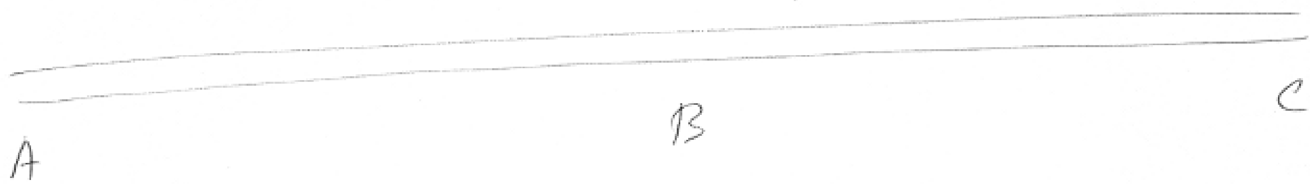
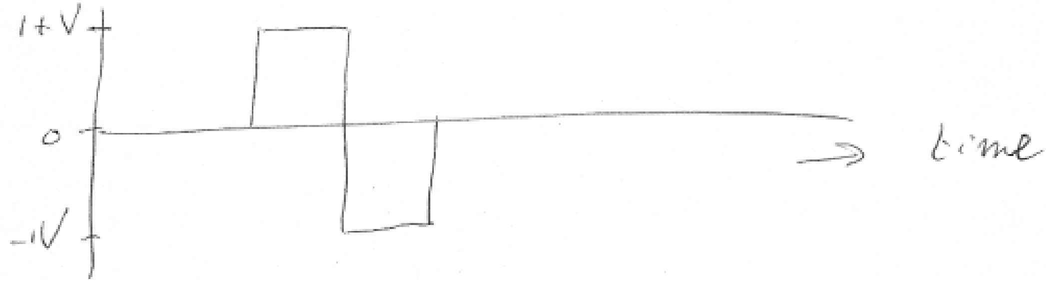
Start lec 09/16/2003.

Electromagnetic Radiation
(through a lossy medium:
Co-ax,
Copper wire,
...
)

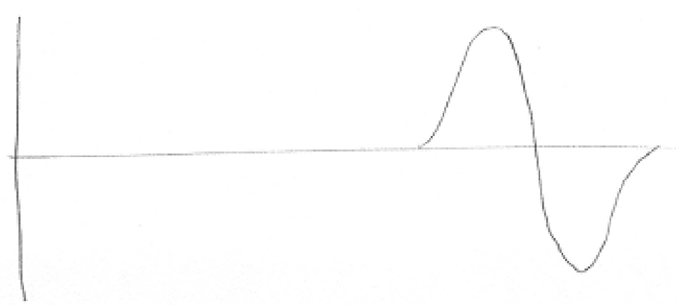
Say we have two copper wires twisted.
(Or coax: core and outer conductor).
Draw as it "straight":



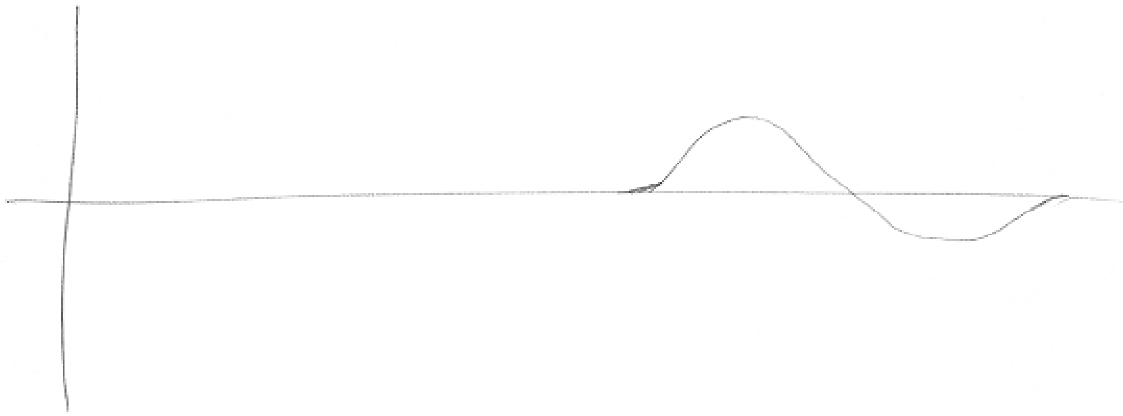
At end A we apply a signal
(voltage), say:



At B we see



At C se we see



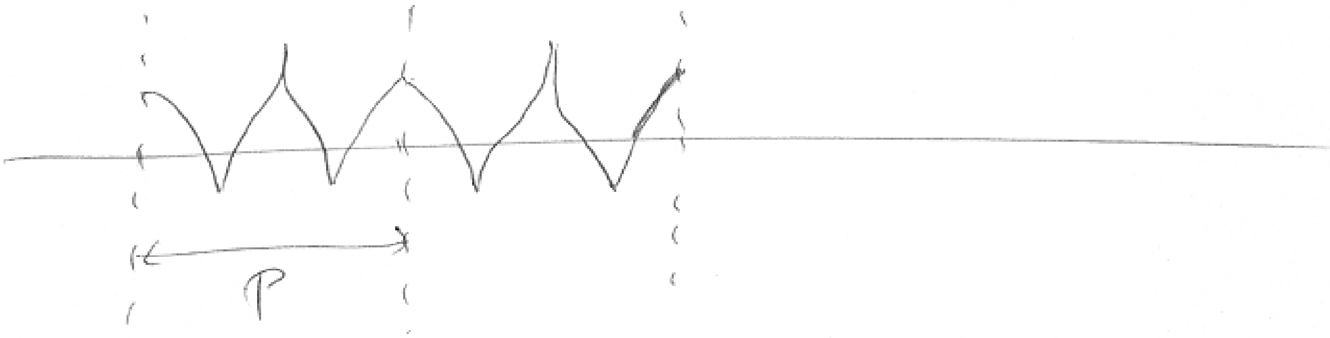
The signal "becomes smoother".
(and <u>weaker</u>).

