Physical Layer

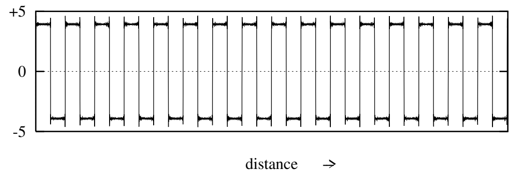
Overview:

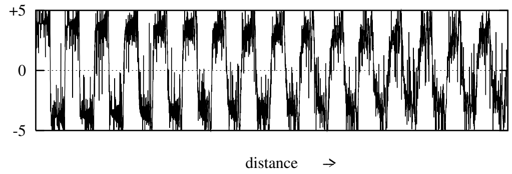
- Talk about theoretical upperbounds on what can be transmitted through a wire.
- Talk about wires (sounds a bit boring...it really isn't that bad).
- Talk about leaving the wires out.
- Talk about telephones and what the PTT has come up with.

Transmitting Signals

- We're living in a digital world, meaning that we'd preferably want to send digital (i.e. two-valued) signals through wires.
- Wires are pretty much physical, meaning that Mother Nature will probably impose a few constraints here and there.

What's the problem? Signals are not entirely transmitted through a wire as you would expect:



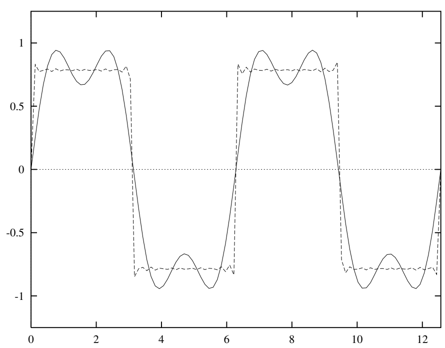


Fourier Analysis

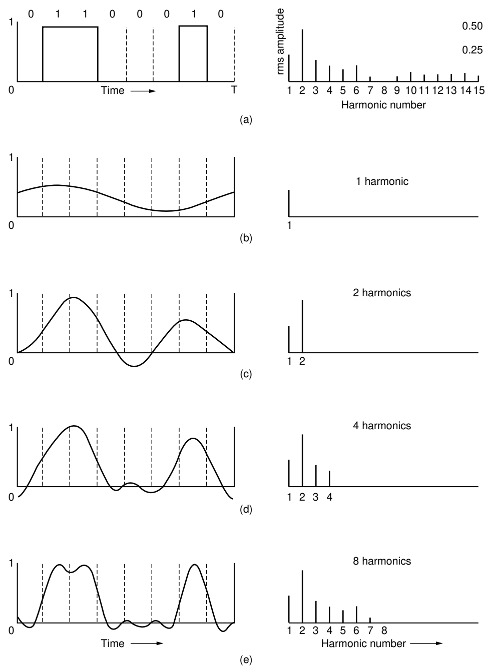
To understand what's going on, we need **Fourier Analysis**. A periodic function with period T (and frequency $f = 1/T$) $g(t)$ can be written as:

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

Example: $g(t) = \sum_{k=1}^{n} \frac{1}{2k-1} \sin[(2k-1)t]$



Fourier Analysis II



Note: root mean squares (on the right) reflect the dispersed energy at the given frequency.

Bandwidth etc.

What does this all mean?

- Digital signal transmission can be thought of as being constructed by an infinite number of periodic analog signals.
- The quality of transmission is frequency dependent $\Rightarrow$ not all parts of the digital signal get through the wire as you'd expect.
- Digital signal transmission is subject to attenuation, distortion, etc. This is partly caused by disallowing high-frquency components to pass through (**bandwidth**).

Example:

- With a bit rate of b bits/sec, it takes $8/b$ seconds to send a byte. The frequency f_1 of the first harmonic is $b/8$ Hz.
- Telephone lines cut off frequencies at 3000 Hz.
- Number of highest harmonic is $3000/f_1 = 24,000/b$...

Bandwidth etc. II

Great: telephone lines will allow at most 9600 bps!

Assumption: We are using a simple encoding technique based on the fact that the line supports only two signal values.

Improvement: If there are four signal values available, we could encode 2 bits at a time:

$$00 \to 0 \text{ volt} \quad 01 \to 2 \text{ volt}$$
$$10 \to 4 \text{ volt} \quad 11 \to 6 \text{ volt}$$

This is called the **baud**. A 2400 bauds line (modem) can make a bit rate of 9600 bps provided it uses 16 signal values.

