot 8	0
Slot 9	0
Slot 10	0
Slot 11	60
Slot 12	20
Slot 13	0

0	0
1	0
2	60
3	20

DMX MAIN VARIABLES

Hardware registers:

int UCSRA // The Status Register of the UART

char DMXByte

Variables Used:

int DMXAdress // Read from the DIP Switch

int DmxState: {Idle,Break,StartB, StartAdr, Data}

char Array DMXRxField[4]

int DmxCount // Used as a counter

DMXRxField:

0	0
1	0
2	60
3	20

DMX RECEIVER

This routine handles reception of DMX frames from USART.

Requires a state machine (*DmxState*) to know which parts of the frame have already been received.

This is a fairly “classic” communications protocol design.

Updates *DmxRxField[]* based on contents of DMX Frame.

It could be made more sophisticated by checking the timing constraints for reception of the data slots.

DMX RECEIVER

- ISR (UART_RX_vect)

```
{
static  uint16_t DmxCount;
    uint8_t  USARTstate= UCSRA;              //get state before data!
    uint8_t  DmxByte   = UDR;              //get data
    uint8_t  DmxState  = gDmxState;

if (USARTstate &(1<<FE))                     //check for break
   {
   UCSRA &= ~(1<<FE);            //reset flag
   DmxCount =  DmxAddress;            //reset channel counter
                 //(count channels before start address)
   gDmxState= BREAK;
   }

else if (DmxState == BREAK)
   {
   if (DmxByte == 0) gDmxState= STARTB; //normal start code detected
   else            gDmxState= IDLE;
   }
```

DMX RECEIVER

```
else if (DmxState == STARTB)
  {
  if (--DmxCount == 0)            //start address reached?
   {
   DmxCount= 1;                   //set up counter for required channels
   DmxRxField[0]= DmxByte; //get 1st DMX channel of device
   gDmxState= STARTADR;
   }
  }

else if (DmxState == STARTADR)
  {
  DmxRxField[DmxCount++]= DmxByte;        //get channel
  if (DmxCount >= sizeof(DmxRxField))   //all ch received?
   {
   gDmxState= IDLE;              //wait for next break
   }
  }
RetI
}
```

RECEIVER ISR ALGORITHM

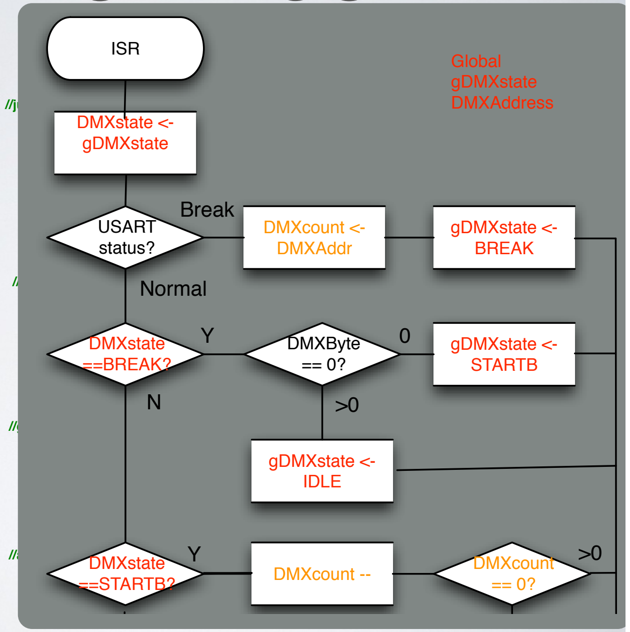
```
      ISR (UART_RX_vect)
{
static  uint16_t DmxCount;
      uint8_t  USARTstate= UCSRA;
      uint8_t  DmxByte   = UDR;
      uint8_t  DmxState  = gDmxState;            //j

if (USARTstate &(1<<FE))
    {
    UCSRA &= ~(1<<FE);
    DmxCount =  DmxAddress;
    gDmxState= BREAK;
    }

else if (DmxState == BREAK)
    {
    if (DmxByte == 0) gDmxState= STARTB;         //
    else              gDmxState= IDLE;
    }

else if (DmxState == STARTB)
    {
    if (--DmxCount == 0)
      {
      DmxCount= 1;
      DmxRxField[0]= DmxByte;                    //
      gDmxState= STARTADR;
      }
    }

else if (DmxState == STARTADR)
    {
    DmxRxField[DmxCount++]= DmxByte;
    if (DmxCount >= sizeof(DmxRxField))          //
      {
      gDmxState= IDLE;
      }
    }
}
```



RECEIVER ISR ALGORITHM

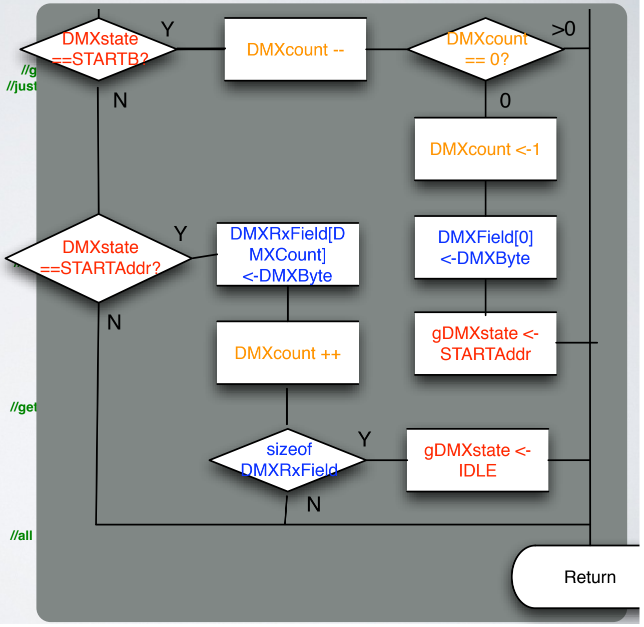
```
      ISR (UART_RX_vect)
{
static  uint16_t DmxCount;
      uint8_t  USARTstate= UCSRA;
      uint8_t  DmxByte   = UDR;                  //g
      uint8_t  DmxState  = gDmxState;            //just

if (USARTstate &(1<<FE))
    {
    UCSRA &= ~(1<<FE);
    DmxCount =  DmxAddress;
    gDmxState= BREAK;
    }

else if (DmxState == BREAK)
    {
    if (DmxByte == 0) gDmxState= STARTB;
    else              gDmxState= IDLE;
    }

else if (DmxState == STARTB)
    {
    if (--DmxCount == 0)
      {
      DmxCount= 1;
      DmxRxField[0]= DmxByte;                    //get
      gDmxState= STARTADR;
      }
    }

else if (DmxState == STARTADR)
    {
    DmxRxField[DmxCount++]= DmxByte;
    if (DmxCount >= sizeof(DmxRxField))          //all
      {
      gDmxState= IDLE;
      }
    }
}
```



DMX MAIN ROUTINE

Initialise hardware - sets I/O pins, clock, USART, Timer, etc.
Initialise software - zero **DmxRxField** array
Setup ISR for UART to load **DmxRxField** array
Setup ISR for output to use **DmxRxField** array
Enable watchdog
Enable Interrupts

Loop:
- Maintain user interface (switches, LEDs, etc)
- Sleep;
- Reset ***watchdog timer***
- *Goto Loop*

This program loops continuously, once initialised.

One ISR implements a watchdog timer to restart after a crash

Control Output ISR

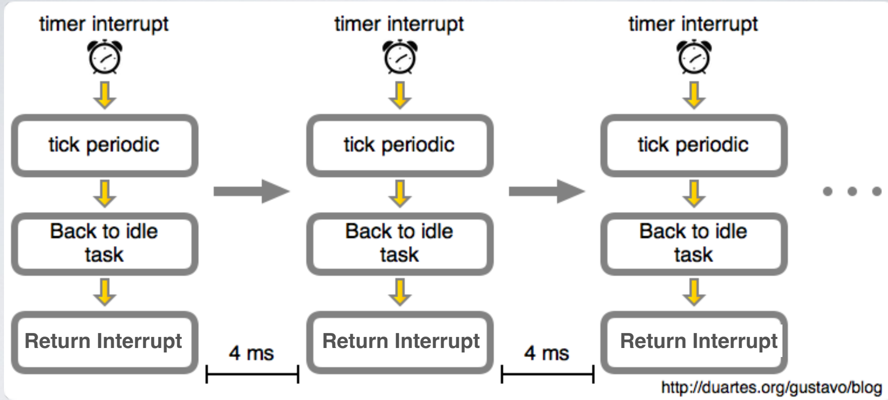
The output ISR runs periodically on a **timer** generating the output waveforms.

The routine takes as input a **shared (read) memory** structure output by the receive ISR (*DmxRxField*).

