Lecture 10: Ethernet PHY Layer & Wiring

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Classical Ethernet (10 Mbps)

- Classical Ethernet (e.g., 10Base-5 thick coaxial, 10Base-2 thin coaxial, 10Base-T twisted pair) is mostly obsolete .
- Common standards nowadays are Fast Ethernet and Gigabit Ethernet (GbE).
- Classical Ethernet used Manchester encoding.
- *Advantage*: Self-clocking code for any sequence of 1's and 0's, which allows the PLL at the receiver to work properly at all times (after preamble).
- *Disadvantage*: Bandwidth = $2f_0 = 2 \times 10 = 20$ MHz.
- Fast Ethernet and Gigabit Ethernet do NOT use Manchester encoding since they would then require a bandwidth of 200 MHz and 2000 MHz, respectively.

Fast Ethernet (100 Mbps)

- Fast Ethernet was standardized as **IEEE 802.3u**.
- Approved by IEEE in 1995 as an addendum to the IEEE 802.3 standard.
- Fast Ethernet is backwards compatible with Classical Ethernet: Uses the same frame format (with minimum and maximum frame lengths), same 48-bit MAC address structure and same CSMA/CD rules.
- The main difference is that bit time is reduced from 100 ns to 10 ns.
- In Fast Ethernet, only twisted pairs and optical fibers are allowed (not coaxial cable).
- Half-duplex (with hubs) and full-duplex (with switches) modes are possible.

Main Variants of Fast Ethernet

Name	Cable	Max. Segment	Comments
100 Base-TX	UTP **(CAT 5)**	100 m	Half-duplex or Full-duplex
100 Base-FX	**Fiber** optics	2000 m	Full-duplex only; long runs

- CAT 5 (Category 5) cable has 4 pairs (8 wires) of copper. Replaces the older CAT 3 cables.
- Each pair in CAT 5 can carry a bandwidth of about 125 MHz for about 100 m distance.
- To send bits on 100 Base-TX:
- 4B/5B followed by MLT-3 line encoding.
- As an example of 4B/5B encoding, let us encode the data stream 0111010000100000.

4B/5B Encoding

	0	1	2	3	4	5	6	7
4-bit Nibble	0000	0001	0010	0011	0100	0101	0110	0111
5-bit Code	11110	01001	10100	10101	01010	01011	01110	01111

	8	9	10	11	12	13	14	15
4-bit Nibble	1000	1001	1010	1011	1100	1101	1110	1111
5-bit Code	10010	10011	10110	10111	11010	11011	11100	11101

Data stream:	**0 1 1 1 0 1 0 0 0 0 1 0 0 0 0 0**			
4 bit nibbles:	0111	0100	0010	0000
5-bit stream:	01111	01010	10100	11110

- Avoids a long sequence of consecutive 0's in MLT-3.
- Bandwidth = $0.9 \times f_0 = 0.9 \times 5/4 \times 100 = 112.5$ MHz

4B/5B Encoding

Data (Hex)	Data (4-bit Nibble)	5-bit code
0	0000	11110
1	0001	01001
2	0010	10100
3	0011	10101
4	0100	01010
5	0101	01011
6	0110	01110
7	0111	01111

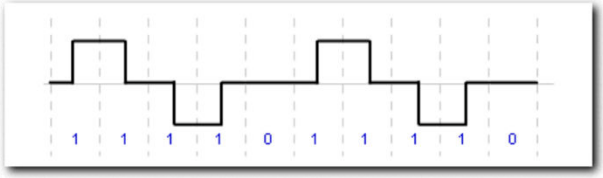
Data (Hex)	Data (4-bit Nibble)	5-bit code
8	1000	10010
9	1001	10011
A	1010	10110
B	1011	10111
C	1100	11010
D	1101	11011
E	1110	11100
F	1111	11101

Control character	5-bit symbols	Purpose
JK	11000 10001	Sync, Start delimiter
I	11111	100BASE-X idle marker
TR	01101 00111	100BASE-X end delimiter
HH	00100 00100	HDLC0
HI	00100 11111	HDLC1
HQ	00100 00000	HDLC2
RR	00111 00111	HDLC3
RS	00111 11001	HDLC4
QH	00000 00100	HDLC5