Finally: what should the receiver do? Nyquist showed that if the cut-off frequency is H Hz, the filtered signal can be reconstructed by making $2H$ samples. No more, no less.

Shannon showed that a *noisy* channel has a limit with respect to the bit rate. For example, a telephone line can do no better than 30 kbps, no matter how you do your encoding (excluding compression).

Transmission media - magnetic tape

> *Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway*

- Take a standard videotape that can carry about 7 gigabytes of data.
- A box of $50 \times 50 \times 50$ cm can hold about 1000 tapes, which corresponds to 7000 gigabytes.
- Sending such a box can be done within 24 hours, worldwide.

We've got a transmission rate of 648 Mbps. That's better than what they're planning with ATM!

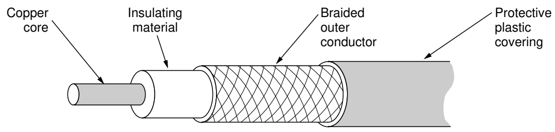
What's the snag here?

Copper wires

Twisted pair: two insulated copper wires, twisted like a DNA string (reduces electrical inference). Often, twisted pairs go by the bundle. Comparable to telephone wiring at home.

Further distinction between shielded (STP) and unshielded (UTP) versions.

Coax cable: exactly like the one you use for your TV Set:

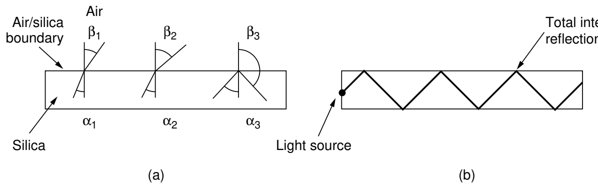


Coax is better than TP when you need more bandwidth, but is now rapidly being replaced with fiber.

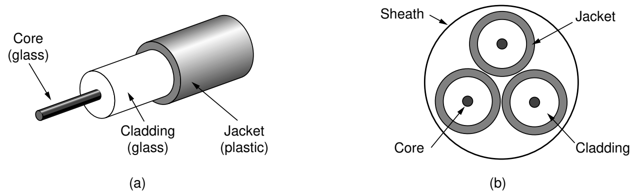
Fiber optics

Rather than using electrical signals, we use optical ones that are passed through otical fiber.

Principal working is based on the refraction property of light:



As it turns out, attenuation is extremely well in optical fiber. This means that they can be used for long distances. In addition, the bandwidth is enormous.



Optical Fiber vs Copper Wire

Bandwidth: Fiber can support enormous bandwidths, exactly what we need with upcoming image-based applications (video-on-demand).

Attenuation: Because the attenuation in fiber is less than in copper (can you imagine why?), we don't need to boost the signal as often. In practice, fiber requires an *active repeater* every 30 km, copper every 5 km.

External influences: That's right, no more interference from other cables, radios, power failures, etc. Crosstalk (you hearing another conversation) is out of the question.

Weight: Fiber simply doesn't weigh as much. Good for backs, bones, and the use of heavy maintenance equipment.

Wireless Transmission

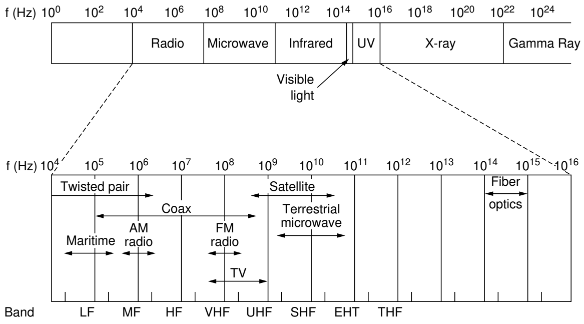
Wireless transmission is really great for all of us who can't sit still, or feel they have to be on-line all the time (watch it – you may miss something). It's also convenient when wiring is needed where it can't be done, or isn't really worth the trouble (jungles, islands, mountains).

Wireless transmissions travel at the speed of light (c), uses a frequency (f) which has a wavelength (λ):

$$c = \lambda \cdot f$$

The larger the wavelength is, the longer the distance it can travel without attenuation. Also, the dispersion of higher frequencies is much lower.