If multiple bytes are being read, it may require a technique to prevent the receive ISR from partially updating *DmxRxField (sempahores)*

The routine runs as often as required (e.g. synchronised to mains transitions for a “dimmer” controller).

OUTPUT A WAVEFORM

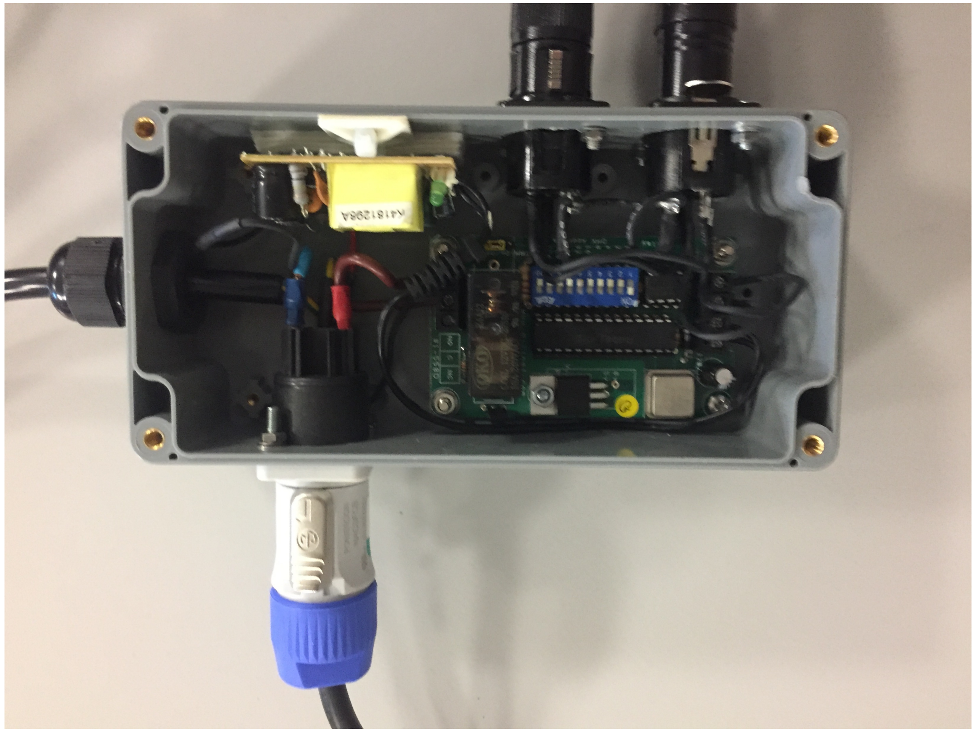


Each clock tick outputs next value
4ms = 250 Hz; 10ms = 100 Hz; 20ms = 50 Hz

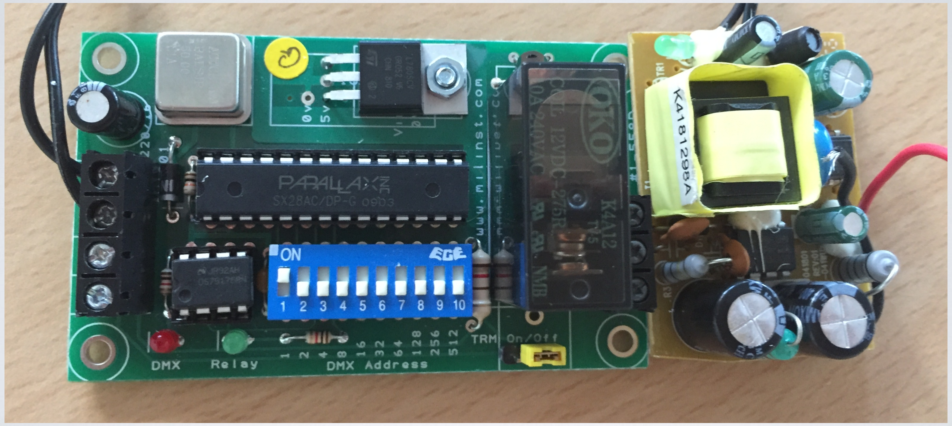
DIGITAL OUTPUTS & RELAY CONTROL

Control Slot
Slot 1
Slot 2
Slot 3
Slot 4
....
Slot 512

Module 5.5



SWITCHED RELAY



Bus Receiver | Microcontroller | Relay | Power Supply

EIA-485 SIMPLEX EQUIPMENT BUS: DMX512 CONTROL

Module 6.0

CONTROLLING POWER

Module 6.1

WHAT ABOUT MAINS?

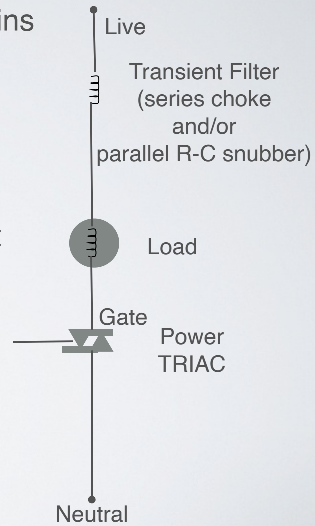
Traditional lamps driven directly from the mains

Need more control than on/off

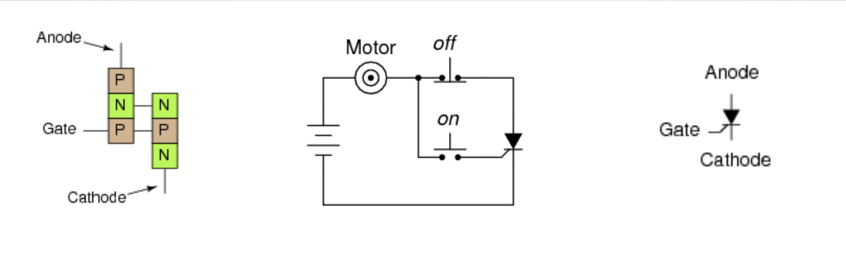
Normal method uses a TRIAC dimmer circuit

Gate fires Triac, turning on load

Choke/RC-Snubber suppresses interference



SILICON CONTROLLED RECTIFIER (SCR)



SCR fires when gate voltage is above a ***threshold***

Current flows from Anode to Cathode

This turns on load

Conduction continues until current ceases to flow ($I_{fwd} > I_H$)

The device functions as a ***latch***

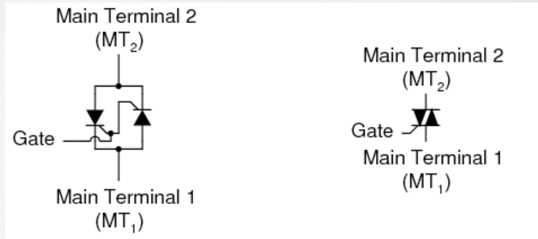
AC TRIAC (THYRISTOR)

A TRIAC is effectively two SCRs

- allows AC operation

For high power, important:

- TRIAC fires ***cleanly***
- Turns-off at end of cycle



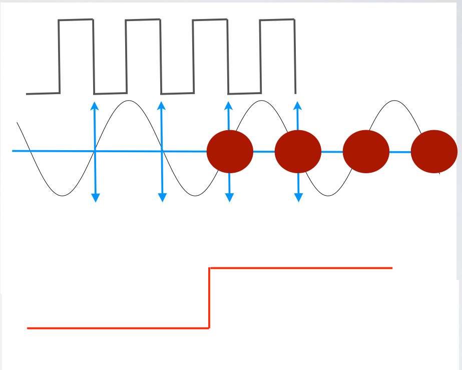
TRIAC equivalent circuit *TRIAC schematic symbol*

MAINS TRIAC SWITCH

Zero-Crossing Sync

Mains Cycle

+5V Trigger to Gate



Switching is at zero-crossing point (no current flowing)

TRIAC "fired" after each zero-crossing when enabled (red)

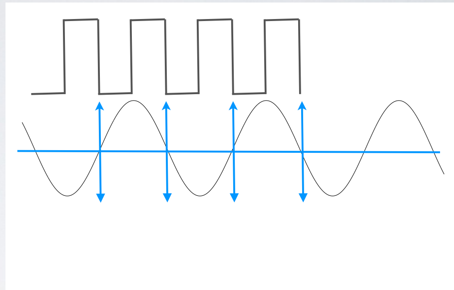
TRIAC always switches off at end of each half-cycle

Zero-loss switch - can be used for inductive loads, e.g. motors.