The signal becomes <u>weaker</u>: attenuation.
Why <u>smoother</u>?

We can <u>think</u> of the signal being a mixture of ~~signals~~ signals of different frequencies. And different frequencies <u>attenuate</u> at different rate.

Now some math.

Arbitrary Function, Periodic, period P.



$$f(t) = f(t+P) = f(t+k.P)$$

All integer k.

"Every" such function can be written as

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

$$c = \frac{2}{P}\int_0^P f(t)\, dt$$

$$a_n = \frac{2}{P}\int_0^P f(t) \sin\left(2\pi \frac{nt}{P}\right) dt$$

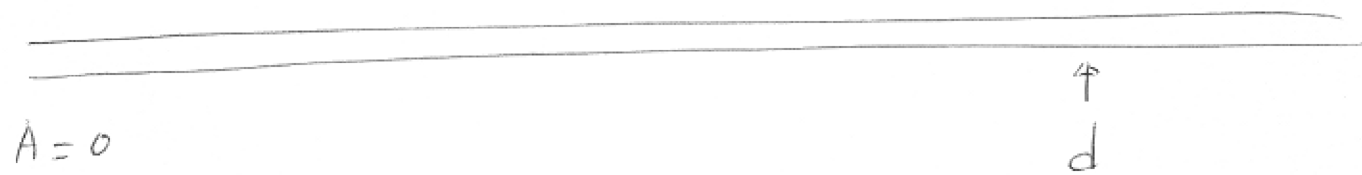
$$b_n = \frac{2}{P}\int_0^P f(t) \cos\left(2\pi \frac{nt}{P}\right) dt$$

Fourier Analysis.

Not really deep math.

$(a_n^2 + b_n^2)$ proportional to

Energy at frequency $\frac{n}{P}$



At A: Signal

$$f(t) = \frac{c(0)}{2} + \sum_{n=1}^{\infty} a_n(0) \sin\left(2\pi \frac{nt}{P}\right) + \sum_{n=1}^{\infty} b_n(0) \cos\left(2\pi \frac{nt}{P}\right)$$

At distance d:

At distance d:

$$f_d(t) = \frac{c(d)}{2} + \sum_{n=1}^{\infty} a_n(d) \sin\left(2\pi \frac{nt}{P}\right) + \sum_{n=1}^{\infty} b_n(d) \cos\left(2\pi \frac{nt}{P}\right)$$

<u>Often</u>: $c(d) = c(0)$ independent of d. (direct current component). ?

$$\left(a_n(d)^2 + b_n(d)^2\right) = \left(a_n(0)^2 + b_n(0)\right)^2 * \exp\left\{-d * Att\left(\frac{n}{P}\right)\right\}$$

(Attenuation ~~of~~ at frequency $\frac{n}{P}$)

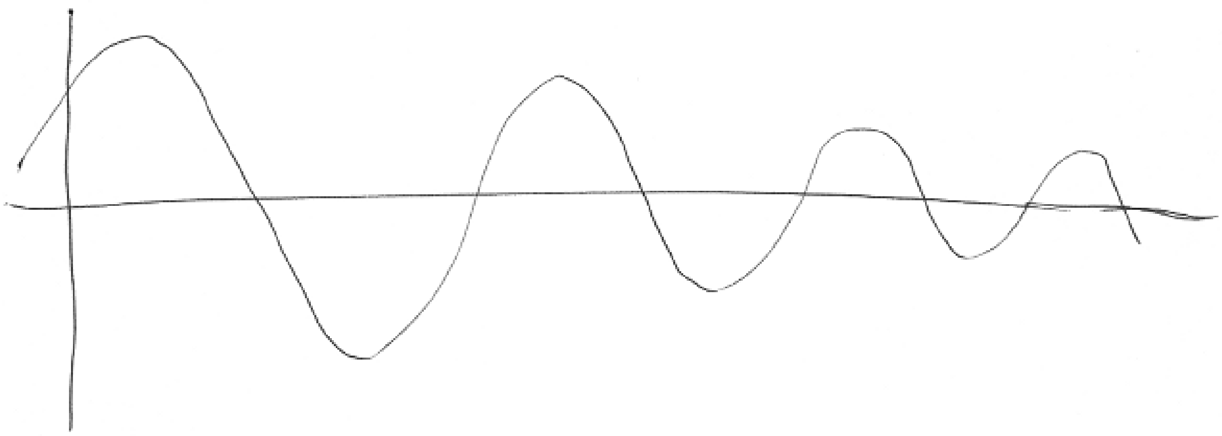
Usually: $A(x)$ larger for larger x.

The high Frequencies disappear.

Not

$$a_n(d)^2 = a_n(0)^2 * \exp\left\{ - d * Att\left(\frac{n}{p}\right) \right\}.$$

Why not. ?



at location zero ! time and space.

$$f_0(t) = A \sin(\omega t)$$

speed of signal: v (velocity).

$$f_d(t) = A * \exp\left\{ - \frac{d * Att(d)}{2} \right\} \sin\left(\omega\left(t - \frac{d}{v}\right)\right)$$

