Communications throughout the ages: significant communications events/advances in history, ***pre-***Joseph Smith

King Benjamin

Papyrus: came from the pith of a reed-like plant; much work was necessary to go from the thin

strips to the final product.

Parchment: a thin skin of a sheep, goat, etc; also required much processing

Paper: invented by Chinese; in Joseph Smith’s day, a piece of foolscap (about 11 x 17) cost 2-3 cents, or about $3-$4 in today’s money - very expensive.

Pheideppedes on the Plains of Marathon to deliver message of victory to Athens

Smoke signals, semaphores, flashing lights

Tower of Babel

Elimination of Nephites and their written records; subsequent effect on Lamanites.

Johann Gutenberg (c. 1438): invention of moveable type (much faster setting of typeface)

Before: hand-written copies, or custom-made typefaces for great works, cut in wood and filled with molten lead

Laborious process; in Joseph Smith’s day, it cost $5000 for 3000 copies, or $1.60 each, or about $300/copy in today’s money.

Printed materials had only by the rich.

Hand-written copy of Bible: about 1 year’s worth of work for a well-educated person ($70,000 today)

Adam with his posterity in Adam-Ondi-Ahman (D&C 107:53-56)

Pony Express: $10/½ oz., or about $400/½ oz today. Today: $10 overnight, anywhere in US, more oz

Communications throughout the ages: significant communications events/advances in history, ***post-***Joseph Smith

Telegraph 1840

First transcontinental telegraph killed the Pony Express after only about 18 months (1868)

First transAtlantic cable - 1866 - after 2 failures

Alexander Graham Bell - 1876 - telephone, later improved upon by Thomas Edison. Businessman

quoted to have asked, “Who needs it?”

Thomas Edison - 1880 - phonograph, motion pictures

All the preceding used electromechanical devices; no electronics existed. Also all wired.

James Clerk Maxwell - 1873 - mathematically showed that light was only one form of electro-magnetic waves, and predicted the existence of others.

Heinrich Hertz - 1888 - used spark gaps and iron filings to demonstrate the existence of these waves

Guglielmo Marconi - 1901 - went from transmitting in his workshop to across his garden, to several kilometers; ridiculously believed he could transmit across the Atlantic, in spite of the fact that he

knew that EM waves travel in a straight line and the Earth is curved. In Dec 1901 transmitted the letter “S” from Scotland to Newfoundland. Pioneered the field of commercial radio.

Reginald Fessenden - 1906 - first successful voice and music transmission

Lee DeForest - 1908 - triode vacuum tube and first amplification

1927 - first transAtlantic voice (1 call at a time, $30/minute, or $300 in today’s money)

1930 - B/W TV

1947 - Transistor

1958 - Integrated circuit

1960 - Color TV

1987 - Voyager 1 & 2 - incredible pictures of Neptune from 2 G miles +!

If we were to list today’s communications advances and equipment, it would occupy pages.

Time line of communications, from Adam until now; note the dramatic outpouring of knowledge subsequent to 1830. Strange coincidence?

**Terms - memorize these**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Term** | **Units** | **Unit Abbrev** | **Symbol** | **Meaning** |
| Voltage | Volts | V | E | ElectroMotive Force (EMF) |
| Current | Amperes | A | I | Flow of electrons |
| Resistance | Ohms | Ω | R | Opposition to electron flow |
| Power | Watts | W | P | Energy/unit time – Joules/sec |
| Frequency | Hertz | Hz | f | Cycles/sec |
| Capacitance | Farads | F | C | 1 F = 1 Coulomb (6.24 x 1018 electrons) at 1 Volt |

**Scientific Prefixes - memorize these** (p. 5 of packet)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Prefix Name** | **Symbol** | **Multiplier** | **Prefix Name** | **Symbol** | **Multiplier** |
| milli | m | 10-3 | kilo | k | 103 |
| micro | µ | 10-6 | Mega | M | 106 |
| nano | n | 10-9 | Giga | G | 109 |
| pico | p | 10-12 | Tera | T | 1012 |
| femto | f | 10-15 | Peta | P | 1015 |
|  |  |  | Exa | E | 1018 |
|  |  |  | Zetta | Z | 1021 |
|  |  |  | Yotta | Y | 1024 |
|  |  |  | Xona | X | 1027 |
|  |  |  | Weka | W | 1030 |
|  |  |  | Vunda | V | 1033 |

These are used in engineering notation, and must be used throughout this class.