MAINS DIMMER - ZERO X

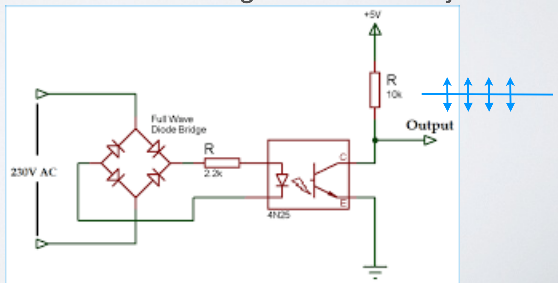
Zero-Crossing Sync

Mains Cycle

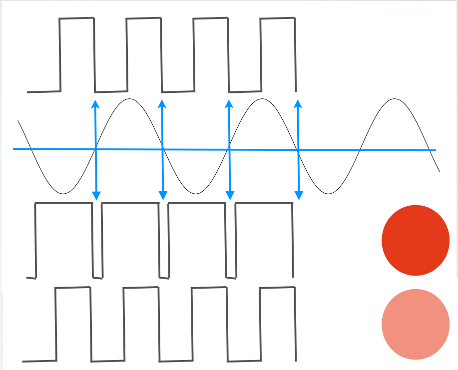


Switch-on is synchronised to zero-crossing of each half cycle

Example. simple circuit



MAINS DIMMER



A mains "dimmer" works at 100Hz (50 Hz mains)

Gate Trigger is a 100 Hz PWM signal aligned to crossing point

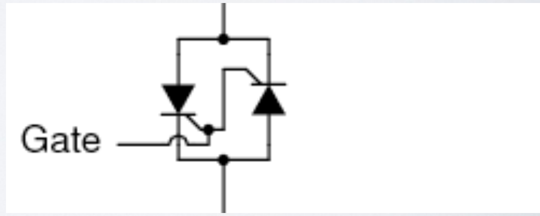
Varies the start time of the pulse that fires the power TRIAC

Dimmer suitable for non-reactive loads.

TRIGGERING THE TRIAC

The gate signal needs to be:

- Have a OV at the time of zero current
- Have an on voltage at the position in the mains cycle where the TRAIC is to fire
- The On-signal needs to rapidly force the TRIAC into conduction



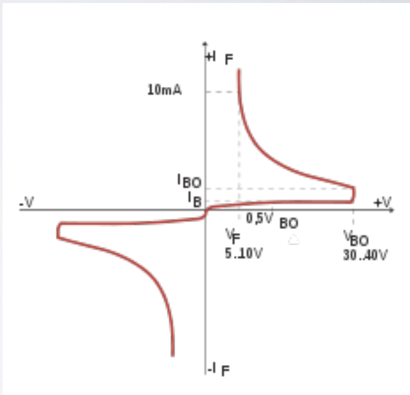
DIAC

A DIAC resembles two diodes combined for AC operation

Conducts ***only above*** a threshold

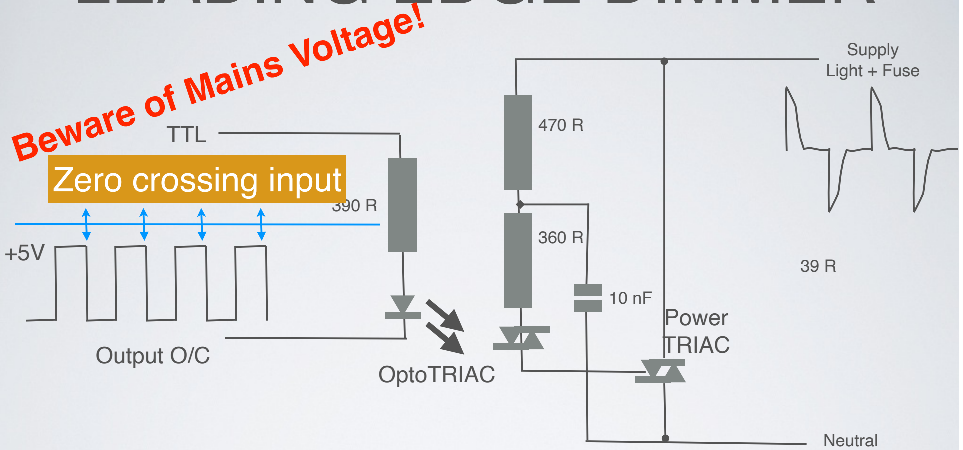
Opto-TRIACs are effectively a DIAC triggered by light level (from a LED)

Provides an easy way to reliably trigger a TRIAC gate



This effectively operates as a threshold voltage trigger

LEADING EDGE DIMMER



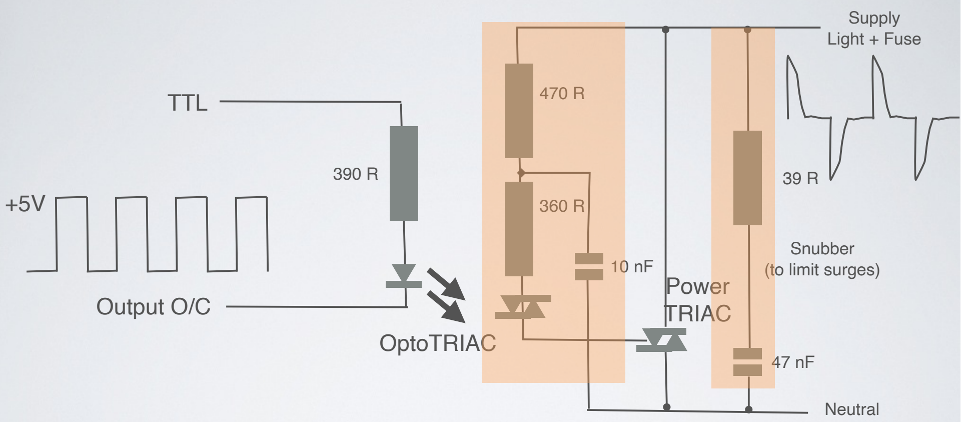
OptoTRIAC fires,

DIAC triggers at a threshold voltage

Dumping charge to the gate of the power TRIAC

TRIAC conducts once triggered, until supply returns to zero

RELIABLE TRIGGER



Snubber filters transients, preventing false triggers

10nF capacitor charges at start of cycle

Choke/Filter limits switching surges

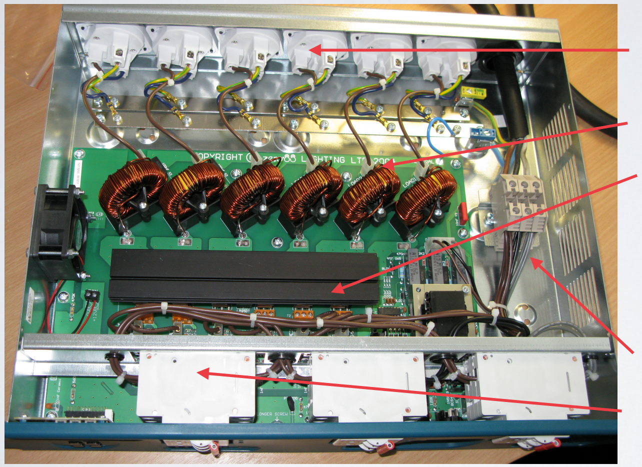
PROFESSIONAL DIMMER

Input: 3-Phase supply (3 x 32A)

Output: 6 Channel each at 10A (2 per phase)

Control: DMX (with RDM); CAN (ChilliNet)

PROFESSIONAL 6 CH



Output:

6 Channel at 10A

RF filter

Triac

Input:

2 Channel / phase

6 Circuit Breakers

Transfer Function -i.e. Dimmer Curve

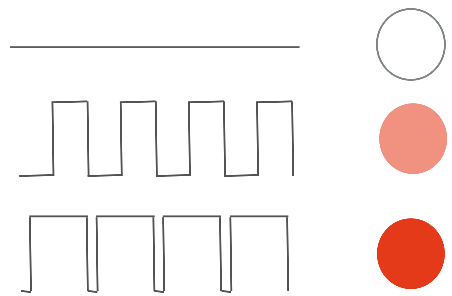
How does the microcontroller map a slot value to a fine signal for the TRIAC?