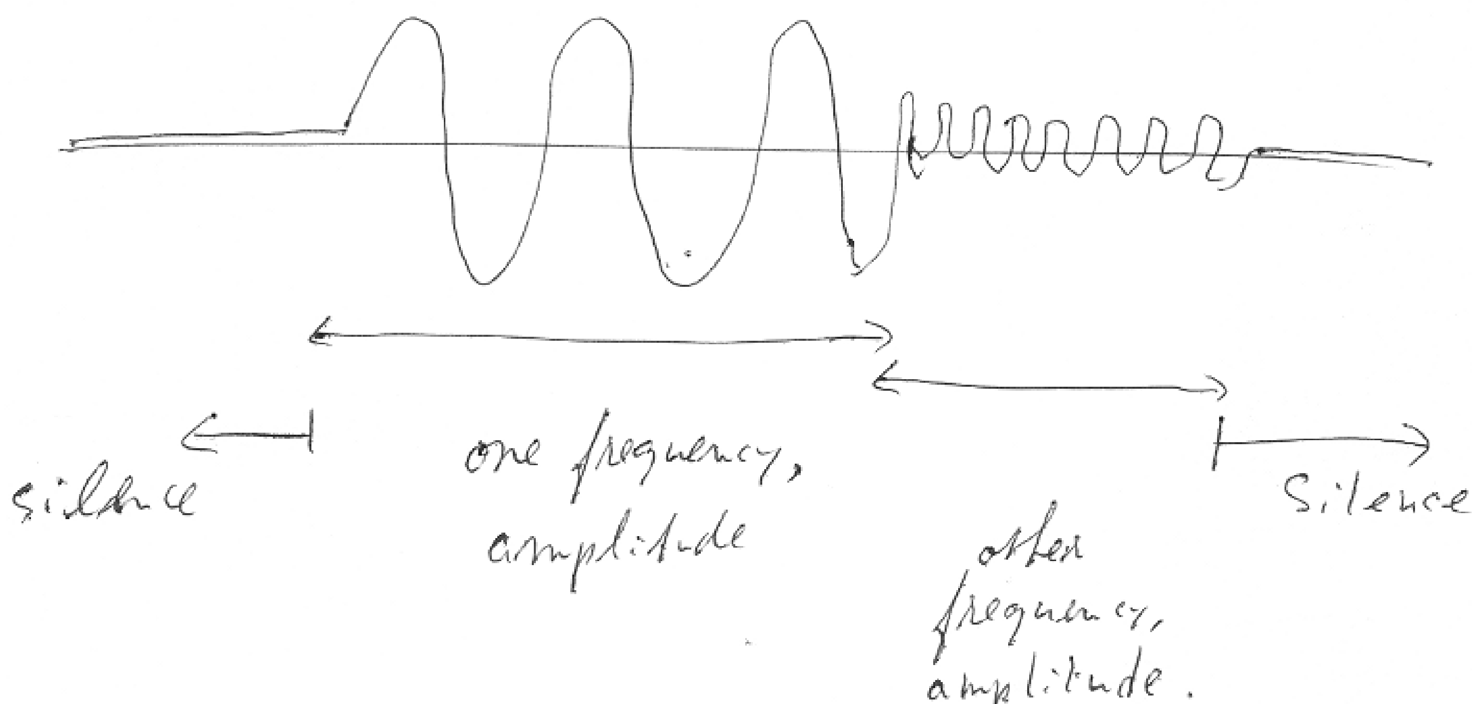
$$= A * \exp\left\{ - \frac{d * Att(d)}{2} \right\} \cdot \left((\sin \omega t)\left(\cos \frac{\omega d}{v}\right) - \cos(\omega t) \sin\left(\frac{\omega d}{v}\right) \right)$$

(9-th grade trigonometry).

Problem:

Real signals are not periodic.

e.g.



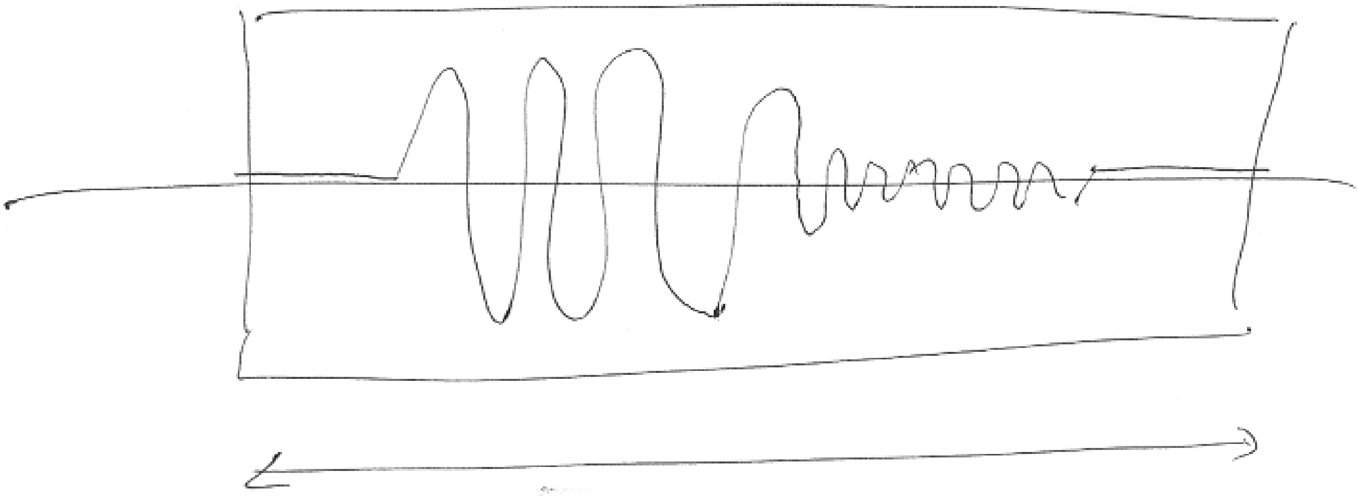
We have to Fuzz around this.

"The $a(\omega)$, $b(\omega)$ depend on time".

$a(\omega, t)$, $b(\omega, t)$

Mathematically: this is nonsense.

But:



window.

(~~loc~~ actually: in <u>time</u>,
<u>one</u> location).

Now <u>pretend</u> this is periodic.

Gives $a_n(0)$, $b_n(0)$

"This is the frequence distribution in the middle ~~of~~ of the window".

(Depends on window size!)

Human Voice is comprehensible as long as we do well on Frequencies ~ 50 – ~ 3000 Hz.

Hertz.

PCM: We want to do well on Frequencies up to ~ 4000.

Back to p 39

Why 8000 times/sec.?

Assume a window of 1 sec.
(Unreasonable assumption).

We have to be able to compute a_n, b_n for $n = 1, 2, \dots, 4000$:
8000 coefficients $\Longrightarrow$ 8000 samples.
8000 equations with 8000 unknowns.

Nyquist ~ 1924:

To represent frequencies in the range [1, H] reasonably accurately, you need to take 2H samples/sec.