**Resistor Color Code:**

0 = Black 5 = Green 1% = Black five stripes

1 = Brown 6 = Blue 2% = Red

2 = Red 7 = Violet 5% = Gold

3 = Orange 8 = Gray 10% = Silver four stripes

4 = Yellow 9 = White 20% = No stripe

Mnemonic: Better Boys Realize Our Young Girls Become Very Great Women

**Voltage, Current & Resistance (Supplemental, Section 1-1); Electrical Circuits (Supplemental, Section 1-2)**

Ohm's Law: I = E/R and its derivatives

Discuss large and small loads

\* Analogy to water, pump and faucet (\*)

Power formula: P = IE and its derivatives, as well as I2R and E2/R

Go over some examples:

Power drawn by an 80% efficient, 2 HP electric motor

100 W incandescent light bulb

**The Kilowatt-Hour**

kW hours, measurement, calculation of total

Lab 1: Ohm's Law and Series Circuits

**Series Circuits (Supplemental, Sections 1-3, 1-4)**

Series

Voltage divider

RT, IT

Connected in series, each uses only a portion of the voltage (miniature Christmas lights)

Adding voltage sources (extra batteries):

Connect them in series for extra voltage

**Parallel Circuits (Supplemental, Sections 1-5, 1-6)**

Adding voltage sources (extra batteries):

Connect them in parallel, so they see the same voltage

Schematic diagrams of simple circuits (lights in room, flashlight w/ multiple bulbs. Discuss analogy of load resistors to actual loads. Connect them in parallel for longer-lasting under higher current

Example: car battery for 12 V, 1200 A

Car battery for 24 V, 600 A

How can you make a flashlight brighter?

Does a voltage source also supply current? Why do we call them voltage sources?

Formula for RT of parallel resistors; RT < smallest of resistors

RT = 1/R1 + 1/R2 + ... + 1/RN

Discuss why this is intuitively so (that the total amount of resistance is less than the smallest)

Other useful relationships:

RT = (R1R2)/(R1 + R2) (Equation 6.5, p. 156)

When adding resistors in parallel:

If R2 >> R1, then RT has not changed appreciably

R1 = 1/10 R2, then RT = .909 R1 (10% decrease)

R1 = 1/100 R2, then RT = .990 R1 (1% decrease)

If R1 = R2, then RT = 1/2 R1

Example: amplifier driving two 8Sspeakers.

If R1 = 1/2 R2, then RT = .667 R1 (33% decrease)

If R1 = R2 = R3, then RT = 1/3 R1

If R1 = R2 = R3 = R4, then RT = 1/4 R1, Etc.!!

**Power in Electric Circuits**

P=IE

P=I²R

P=E²/R

**Electronic Measuring Equipment (Supplemental, Sections 2-1 to 2-6)**

**Conductance** (not in Packet):

Symbol is G; units are Siemens; =1/R; used for rating insulation

Typical value: 100 pS (10 MΩ) to 1 fS (1 PΩ)

**Electronic Measuring Equipment**

You cannot measure anything without disturbing that which you are measuring. This in turn means that any time you measure something, you are measuring only to some degree of accuracy.

Accuracy: Degree of conformance to a known or given reference or standard.

Precision: Degree of repeatability; gives same reading each time for identical stimulus.

Resolution: The smallest increment that can be resolved. High resolution equals small increments.

Example: True voltage = 3.00000000000 V

Reading 1 = 2.99 V---, Accuracy = (Avg Measured-Actual)/Actual=(2.997-3.0)/3.0=.1%

Reading 2 = 2.99 V /)) Precision = (high reading-low reading)/average reading =

Reading 3 = 3.01 V—- (3.01 - 2.99)/2.997 = .667%

Resolution = 1 part of 1000 (0 to 999) = .1%

Voltage measurement, parallel effects

1 MΩ input impedance, circuit = 10 kΩ, 10 kΩ , 10 V.

1MΩ input impedance, circuit = 10 MΩ, 10 MΩ, 10 V.

Current measurement, series effects

1Ω input impedance, circuit = 10 kΩ, 10 kΩ (parallel), 10 V.

1Ω input impedance, circuit = 1Ω, 1Ω, (parallel), 10 V.

Input impedance of various meters:

DMM: 10 MΩ (voltage, other parallel measurements)

.01Ω (current)

Analog: 20 kΩ /V (voltage, other parallel measurements)

.1Ω (current)

Oscilloscope: 1 MΩ (x1 probe), 10 MΩ (x10 probe) - (voltage, other parallel measurements)

Special probe required to measure current.