- Actually there are different possibilities: e..g one way:

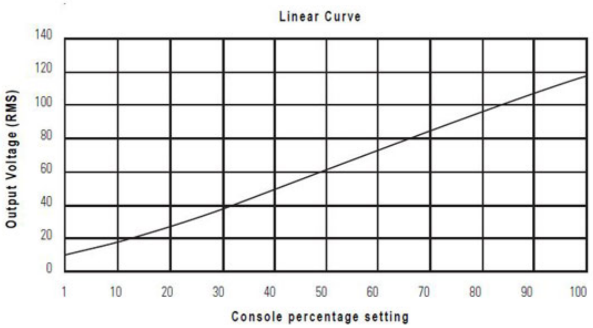
0x00
TRIAC Gate Trigger 0%

0x7F
TRIAC Gate Trigger 50%

0xF2
TRIAC Gate Trigger 95%



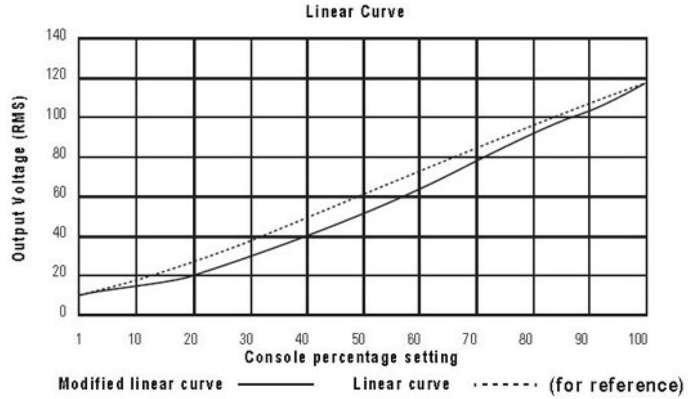
Linear



1:1 Ratio

Control input percentage to Root Mean Squared (RMS) voltage output

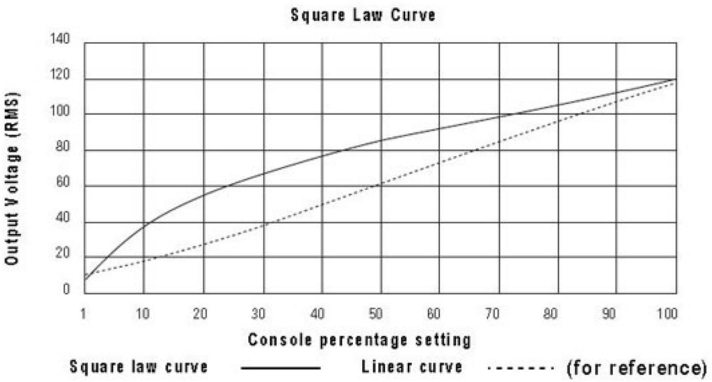
Modified Linear



Output does not have to be proportional to the control value.

Improved control at low levels for better performance in low-wattage fixtures.

Square law curve



Improved control at low values.

A square law curve applies a multiple derived from the square root of the control level (with full output equal to 1.00) to increase voltage response at low control levels to compensate for the infrared loss of an incandescent lamp.

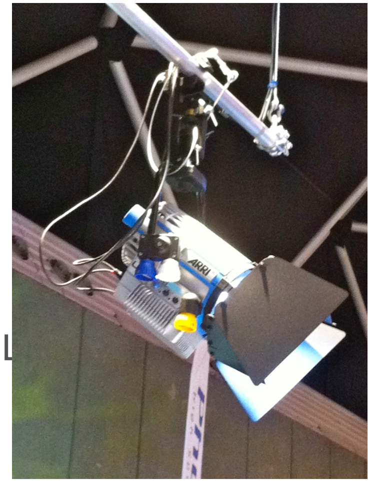
SUMMARY

- **We talked about:**
  - SCR, TRIACs, DIACs, OptoTRIAC
  - Firing Triac, Zero-Crossing synch, Snubber and Filters
- **TRIAC Control**
  - TRIAC Dimming Output (“random” turn-on within cycle)
  - TRIAC Switching Output (“ZC” turn-on at start of

LANTERNS
LENSES
& LUMENS

LIGHTING LEVEL

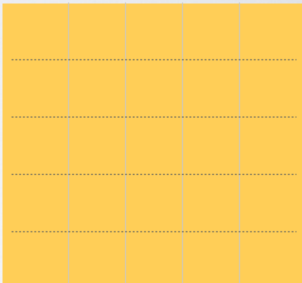
1 lux = 1 lumen per m^2



Moonless Night 0.004 Lux
Full Moon, clear night 1 Lux
Living Room 50 Lux
Office Lighting 500 Lux
Stage > 500 Lux
Overcast Day, TV Studio 1,000 L
Spotlight 2,000 Lux
Dull Daylight 10,000 Lux
Direct Sunlight 100,000 Lux

HOUSE LIGHTING LEVEL

- 100W Bulb - OK for a living room

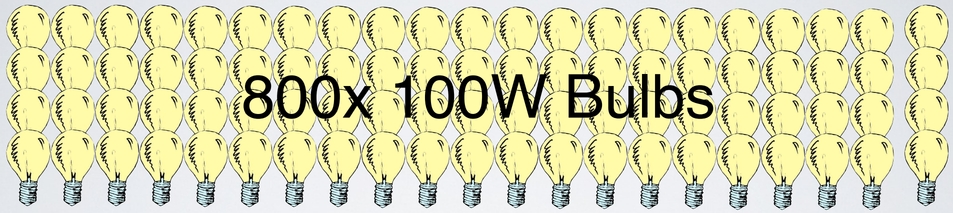


Target output 50 Lux

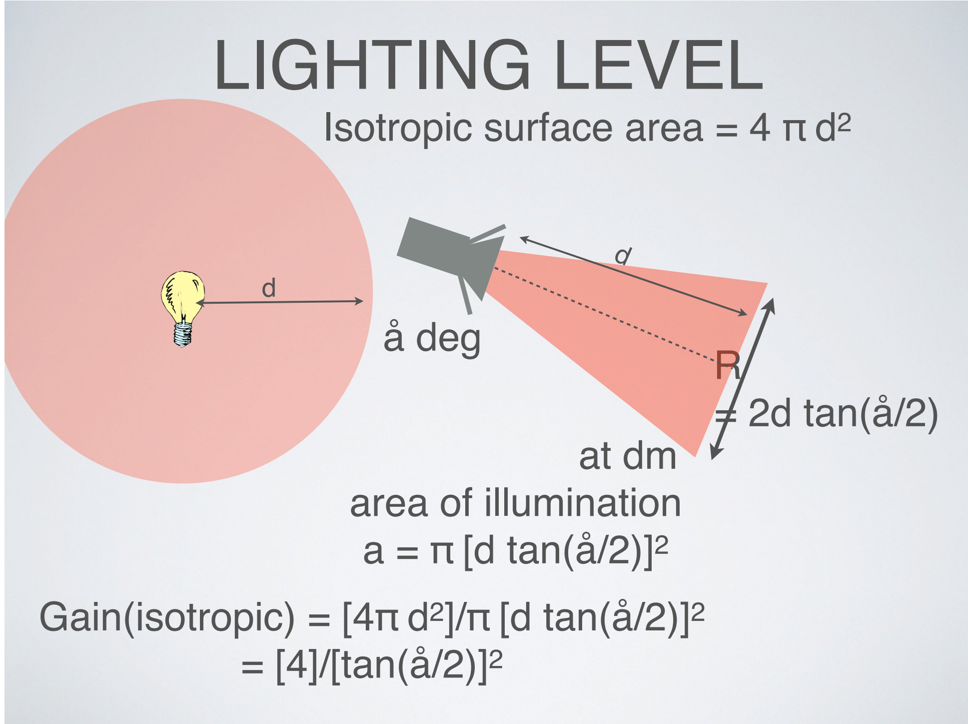
100W => 1200 lumens
Area = 5 x 4m = $20m^2$
Illumination = 1200/20 = 60 Lux