Wireless Transmission II



Note: we can encode only a few bits per Hertz in the low frequency range, but much more in the higher ranges. This means that wireless transmission will generally have a much lower bandwidth (in practice: 1-2 Mbps).

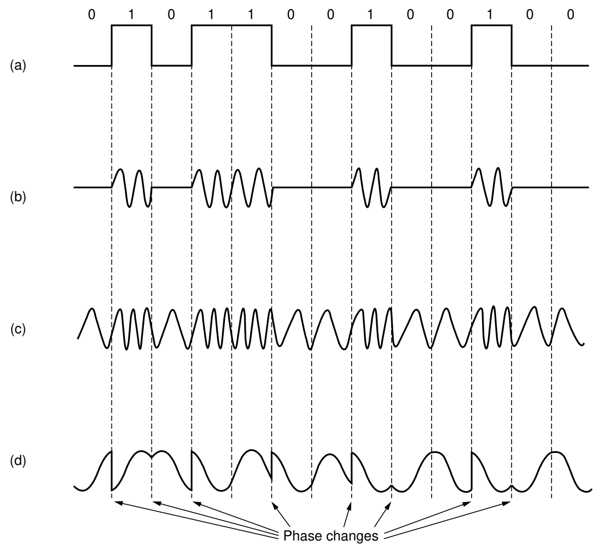
Modulation techniques

Problem: how can we encode our signals when we can effectively use only a single frequency (or small frequency range)?

Answer: Apply **modulation techniques**:

- change the amplitude (strength) of the signal: changing amplitude means a binary 1, constant amplitude a binary 0.
- use *two* frequencies to encode your bits (these frequencies can be put "on top" of your base frequency).
- change the phase of the wave (cf. sine and cosine) to do signal encoding.

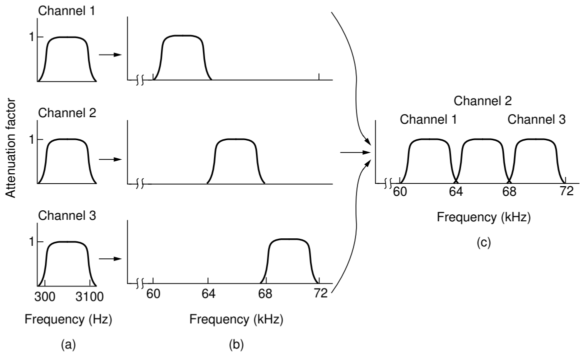
Modulation techniques II



Multiplexing

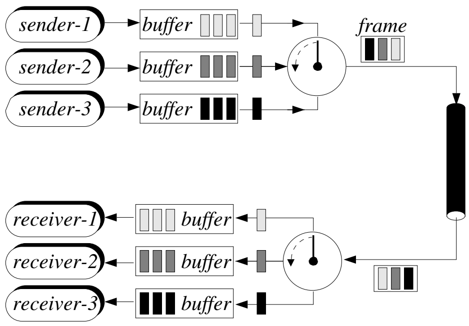
Problem: Considering that the bandwidth of a channel can be huge, wouldn't it be possible to *divide* the channel into sub-channels?

- **Frequency Division Multiplexing**: Divide the available bandwidth into channels through frequency filtering, and apply modulation techniques per channel:

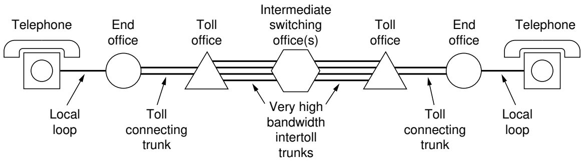


Multiplexing II

- **Wavelength Division Multiplexing**: Actually the same as FDM, but used for fiber optics.
- **Time Division Multiplexing**: Simply merge/split streams of digital data into a new stream. Data is handled in **frames** – a fixed series of consecutive bits:



Telephone System

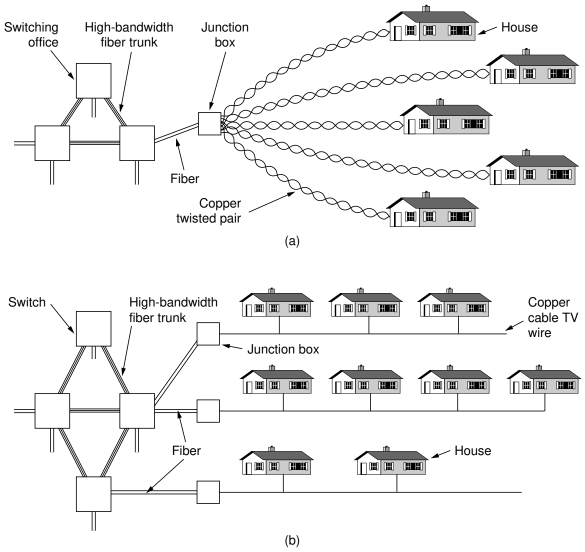


Essentials:

- **local loop** connects a home with an end office. The local loop is usually just twisted pair ⇒ we have a serious bandwidth problem. Generally no digital transmission.
- **trunks** connect the various offices. Usually high-speed stuff (fiber optics, microwave), and digital. These things make PTTs competitive.
- **switching offices** just set up connections and route voice/data.

Telephone System II

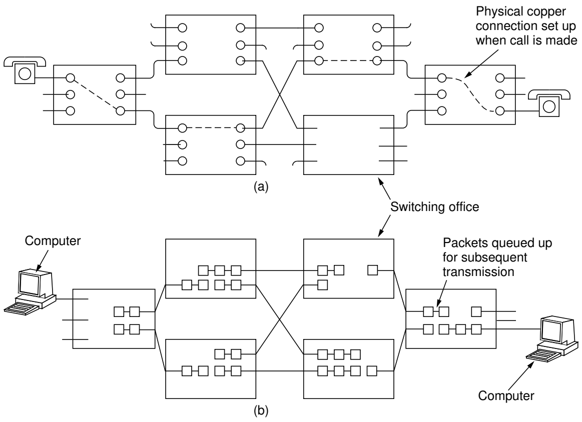
Note: we have to solve the local loop problem before we can do anything that resembles video-on-demand! Cable companies are making life hard for the PTTs.



Telephone System – Switching

Circuit switching: Make a true **physical** connection from sender to receiver. This is what happens in traditional telephone systems.

Packet switching: (1) Split any data into small **packets**, (2) route those packets separately from sender to receiver, and (3) assemble them again.



Telephone System – The Future (!?)

To get into the future, the PTTs invented something really new – **Integrated Services Digital Network** (ISDN):

- A full digital network right down to your own home.
- Integrates voice (telephone) and data (computer).
- Intended for domestic use, and use by businesses.

Unfortunately: the planned bandwidth was only 128 kbps (at the most), and the standards were already obsolete when they were published.

What's perhaps saving it now for the next decade, is Internet access: traditional telephone systems aren't really good at supporting Internet services.

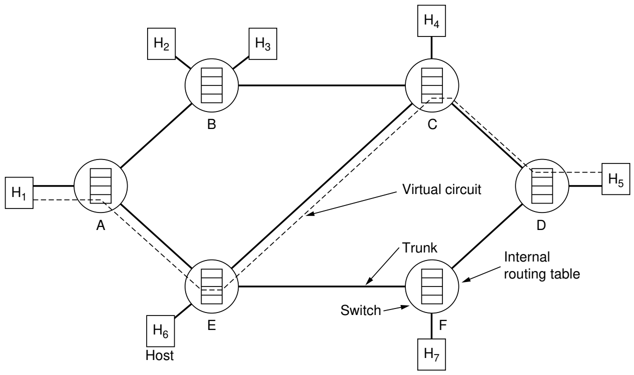
Broadband ISDN

Because they were far too late with ISDN, they did something radical: they came up with **Broadband ISDN**.

- Supports the same services as ISDN.
- Offers enhanced services based on 155 Mbps and 620 Mbps. This means:
  - Video-on-demand
  - Multimedia
  - LAN interconnectivity
  - ...

Virtual circuits

The basic B-ISDN services are built around the concept of **virtual circuit**: A full connection is set up between sender and reciever, but is implemented through packet switching.



Problem: how are we going to do the actually switching $\Rightarrow$ ATM.

ATM Technology

Basic idea: we transfer very small packets, called **cells** and maintain the order of their transmission.

An ATM switch keeps a table in which it records to which outgoing link an incoming cell should be routed. Setting up a connection implies setting the right table entries from the sender to the receiver.