(Even if you do *not* compute Fourier coefficients.).

This was a *very* handwaving proof.

~~Why 64,000 /sec. bits/sec.~~

~~(56,000 bits/sec)~~ :

~~(1) 8000~~

~~[illegible]~~

PCM

(1) 8000 samples/sec.

in order to represent
frequencies 1 – 4000 fairly well.

(2) 7 bits/sec is good enough

<u>Fewer than</u> 8000 samples/sec.

Clips frequency,
higher precision/sample does not help.

<u>More than</u> 8000 samples/sec.:

increases frequence range,
does not improve comprehensibility.
and lower accuracy would <u>hurt</u>.

HiFi: ~ 30,000 samples/sec.

bits / sample : ?

(Ego not expert).

Later we will talk about

Multiplexing.

Time Division Multiplexing,

Code Division Multiplexing, ~~etc.~~

Frequency Division Multiplexing, … .

FDM:

~~1 ch~~ 1 link,

Frequency Range (say)

1 MHz – 2 MHz   Mega Hertz.

We could subdivide this into say

10 channels, each ~ 100 kHz.

~~"~~ Or 100 channels, each 10 kHz

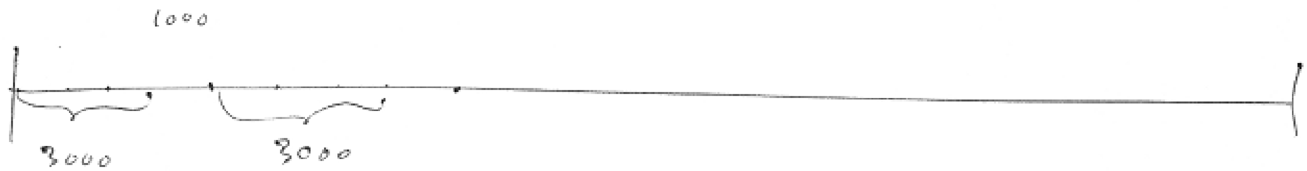
Or 250 channels, each 4 kHz.

(250 Voice Channels).

Before digital transmission:

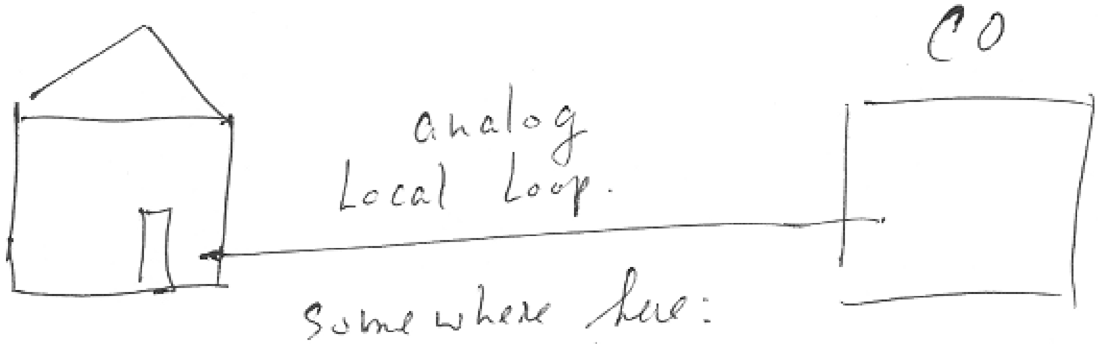
Multiplexing of Voice Channels.

With guard bands



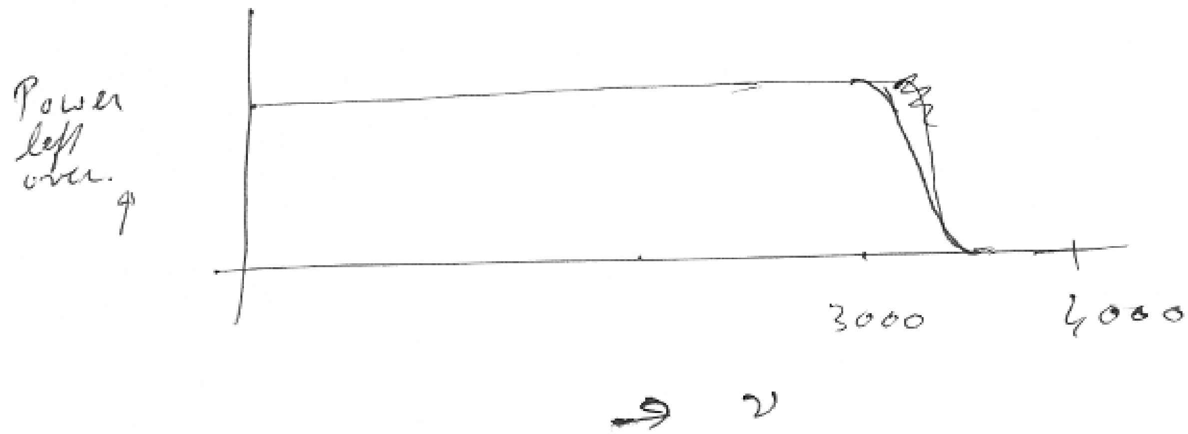
The "raw" (analog) voice signal was transformed <u>analog</u> to higher frequence: some spread of frequency. (I forgot exactly how).

<u>Required</u>: make sure it is only 3000 Hz wide to start with.



Somewhere here:
Low pass filter.

Low pass Filter: (Loading Coils).