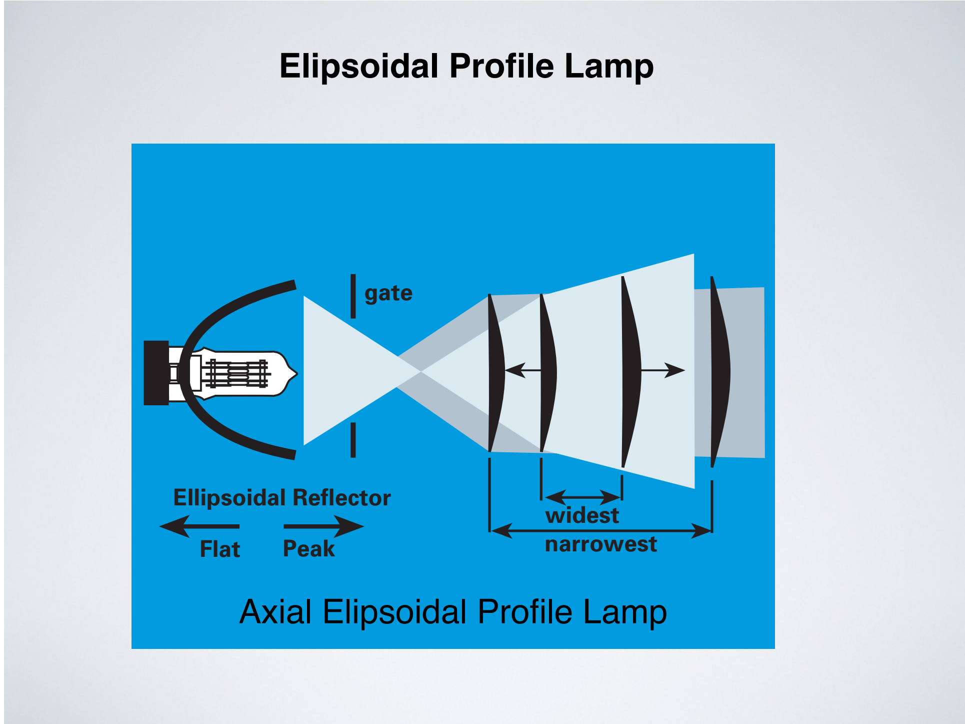
STAGE LIGHTING LEVEL

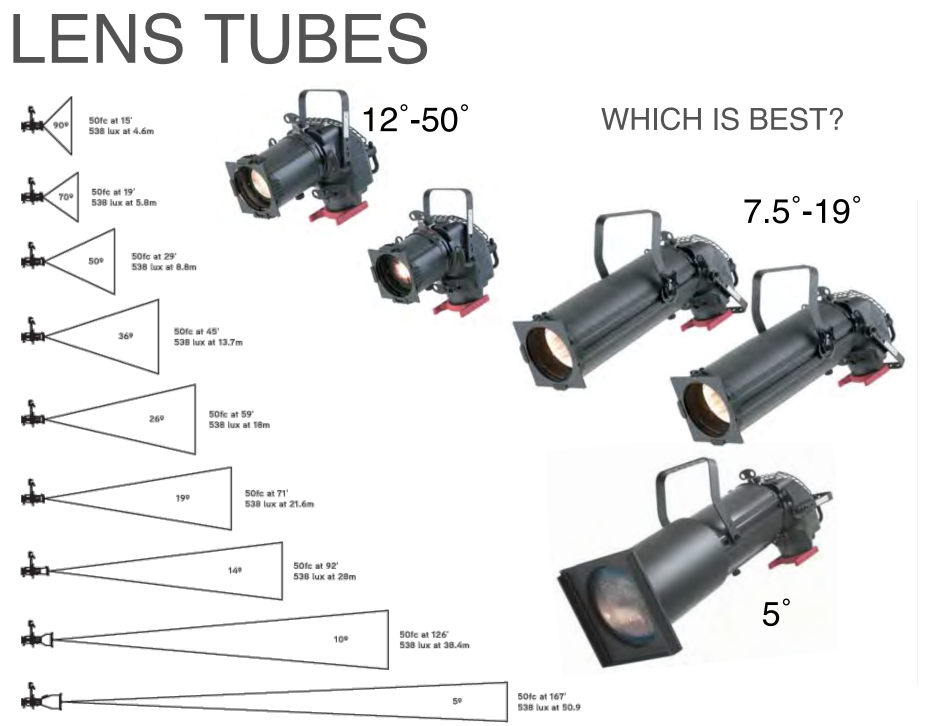
- How many 100W bulbs would I need for a stage 8x6m at 2000 Lux?

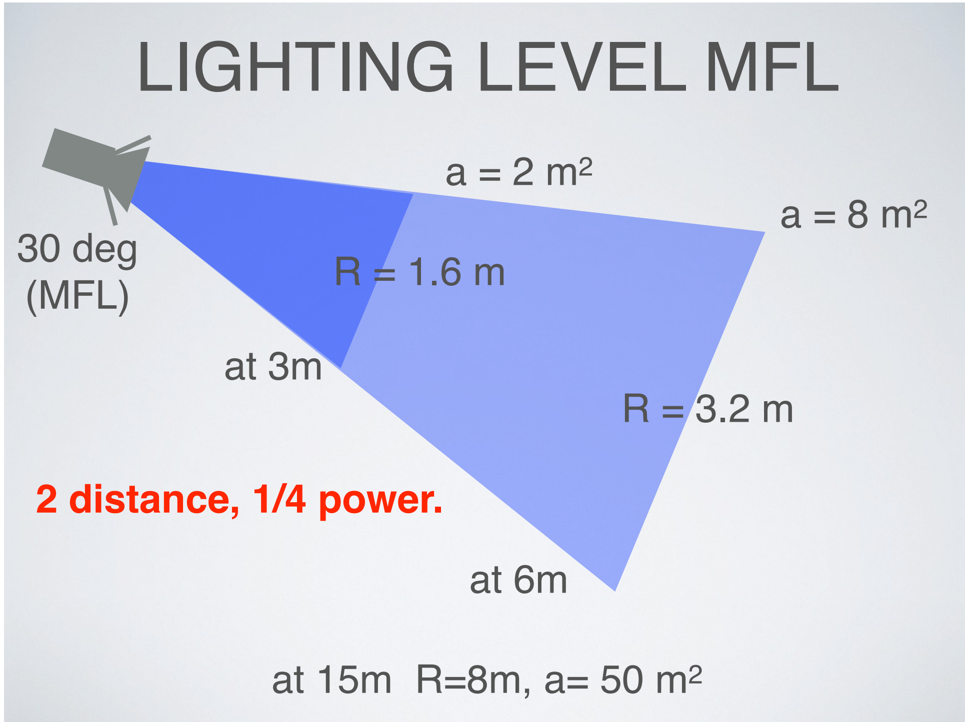


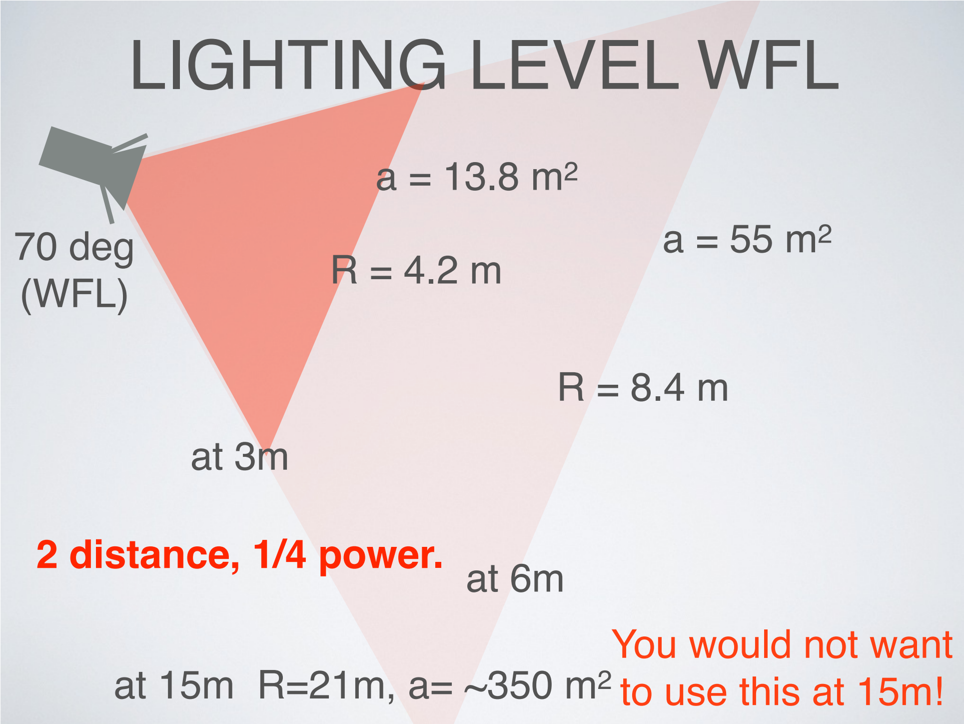
1000W Bulb 100,000 Lumen
Lens/Reflector focuses this on stage
Result 2000 Lux