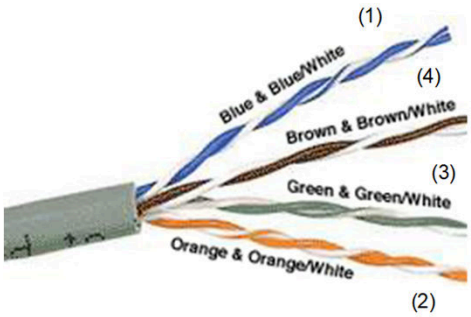
4B/5B encoding with MLT-3

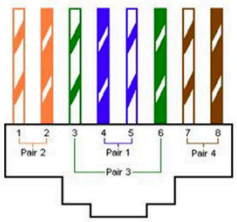
- When applying 4B/5B encoding before MLT-3, we ensure transitions occur even when a long series of 0's are sent.
- As an example let us encode the data stream 0 0 0 0 0 0 0 0.

Data stream:	**0 0 0 0 0 0 0 0**	
4 bit nibbles:	0000	0000
4B/5B Stream:	11110	11110
MLT-3 Stream:	+0-00	+0-00



100Base-TX Wiring

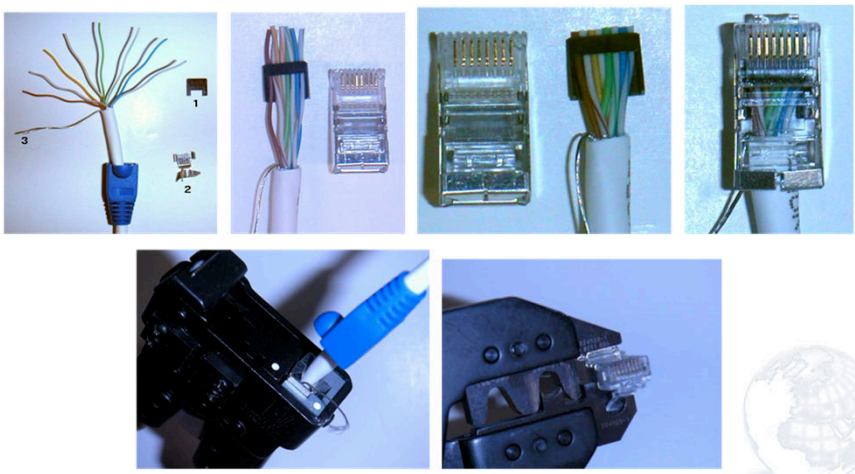




Standard EIA/TIA T568B Wiring Diagram

RJ-45 Connector

How to create Cat-5 or Cat-6 cable (straight-through or crossover)



What you need…

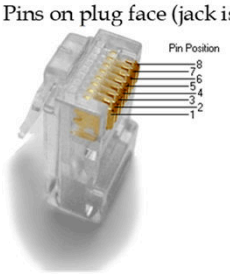
RJ45 Crimper

CAT-5 Tester

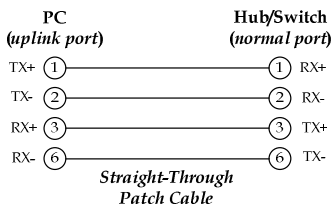
Ethernet Ports and Cables

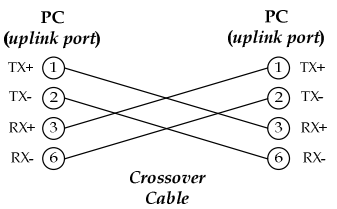
- An Ethernet **Cable** can be:
  - Straight-Through (or Patch) cable.
  - Crossover cable.
- An Ethernet **Port** can be:
  - Uplink Port (TX on 1 & 2) (sometimes called WAN port).
  - Normal Port (TX on 3 & 6) (sometimes called LAN port).