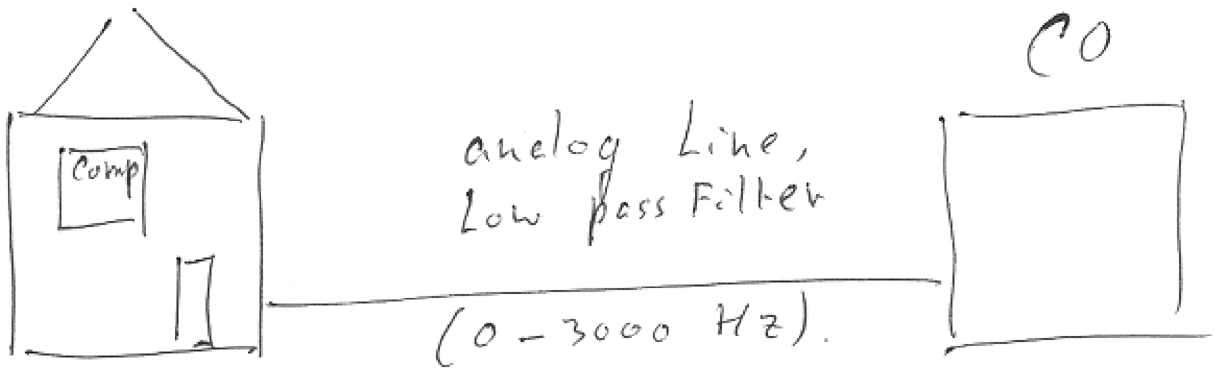


Hence:
once in (or past) CO:
Frequencies > ~ 3000 Hz are gone

Safe to multiplex.

To here 09/16/2003

Modems.



<u>Modem</u> : takes <u>bits</u>, tries to send over telephone line (analog).

Modulator – Demodulator.

Q: <u>Given</u> that the local loop can carry only frequencies (say) 50 – 3000 Hz (because of "conditioning"), How many bits/sec ~~can~~ can a modem take care ~~of~~ of?

A: more than you think!

If the signal is restricted to 50 - 3000 Hz:

(Fourier Analysis)

compute $a_{50}, a_{51}, \ldots, a_{3000}$

$b_{50}, b_{51}, \ldots, b_{3000}$

each (potentially) <u>infinite precision</u>.

Unlimited # bits/sec. !

But:

Signal received at demodulator <u>not</u> exact replica of signal sent by modulator.

<u>Noise</u> added.

a_n, b_n: <u>not</u> computed with "infinite precision".

<u>Limited</u> number of bits/sec.

How Limited?

Shannon ~ 1947:

If you have an analog channel of range H Hz (frequencies), with signal strength S and noise strength N, the largest number of bits/sec. you can reliably transmit is

$$H * \log_2 \left(1 + \frac{S}{N}\right)$$ (Assumes "white noise").

(For experts: you are talking about a a random stream of bits)

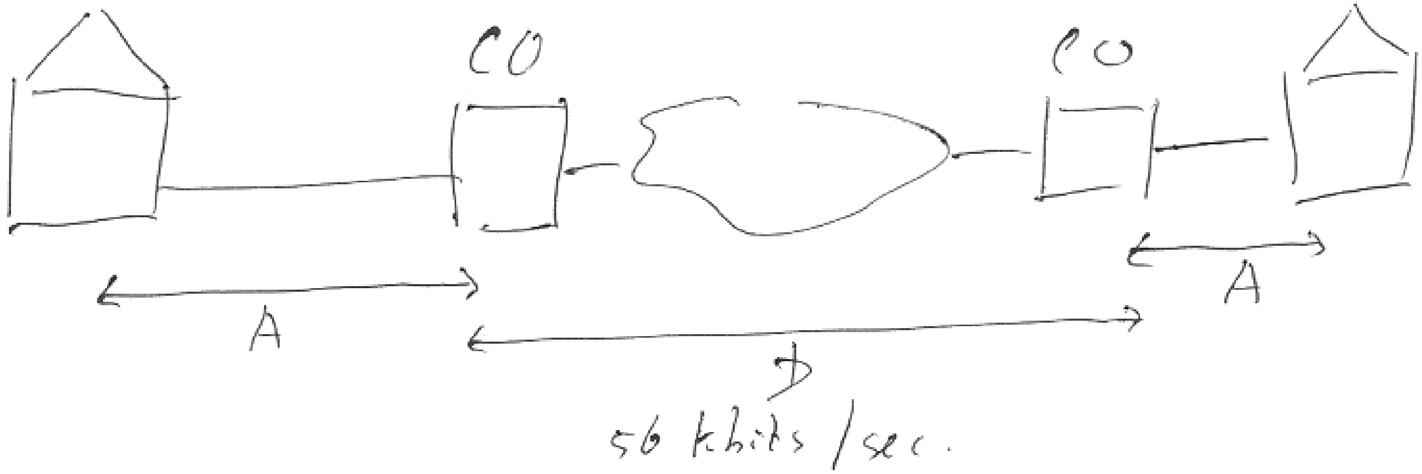
$\frac{S}{N}$: signal to noise ratio.

usually expressed in decibels dB.

$$\# \text{ dBs} = 10 * \log_{10}\left(\frac{S}{N}\right).$$

Say if $\frac{S}{N} = 100$, then it is $10 * 2 = 20$ decibels.

Confounding issue: A-D converters.



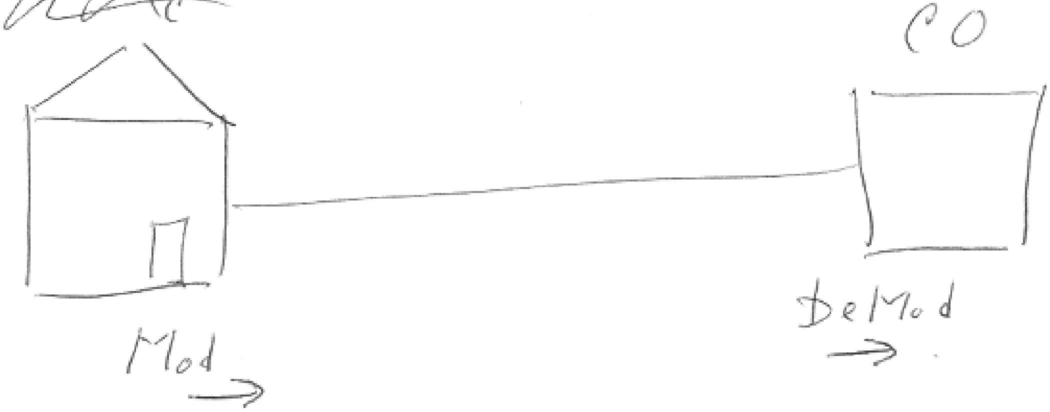
However <u>super</u> good the local loops are: you can <u>never</u> send more than 56 kb/sec.