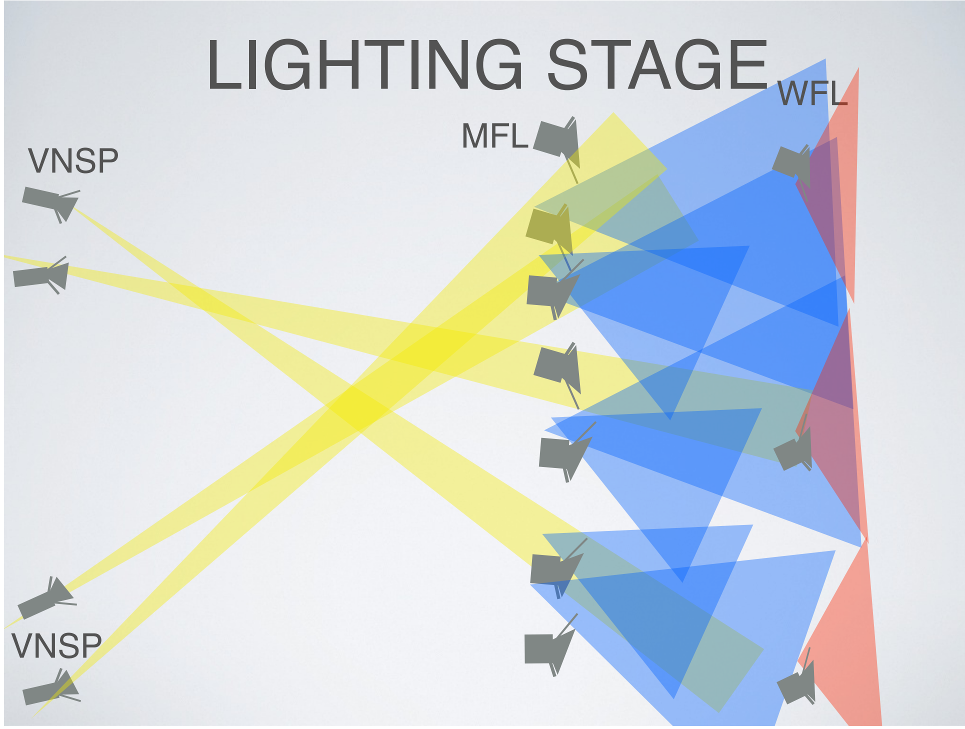

LIGHTING LEVEL
Isotropic surface area = 4 π d²
d
d
å deg
R
= 2d tan(å/2)
at dm
area of illumination
a = π [d tan(å/2)]²
Gain(isotropic) = [4π d²]/π [d tan(å/2)]²
= [4]/[tan(å/2)]²


Elipsoidal Profile Lamp
gate
Ellipsoidal Reflector
Flat
Peak
widest
narrowest
Axial Elipsoidal Profile Lamp

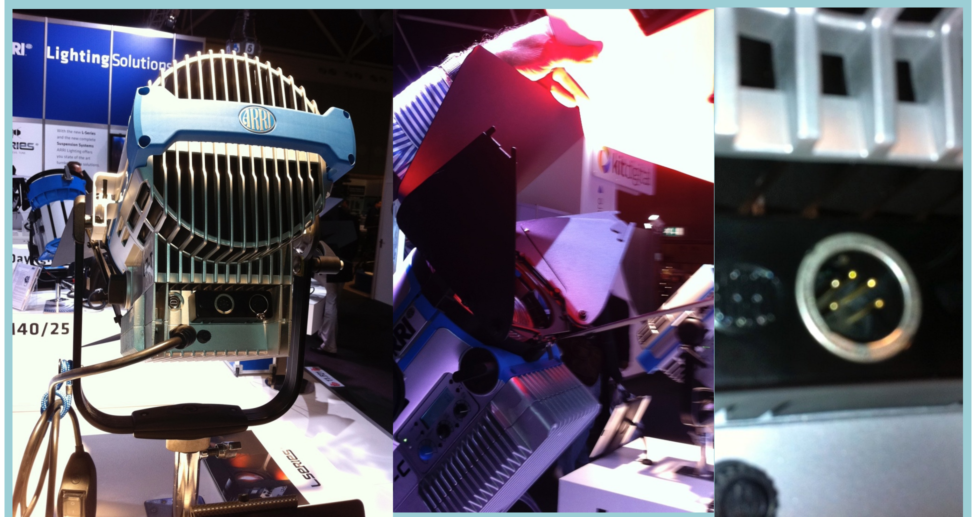

LENS TUBES
90º
50fc at 15'
538 lux at 4.6m
70º
50fc at 19'
538 lux at 5.8m
50º
50fc at 29'
538 lux at 8.8m
36º
50fc at 45'
538 lux at 13.7m
26º
50fc at 59'
538 lux at 18m
19º
50fc at 71'
538 lux at 21.6m
14º
50fc at 92'
538 lux at 28m
10º
50fc at 126'
538 lux at 38.4m
5º
50fc at 167'
538 lux at 50.9
12˚-50˚
WHICH IS BEST?
7.5˚-19˚
5˚


LIGHTING LEVEL MFL
a = 2 m²
a = 8 m²
30 deg
(MFL)
R = 1.6 m
at 3m
R = 3.2 m
2 distance, 1/4 power.
at 6m
at 15m R=8m, a= 50 m²





LEDS AND PWM



Module 6.4

LED DRIVERS

LEDs are non-linear: Power supply circuits for LEDs need to avoid thermal runaway - when LED junction heats, the LED junction resistance decreases - as they heat they draw more power!

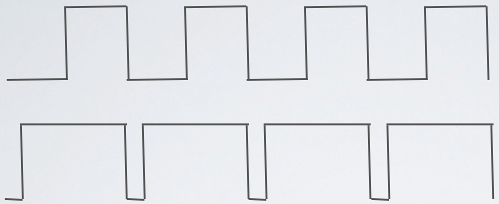
$$R_{ballast} = \frac{V_{in} - V_{forward}}{I_{LED}}$$

Simplest LED circuit uses a series ballast resistor
(significant for high power LEDs)
e.g. Vf =3.7V, I=300 mA
However, voltage drop across the ballast resistor wastes power!

Care is therefore needed to limit current for high-power LEDs

A constant current source is a better solution for high power

DIMMING LEDS: PWM



128 = 50%

230 = 90%

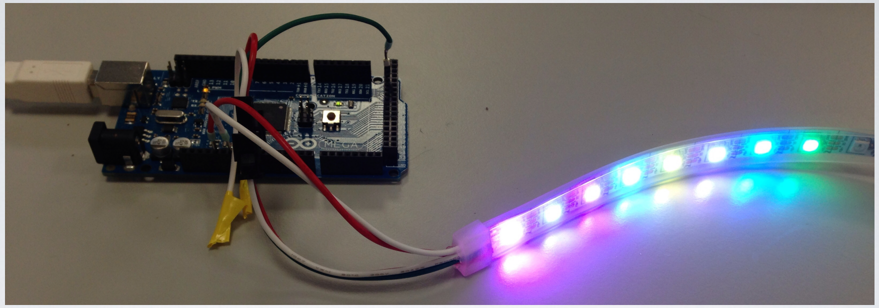
Uses a MOSFET in series with the LED string

Pulse Width Modulation used to control ***power*** of LED Lamp

Receivers interpret DMX slot value as ***Pulse Width Ratio***

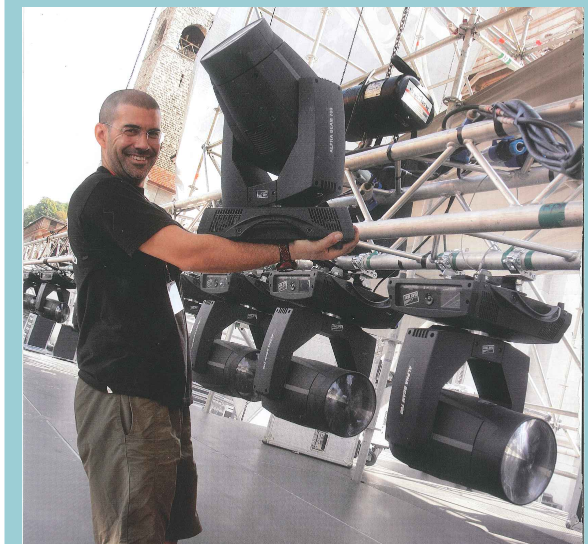
Pulses typically repeat at **kHz** rates for LEDs (re.g. 4kHz)

WS2812 LED PIXEL STRIP



Pixels are mounted along a tape.
Each pixel can be individually controlled with a value for the Red Green and Blue LEDs forming each pixel.
Power is fed to the tape to drive LEDs along with a control signal

FIXTURES



Module 6.3

MULTI-SLOT CONTROL

- Many receivers need more than one slot of control data
- Receiver needs to ensure the set of slots is consistent (use a flag to indicate if data is ready)

COLOUR LED DMX

Profile for 3 colour LED lamp

A	Red
A+1	Green
A+2	Blue

Profile for 7 colour LED lamp

A	Red
A+1	Amber
A+2	Lime
A+3	Green
A+4	Cyan
A+5	Bliue
A+6	Indigo

Each slots control one LED source

PAN/TILT SLOT VALUES

Device is tilted using stepper motors (or servos)

A simple” device uses a 8-bits for each value:

Maximum 255 (i.e. 1.4 degrees /step for 360 degrees)

n use a 16 bit value (a pair of two *consecutive* slots)

Maximum 64 k value (i.e. 0.005 degree /step)

A	Pan

1.4 degrees /step

A	Pan coarse
A+1	Pan fine

0.005 degrees /step

EIA-485 SIMPLEX EQUIPMENT BUS: CONTROL NETWORKS

Module 7.0

REPEATERS & REGENERATION

Module 7.1

LARGER APPLICATIONS

Digitally ***regenerates*** the signal

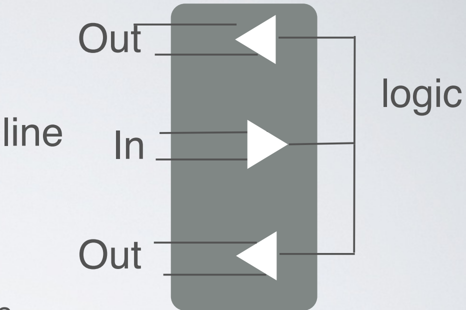
- All parts of the “Universe” see the ***same 512 DMX Slots***