Pins on plug face (jack is reversed)



Uplink Port	*Normal Port*
TX+ 1	1 RX+
TX- 2	2 RX-
RX+ 3	3 TX+
RX- 6	6 TX-





Note:
Pins 4, 5, 7 and 8 are not used

Pin number	Wire Color
Pin 1 ==>	Orange/White
Pin 2 ==>	Orange
Pin 3 ==>	Green/White
Pin 4 ==>	Blue
Pin 5 ==>	Blue/White
Pin 6 ==>	Green
Pin 7 ==>	Brown/White
Pin 8 ==>	Brown

Straight-Through

Wire	Becomes
1	1
2	2
3	3
6	6

Pin number	Wire Color
Pin 1 ==>	Orange/White
Pin 2 ==>	Orange
Pin 3 ==>	Green/White
Pin 4 ==>	Blue
Pin 5 ==>	Blue/White
Pin 6 ==>	Green
Pin 7 ==>	Brown/White
Pin 8 ==>	Brown

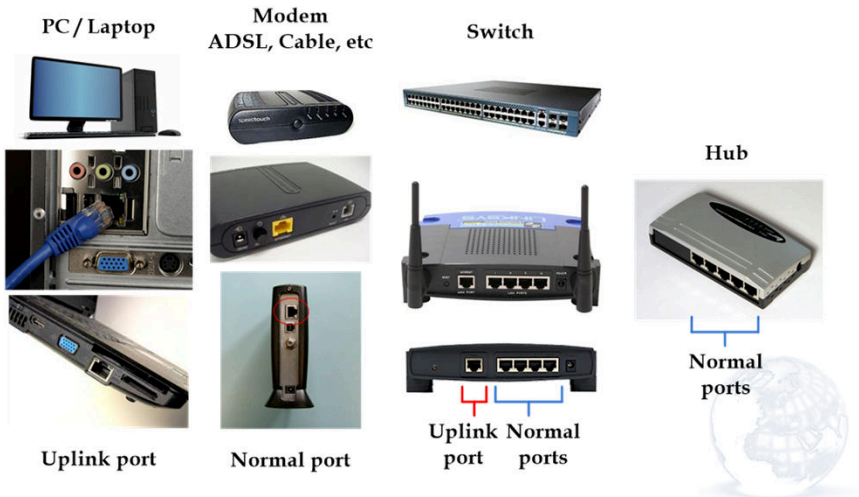
Pin number	Wire Color
Pin 1 ==>	Orange/White
Pin 2 ==>	Orange
Pin 3 ==>	Green/White
Pin 4 ==>	Blue
Pin 5 ==>	Blue/White
Pin 6 ==>	Green
Pin 7 ==>	Brown/White
Pin 8 ==>	Brown

Crossed-Over

Wire	Becomes
1	3
2	6
3	1
6	2

Pin number	Wire Color
Pin 1 ==>	Green/White
Pin 2 ==>	Green
Pin 3 ==>	Orange/White
Pin 4 ==>	Blue
Pin 5 ==>	Blue/White
Pin 6 ==>	Orange
Pin 7 ==>	Brown/White
Pin 8 ==>	Brown

Ethernet Ports



Ethernet Ports *Continued*

Switch / Router Combo
(Multilayer switch)
(L2 and L3 switch)

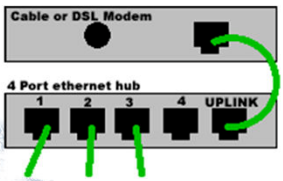
Normal ports (some Uplink)

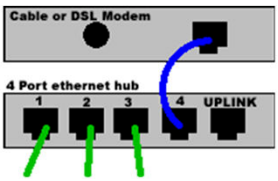
Router
(Integrated Services)

Uplink ports

Ethernet Connections

- Exercise 1: What type of cable do you use to connect a normal port of a switch to a normal port of another switch or switch/router combo?
- Exercise 2:





Features of Switch Port

- **Auto-sensing:** Automatically sense (negotiate) data rate (100 or 1000 Mbps, etc).
- **Auto-configure:** Automatically negotiate duplexity (half- or full-duplex) using a short circuit in the port (called *loopback*).
- **Auto-uplink:** Automatically adjust the port into normal or uplink port, using built-in analog switches. Also called Auto-MDIX (MDIX: media-dependent interface crossed).