(or 64 kb/sec. ~~[illegible]~~ if the network gives back to the signalling bit.

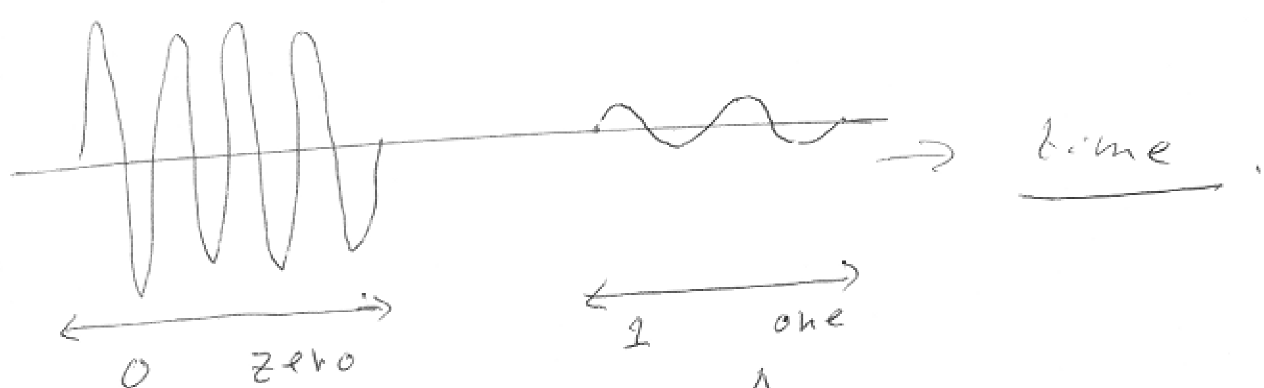
SS7: out of band signalling.

Modem.

Modulator – Demodulator.



It could work as Follows:



Amplitude: A_0 A_1

Frequency: ν_0 ν_1.

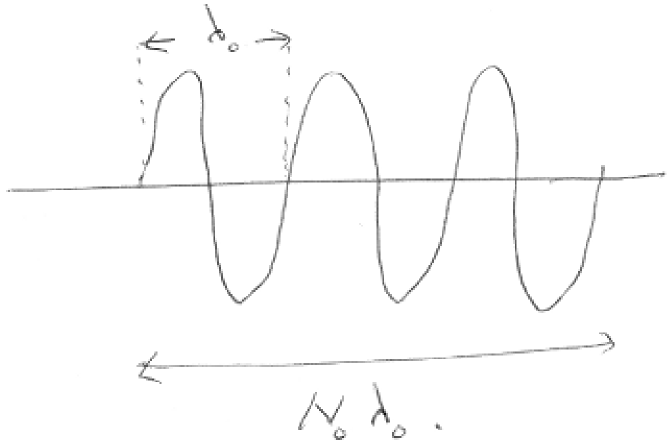
Is this a good idea?

NO!

This is <u>not</u> a good idea.

Why not?

Say a zero takes N_0 wavelengths:



At most $\dfrac{1}{N_0 \lambda_0} = \dfrac{\nu_0}{N_0}$ zeros per sec.

At most $\dfrac{1}{N_1 \lambda_1} = \dfrac{\nu_1}{N_1}$ ones per sec.

$N_0 \lambda_0 = \dfrac{N_0}{\nu_0}$: duration of a zero (sec)

$N_1 \lambda_1 = \dfrac{N_1}{\nu_1}$: duration of a one (sec).

~~([illegible] $N_0 \lambda_0 =$~~

<u>Assume</u> $N_0 \lambda_0 = N_1 \lambda_1$ = duration of ~~digit~~ bit.

Bit rate: $\frac{\nu_1}{N_1} = \frac{\nu_0}{N_2}$ # bits/sec.

We know that $\nu_i \leq 3100$.

At most $\sim$ 3000 bits/sec.,

and that only if a bit is at most 1 wavelength long!

(Or shorter?).

We know rates of up to $\sim$ 32,000 bits/sec. are possible!

How to achieve that?

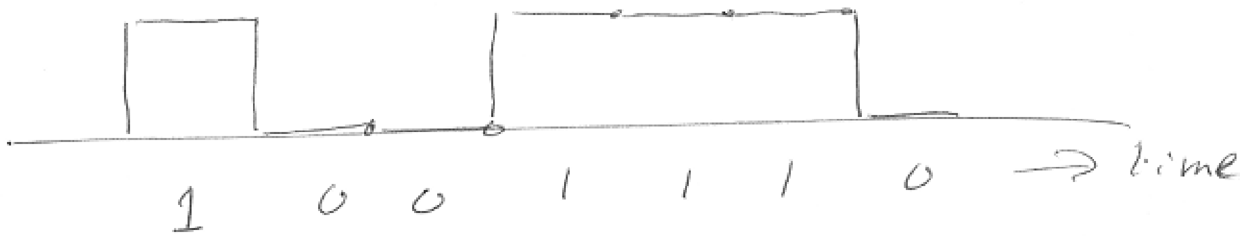
Modems of 56,000 bits/sec:

other kettle of Fish!

Later.

Modulation.

1. Unipolar. (not in Tanenbaum).



Problems:
- (i) DC Component
- (ii) Synchronization.

---

2. Polar: two levels +X, −X.

---

3. Bipolar: <u>three</u> levels +X, 0, −X

Polar.
Three sub cases.