Enables:

- Run cables > 300m

- Connect more than 32 devices within a single “DMX Universe”

SPLITTERS/REPEATERS



Splitters regenerate signal

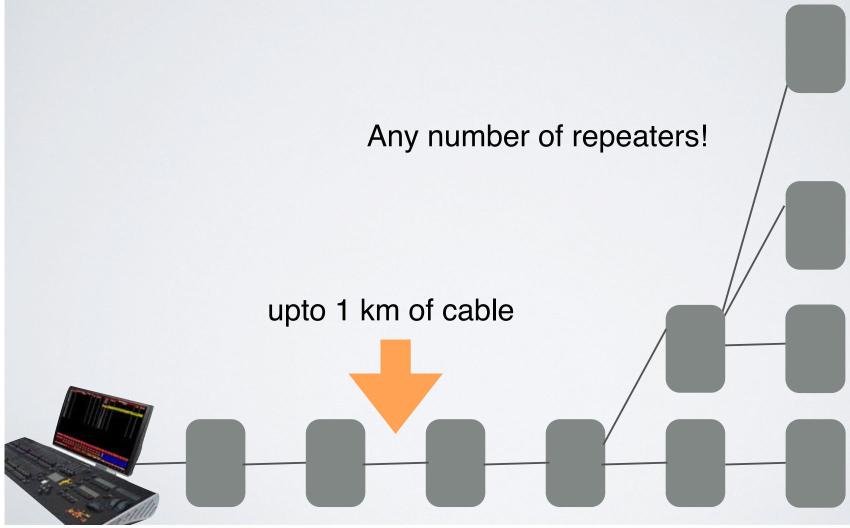
Simple for a unidirectional bus

Ground isolation (transmitter grounded)

Many splitters usually allow user to isolate specific output

More complicated for bi-directional links (e.g. RDM)

REPEATERS “REGENERATE”

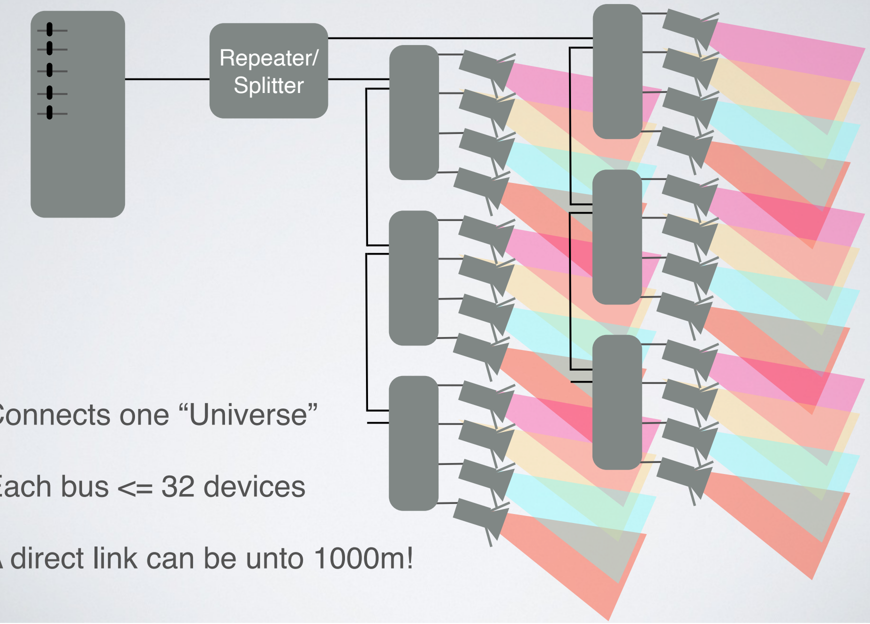


REGENERATION - NOT JUST FOR DR WHO

- Attenuation: 101101 101101 101101
- Noise: 101101 101101 101101
- Distortion: 101101 101101
- Result is signal degrades with ***distance***
- Regenerative repeaters enable operation at a ***distance***

101101 101101
101101 101101
101101 101101

SPLITTERS/REPEATERS



Connects one “Universe”

Each bus <= 32 devices

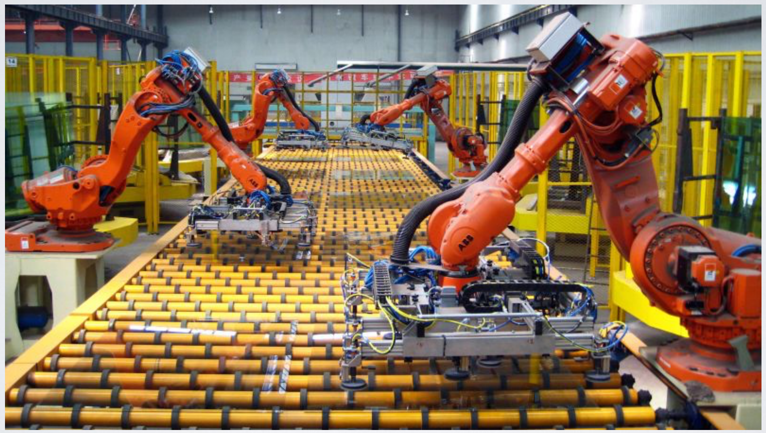
A direct link can be unto 1000m!

DESIGN SOLUTIONS:

(1) ROBOT PRODUCTION LINE
(40 ROBOTS, EACH WITH 6 X16 BIT SIMPLEX CONTROL WORDS)

(2) LIGHTING EDINBURGH CASTLE
(A DMX-BASED ARCHITECTURAL LIGHTING SYSTEM
1 X REMOTE CONTROL POINT 800M FROM MAIN REPEATER
1 X LOCAL CONTROL 100M FROM MAIN REPEATER)

(1) ROBOT PRODUCTION LINE



LIGHTING A CASTLE

(1 REMOTE CONTROL POINT 800M FROM MAIN REPEATER
LIGHTS ON MULTIPLE BUSSES

START CODES

Module 6.5

NETWORK TEST PACKET

Start Code = 0x55
All 512 data slots also carry value 0x55

A test frame be sent at any time.
It travels to all parts of the "universe".
It can be received by any DMX tester.
This can be used to discover any cable/repeater faults.
The start code 0x55 cause all ***normal*** receivers to ignore the frame

IDENTIFICATION OF UNIVERSE

If there is only one controller, it’s easy to plug into the correct cable bus.

As systems became more complex, people needed multiple buses. How do you know which receiver plugs into which cable?

We call each set of cables and equipment a “UNIVERSE”. Universes can be numbered.

MFID PACKET & SI PACKET

0x91 (145) MFID packet

first two slots contain a 16-bit Manufacturer-ID, remaining slots with proprietary data

0xCF (207) System Information packet (SIP)

- normally 24 slots containing various data in pre-defined fields

slot 1: Slot count (a.k.a. SIP Checksum Pointer) [default is 24]
slot 2: Control Bit Field
slot 3 & 4 Checksum of Previous Packet
slot 5: Sequence Number
slot 6: DMX Universe Number
slot 7: DMX Processing Level
slot 8: Software Version
slot 9 & 10: Standard Packet Length (a.k.a. Universe Size)
slot 11 & 12: Number of Packets sent since previous SIP
slot 13 & 14: Originating Device's MFID
slot 15 & 16: 2nd Device's MFID ...
slot 21 & 22: 5th Device's MFID

Universe identifies the bus

ID identifies

CHECKING RECEIVE DATA

Send data frame(s) (SC 00) followed by SI Packet (SC 207)

SI Packet contains data about the UNIVERSE

SIP identifies the Universe number

Can identify which equipment ***sent frame***

Can verify ***no SI Packets were lost*** (sequence number)

Count of how many frames since last SI Packet

Can verify ***no Data Packets were lost***

Count of how many frames since last SI Packet

Count of how many bytes per data frame (standard length)

MFID PACKET & SI PACKET

Also contain integrity check….