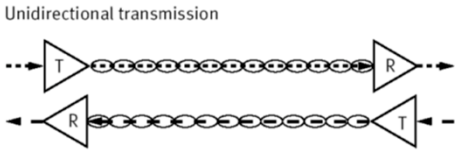
Exercises

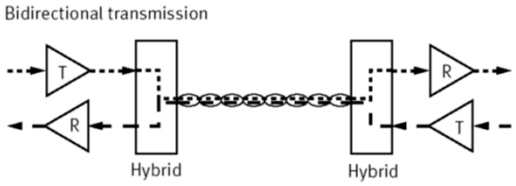
- Modem to a PC/Laptop?
- PC to an Ethernet switch?
- Modem to an Ethernet switch?
- Ethernet core switch to aggregation switch?
- Ethernet core router to aggregation switch?
- PC to PC (If Auto-uplink on one or both of them? If no Auto-uplink but Autoconfig on both? If no Auto-uplink and no Autoconfig)?
- PC to an Ethernet Hub?

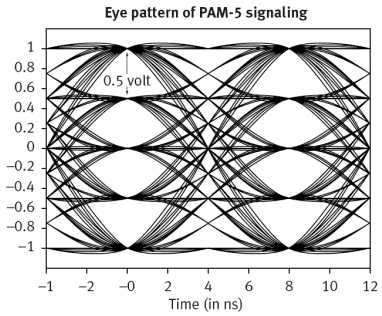
Gigabit Ethernet (GbE) (1000 Mbps or 1 Gbps)

- Gigabit Ethernet was standardized as IEEE 802.3z.
- Ratified by IEEE in 1998.
- Backwards compatible with previous Ethernet standards.
- 1000Base-T is IEEE 802.3ab.

Name	Cable	Max. Segment	Comments
1000 Base-T	**UTP**	100 m	Deployed CAT 5e or CAT 6 UTP.
1000 Base-SX	**Fiber** optics	550 m	Multimode fiber.
1000 Base-LX	**Fiber** optics	5 km	Single or Multimode fiber.
1000 Base-LH	**Fiber** optics	10 km	Single mode fiber.



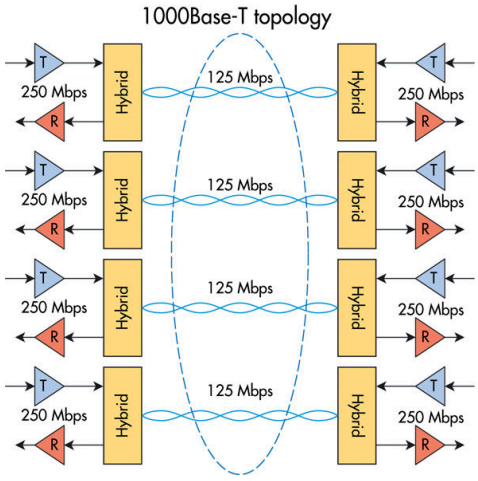




1000Base-T Encoding

- Uses 8B1Q4 (8-bit to 1 four quinary "five" symbol) combined with 4D-PAM5 (Four-dimensional Pulse Amplitude Modulation 5-levels) encoding method.
- 8B1Q4: divide each group of 8 bits into four 2-bit groups. Each 2-bit group is converted to a 3-bit group to allow for forward error correction. Each 3-bit group is called a quinary symbol.
- The quinary symbols are then line encoded using 4D-PAM5, where each 3-bit group is mapped into one of five possible voltage levels through a non-trivial linear feedback shift register. The mapping varies continuously during transmission. Four symbols are transmitted in parallel in each symbol period.
- A total of 125 Msymbols (4D-PAM5 symbols) is sent per second over the four pairs. This translates into a total of 8 bits per symbol x 125 Msymbol/s = 1000 Mbps for the cable.

1000Base-T



10 Gigabit Ethernet (10GbE)

The following three varieties use the LAN PHY:

Name	Max. Segment	Comments
10GBASE-SR	26 m – 82 m	*Short Range* over deployed multi-mode fiber.
10GBASE-LR	10 km	*Long Range* over single-mode fiber (1310 nm).
10GBASE-ER	40 km – 80 km	*Extended Range* over single-mode fiber (1550 nm).

The following use the WAN PHY, designed to interoperate with OC-192/STM-64 SDH/SONET equipment using a light-weight SDH/SONET frame.