Note: Article on instrumentation loading: Electronic Design, Mar 17, 1997, pp. 155-162; by Howard Johnson. "Probing High-Speed Digital Designs"

**Operation of oscilloscopes**

& Demo: Oscilloscope, function generator, power supply

@ Four main sections of scope (@Handout: Setting the Controls)

Screen control: intensity, focus, astigmatism, scale illumination, beam finder

Vertical amplifier

Cover various amounts of amplification

Horizontal timebase

Cover variable time/div sweeps

Triggering

Demonstrate need for and operation of triggering

Scope ground lead is connected to earth ground; do not try to make it otherwise.

Lab 2: Parallel Circuits & the Power Formula; Electronic Measuring Equipment

**AC Waveforms & Terms (Supplemental, Section 3-1)**

AC waveforms:

Triangle

Sawtooth

Square

*Sinusoidal* (the big one for analysis, & for power generation & distribution)

Why the sine wave is sinusoidal

\* Basic generator output voltage (\*)

Analogy to pedaling a bicycle

Basic equation: v = Vp sin Θ

**Units of Measure for AC Voltages and Currents**

Vpeak

Vp-p Go over examples



Vrms



Go over relation between each, and why Vrms is used

Calculating power consumption in AC circuits

**Frequency**

f = 1/t; t = 1/f --- Go over examples, especially in estimating

**Vectors with AC (Supplemental, Sections 3-2, 3-3)**

\* Phasors (\*)

Vector addition and subtraction

Review of complex algebra

Relating back to the Pythagorean Theorem, we know that z/ Θ represents the hypotenuse of a right triangle, and that from this information we can find the remaining two sides. Likewise, x + *j*y represents the two sides of a right triangle, and that from this information, we can find the length and angle of the hypotenuse.

z = √(x2 + y2) x = z cos Θ

Θ = arctan (y/x) y = z sin Θ

Practice a few on your calculators, then learn how to use the shortcut your calculator has.

A few sanity checks:

3 + *j*4 = 5; 6 + *j*8 = 10; 30 + *j*40 = 50; 60 + j80 = 100; etc.; all / 's = 53.13°

1 + *j*1 = 1.414; 2+*j*2 = 2√2 = 2.828; 3+*j*3 = 3√2; all / 's = 45°

Hypotenuse must be longer than either side; both sides must be shorter than hypotenuse.

If *j* component > x component, / > 45°

If *j* component < x component, / < 45°

**Inductors; Series RL Circuits (Supplemental, Sections 3-4, 3-5)**

"Since every current flow produces a magnetic field, and the field strength depends on the current strength, this means that *an alternating current produces a magnetic field that is constantly varying in strength, and therefore induces a voltage in the circuit. The polarity of the voltage thus induced always opposes the change in the current."* This property is known as self-inductance, or just *inductance*.

Thus, inductance opposes changes in the current. Therefore, in inductive circuits, the current changes lag the voltage changes, or vice versa (ELI). This type of opposition to current flow is known as reactance, and its symbol is X; units are Ohms (Ω).

XL is frequency dependent

XL = 2πfL (equation 2-7, p. 44)

Example: find the reactance of a 45µH inductor at 10.7 MHz. (XL = 2π (10.7MHz)(45µH)

3.025 kΩ

Analogy: hanging a mass on a spring (I=mass); also inertia in a moving mass on a frictionless surface.

Inductors in series and in parallel

**Capacitors; Series RC Circuits (Supplemental, Sections 3-6, 3-7)**

Go over buildup of charge between two insulated, conductive plates; one electron at a time.

Analogy to 2-ported reservoir with diaphragm separating ports.

The current changes instantaneously, while the charge takes time to accumulate; thus the voltage cannot change quickly, and therefore lags (ICE).

Thus, capacitance opposes changes in the voltage. This type of opposition to current flow is also known as reactance, but is capacitive (XC). Units are Ohms (Ω).

XC is also frequency dependent, but is inversely proportional:

XC = 1/2πfC (equation 2-13, p. 46)

Example

(@take envelope and supercapacitors)

Review of factors contributing to capacitance:

, which for a vacuum (εr = 1.00), a = 1m2, and d = 1m:



Analogy of reservoir with diaphragm

Capacitors in series and in parallel

**Series RLC Circuits (Supplemental, Section 3-8)**

These are the real types of circuits; only imaginary circuits contain only one of these, although many times we can ignore one as insignificant.