(i) Non-Return-to-zero NRZ

(ii) Return to zero RZ

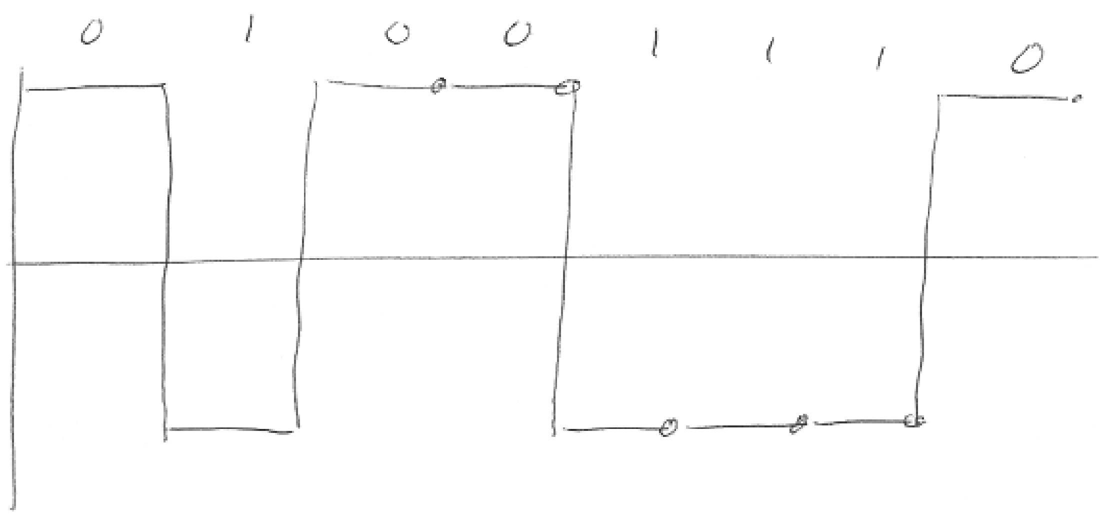
(iii) Biphase.

NRZ has two sub-sub cases.

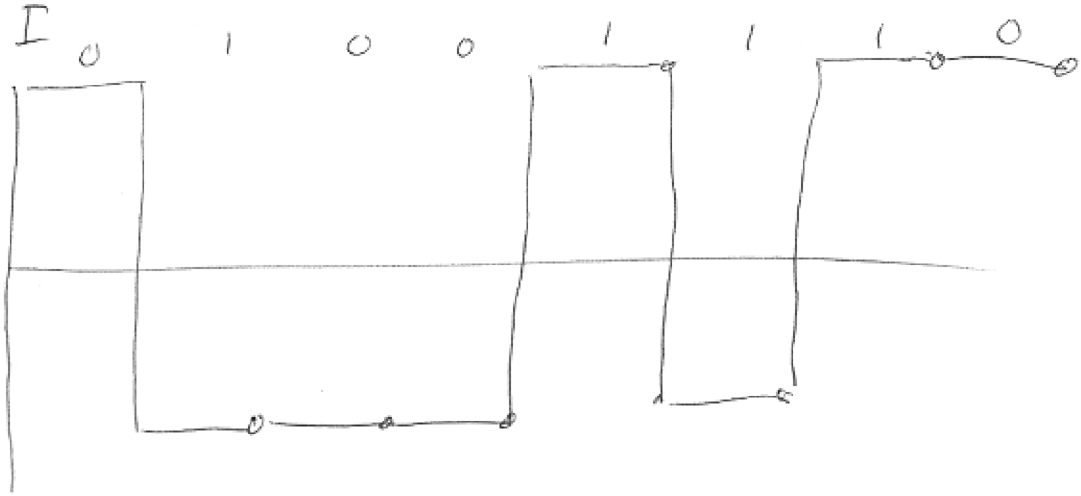
(A) NRZ-L : $+X \equiv 0$
$-X \equiv 1$.

(B) NRZ-I Flip $\equiv 1$
Non-Flip $\equiv 0$.

NRZ-L



NRZ-I



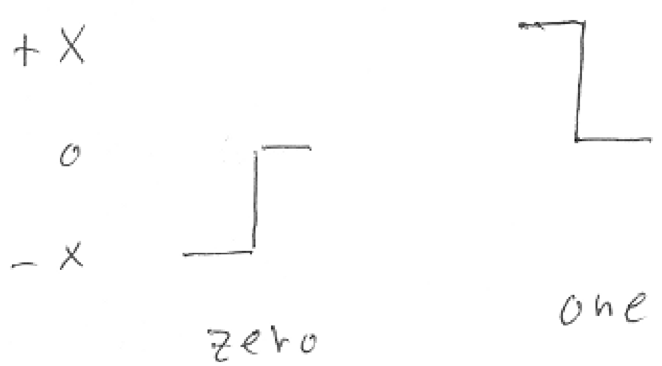
NRZ-L : as long as ~ 50% 0 50% 1 :
NO DC Component.
Synchronization problem if long sequences.

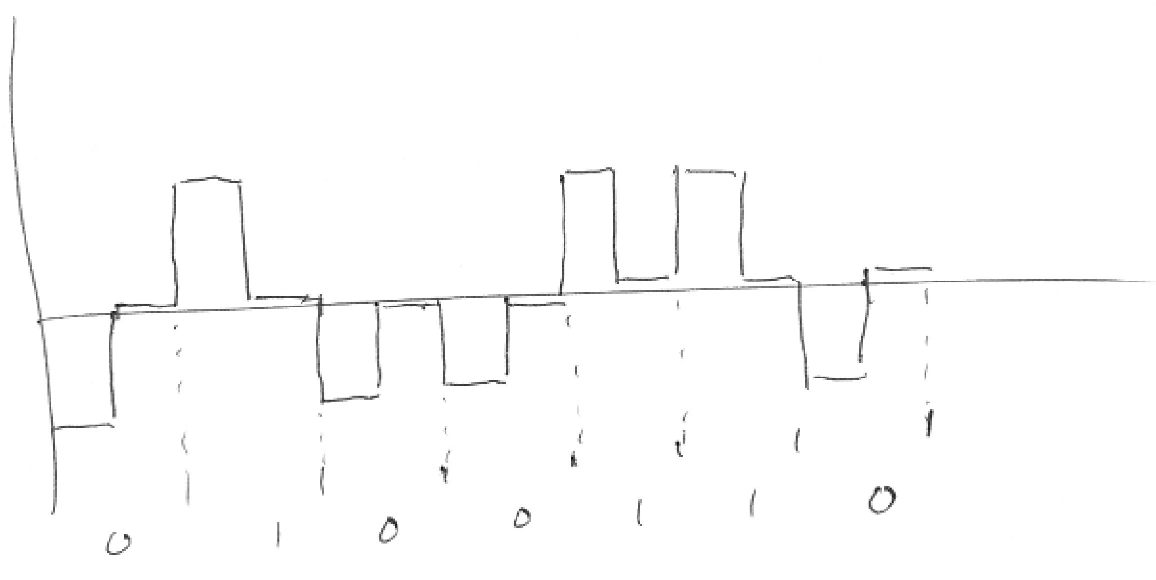
NRZ - I : Better.