Name	Max. Segment	Comments
10GBASE-SW	26 m – 82 m	*Short Range* over deployed multi-mode fiber.
10GBASE-LW	10 km	*Long Range* over single-mode fiber (1310 nm).
10GBASE-EW	40 km – 80 km	*Extended Range* over single-mode fiber (1550 nm).

10GBASE-T (IEEE 802.3an)

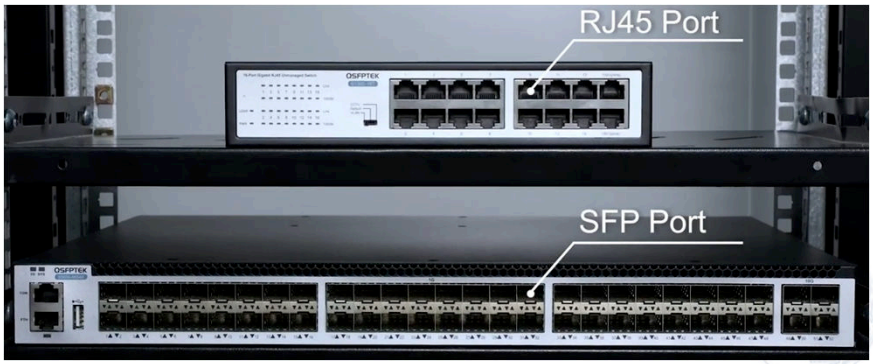
- IEEE 802.3an was released in 2006.
- 10 Gbps over UTP or STP cable over distances up to 100 m.
- Uses Cat-6A (or Cat-7) cable, or 55 m with older Cat-6 cables. Cat-6A has bandwidth of 500 MHz per pair.
- Encoding: 64B/65B then Tomlinson-Harashima precoded (THP) version of pulse-amplitude modulation with 16 discrete levels (PAM-16), encoded in a two-dimensional checkerboard pattern known as DSQ128 (Double Square 128).
- Powerful low-density parity-check (LDPC) linear error correcting code.
- IEEE 802.3cu (released Feb 2021) defines 100 Gbit/s (100GbE) & 400 Gbit/s (400GbE) over single-mode fiber.
- Scheduled for mid 2024 is support for 800 Gb/s and 1600 Gb/s (i.e., 1.6 Tb/s) using multiple lanes.

Intermediate Step

- Electronics (transistors) running at 10 GHz are still expensive.
- The need for newer Cat-6A cable means new investment in infrastructure.
- To allow for cheaper hardware and re-use of older cables, intermediate standard (IEEE 802.3bz-2016) was introduced with two *now popular* data rates:
- 2.5GBASE-T: Supports 2.5 Gbps on Cat 5e UTP (4 pairs) using 64B/65B PAM-16 128-DSQ encoding (about 100 MHz bandwidth used on each pair).
- 5GBASE-T: Supports 5 Gbps on Cat 6 UTP (4 pairs) using 64B/65B PAM-16 128-DSQ encoding (about 200 MHz bandwidth used on each pair).

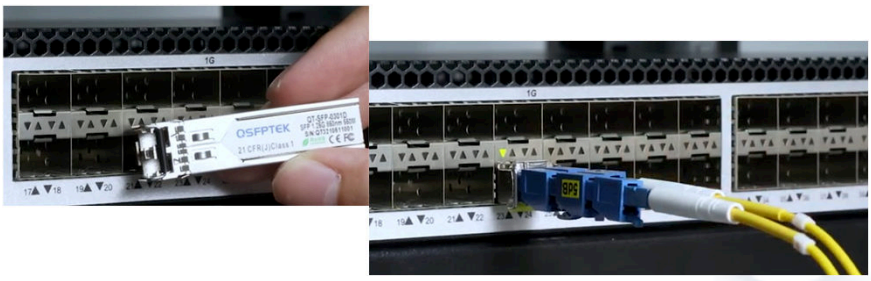
RJ45 vs. SFP Port

- SFP (Small Form-factor Pluggable): compact, hot-pluggable network interface module.



SFP & SFP+

- Allows media-specific transceiver: multi-mode fiber, single-mode fiber, copper cable.
- Advantages: Individual ports can be equipped with different transceivers types as required; transceivers can be replaced in future when needed.



Upgrading your Infrastructure