0xCF (207) System Information packet (SIP)

- normally 24 slots containing various data in pre-defined fields

slot 1: Slot count (a.k.a. SIP Checksum Pointer) [default is 24]
slot 2: Control Bit Field
slot 3 & 4 **Checksum of Previous Packet**
slot 5: Sequence Number
slot 6: DMX Universe Number
slot 7: DMX Processing Level
slot 8: Software Version
slot 9 & 10: Standard Packet Length (a.k.a. Universe Size)
slot 11 & 12: Number of Packets sent since previous SIP
slot 13 & 14: Originating Device's MFID
slot 15 & 16: 2nd Device's MFID ...
slot 21 & 22: 5th Device's MFID

Integrity check for previous frame

SUMMARY

Code	Meaning	Notes
0000 0000	Lighting Control Data	Default format
0101 0101	Network Test	All slots carry the same value
0001 0111	Text Packet	Simple text message
1100 1100	Remote Device Management	RDM Control/Response message
1100 1111	System Information Packet	Identifies a DMX Universe
1111 1111	Dimmer Curve Select	

https://tsp.esta.org/tsp/working_groups/CP/DMXAlternateCodes.php

EFFECT OF ERRORS

What happens if bauds become corrupted?

If any frame has detected errors ***the entire frame is ignored***

Some data errors could go un-noticed

A receiver might think everything is OK if slot data is corrupted

Each frame repeats all data slots values again in the next frame

Does it ***really*** matter if one frame is missed?

DMX MUST NOT be used for mission-critical applications

e.g. do not use for pyrotechnics or where lives might be at risk!

Control for Electromagnets

Control for Electromagnets

PROTECTING DATA

Send data frame (SC 00) followed by SI Packet (SC 207)

SI packet contains a CRC to detect errors ***within the SI Packet***

Can verify which equipment ***sent frame***

Can verify ***no SI Packets were lost*** (sequence number)

An SI packet also carries a CRC that covers the ***last data frame***

Only frames protected by a SI Packet are accepted by a receiver for a critical control application

HIGHER ASSURANCE (1)

How can we use what we know to make a safe design?

Receiver needs to be designed to have a very low chance of accepting a corrupted frame.

Here is one way:

Normally the receiver is disabled

The first step explicitly activates the receiver for a short period of time (called "arming")

The second step sends a command to the armed receiver

All frames are protected by CRCs.

HIGHER ASSURANCE (2)

Send a sequence of 4 frames:

- Frame (SC 00) to “ARM” receiver 4.5-5 seconds before use
- Followed by SI Packet (SC 207), protecting the “ARM”
- Frame (SC 00) with slots to “FIRE” an “ARM”ed receiver
- Followed by SI Packet (SC 207), protecting the “FIRE”

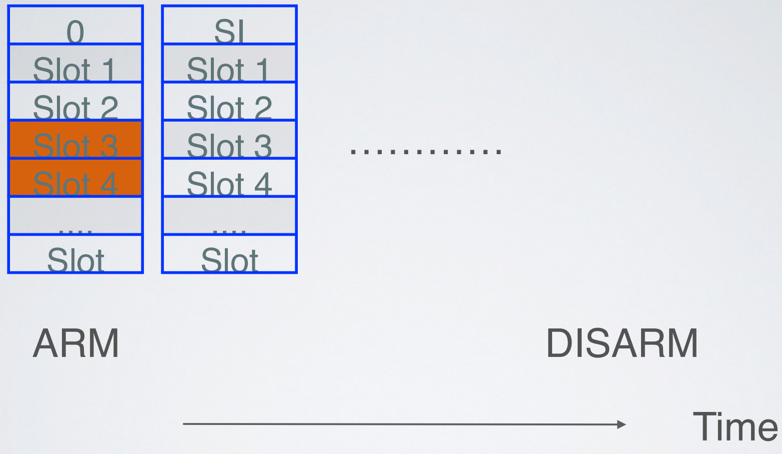
Receiver:

Only accepts frames followed by a valid SI Packet.

Only accepts a “FIRE” when “ARM” previously received *within* 4.5-5 seconds, otherwise it disarms itself.

Some “visible” indicator could show the “armed” units, allowing an operator to cancel the “fire” command if not appropriate.

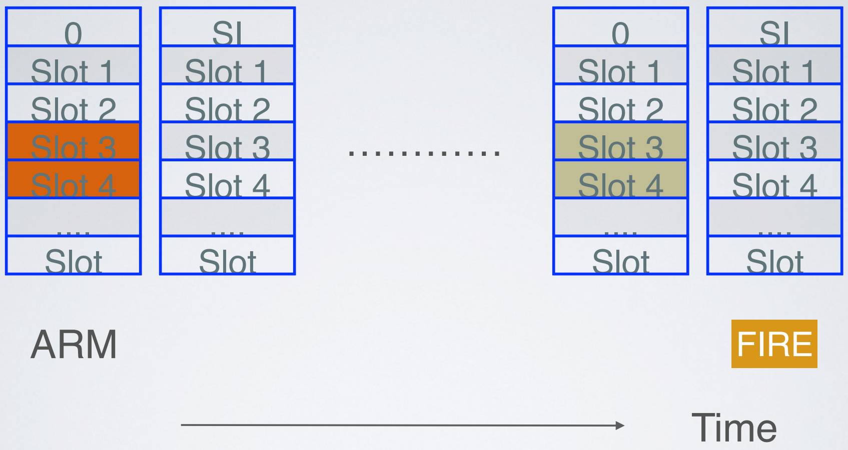
HIGHER ASSURANCE (3)



Receiver armed ***only when next SIP says it is valid***

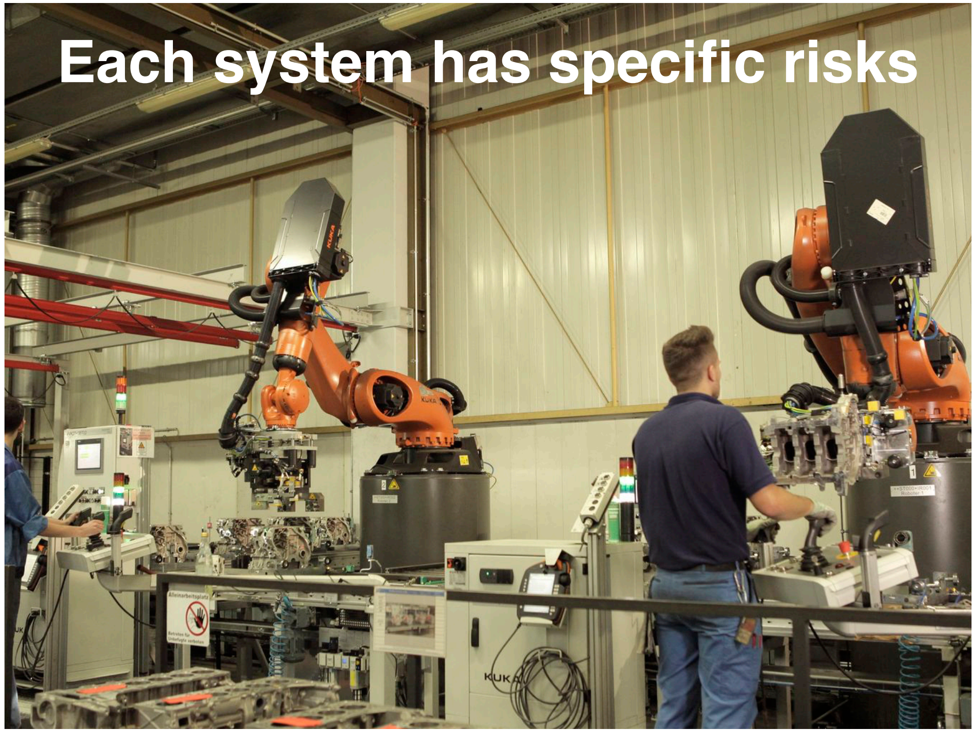
Fails safe if no command received

HIGHER ASSURANCE (4)



Receiver armed then receives the Fire Command

If both verified correctly the action is taken!



CAREFULLY WRITE ABOUT YOUR **RESULTS**

How accurate was the measurement?
If we look for a cat, it is either there or not...
If we have a picture that shows a cat, there may be doubt?

Examine the accuracy:
- How accurately can you really measure?
- How repeatable is the result?

Be careful about describing your results:
- What did you measure? (what units??)
- How many figures of accuracy should you cite?
- Are your results within a referenced norm for the measurement?

BE MINDFUL OF THE ORIGINS OF **IDEAS**

The more we focus on our ideas in a way that systematically ignores their objective origins, the more unreliable those ideas become...

Examine our sources
- How do we know our facts are trusted? who says so?

Provide evidence at multiple levels:
- Primary sources - Published International Standards
- Secondary sources - Reviewed papers, Books, etc (explanation...)
- Supporting sources - product data; web pages; etc (how...)

EXAMPLES

If you measure the baud rate as 9601 bps
- What is the expected nominal rate?
- How accurately can you measure?
- Is this variation acceptable

If you measure 12.001 volts
- What is the expected nominal rate?
- How accurately can you measure?
- Is this variation acceptable

Take care in how you state your conclusions

ASSIGN YOUR MARK

Marking Checklist

END