(There must be "enough" ones)

(ii) Return to zero RZ

(<u>Includes</u> synchronization: Timing).





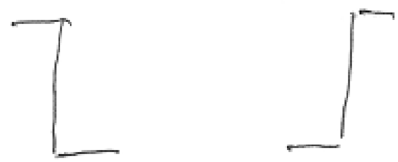
iii Biphase (Flip in middle)

Two sub-sub cases

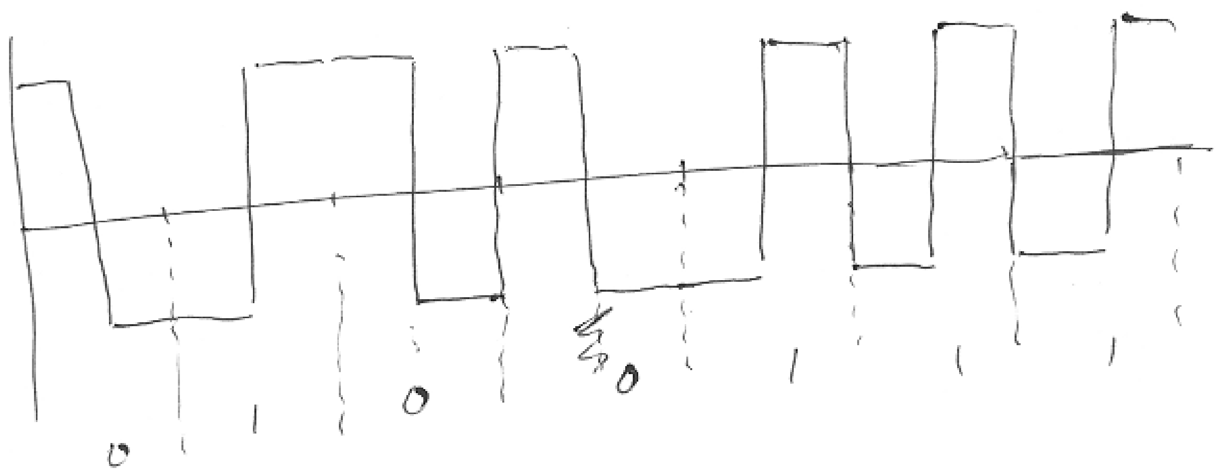
A: Manchester

B: Differential Manchester.

Manchester:



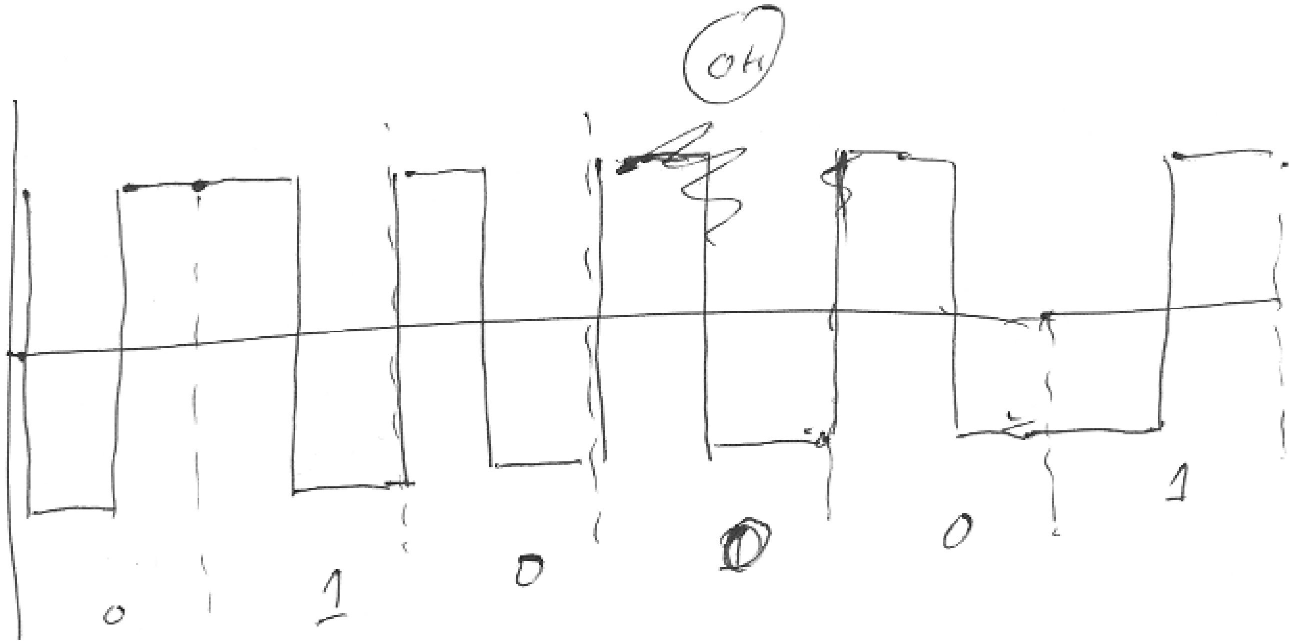
zero one



Differential Manchester:

"Flip" $\equiv 0$

"Non-Flip" $\equiv 1$



Biphase (either Manchester or Differential Manchester)
pretty good, often best.
As long as .... See later.

The original ethernet (802.3)
over co-ax with 10 Base 5, 10 Base 2
used Manchester encoding.

// I do not know what modern versions
of ethernet use (100 Base T, the
type in my lab).