Resistive loads: heaters, power-corrected power supplies

Inductive loads: relays, solenoids, motors

Capacitive loads: long-distance transmission lines, power supplies

Combination of R & X = Z, which is the vector sum of R + X.

Add all the resistive elements, then all the reactive elements, then find the result.

Example (from packet): R1=1k Ω; XC1=3k Ω; R2=2k Ω; XC2=1.5k Ω

RT=3k Ω; XT=4.5k Ω; Z = 5.41k Ω /56.3°

Example 2: f = 455 kHz; C = 116.6 pF; R = 1.0k Ω; L = 1.224 mH; V = 10 Vrms

ZT = 1.0 k +*j*500 Ω = 1.118 kΩ /26.56°

IT = (10 V/0°) / (1.118 kΩ/26.57° = 8.945 mA/-26.57°

*v*R = *i*R \* R = 8.945 V/-26.57°

*v*L = *i*L \* XL = 31.3V/63.43°

*v*C = *iC* \* XC = 26.83V/-116.57°

Plot of XL and XC versus frequency

Note that Z = R + *j*(XL - XC).

**Resonance and Frequency-Selective Circuits (Supplemental, Section 3-9)**

@ Note particularly what happens at XL = XC (@Handout of resonance plot)

Reactive elements store energy from the source, then give it back. But work is required to store the energy

first, so the source must supply this energy. Each cycle, this energy must be restored to the reactive

elements; thus the source is required to provide this energy, even though it is given back.

At resonance, with pure reactances, the energy is merely traded between C and L.

At resonance:

Z = R Q = 1/R √ (LC)

XL = XC

Φ = 0°

fr = 1/2π√ (LC)

Importance in tuned circuits

**Circuit Q**

Q = quality of tuned resonant circuit; depends generally on L, and on RL specifically. Q = XL/R.

Thus there are two ways to raise the Q: lower the resistance, or increase XL, most easily by raising the frequency.

\* BW = fr/Q; discuss the need for narrow bandwidths most of the time. (\*Fig 2-31, p. 59)

**Transformers (Supplemental, Section 3-10)**

Close proximity of two coils, one driven (primary), the other loaded (secondary).

ONLY works with AC; discuss why Z (matching):

\* Symbol and construction (\*Fig 2-15, p. 48)

Significance of turns ratio:

Vs/Vp = Ns/Np

Thus, I can step voltage up or down.

But: I can't get more power out than I put in (2nd law of thermodynamics, or law of entropy), so:

Ip/Is = Ns/Np

So, when I step voltage UP, the current gets stepped DOWN by the same amount;

AND vice versa.

**CHAPTER 1: THE ELECTROMAGNETIC SPECTRUM**

**1.1: An Introduction to Modern Communications Systems**

What is common to all communication systems? (See Figure 1.4)

Message (data) Abstract these from 2 examples:

Sender Me talking to them

Receiver Sending an email to someone

Encoding & decoding method

Medium

Filters

Why is communication so important?

**1.2: Electromagnetic Waves and Energy**

Basic terms: wavelength (λ) = velocity/frequency, or c/f for EM waves in a vacuum. (≈1ft/ns, or .3 m/ns)

(actually = 11.81 “/ns)

Examples: KSL (1160 kHz) = 258.62 meters

Microwave oven (880 MHz) = .34 meters

Cellular phone (1.5 Ghz) = .20 meters

Visible light = 400 - 700 nm; f = c/λ = 428.6 - 750 THz

Propagation factor for EM on PWB ≈ .70; v ≈ 1 ft/ns (.3 m x .7 = .21 m = 8.3")

Frequency-dependent characteristics of EM waves:

Straight-line propagation

Reflection

Refraction

Absorption

Penetration

**1.3: The Electromagnetic Spectrum and Allocations**

\*\*Appendix A, p. ; two overheads.

**1.4: Bandwidth and Information Capacity**

\*Bandwidth: the spectral width occupied by a signal. Rank the following: (\*overhead of signals below)

Voice (telephone) (300 Hz - 3300 Hz = 3000 Hz)

Wideband speech (50 Hz - 7000 Hz = 6950 Hz) - *IEEE Communications*, May 2006, p. 59

AM station (10 kHz station spacing; BW = 7500 Hz)

Full-spectrum audio (20 Hz – 20 kHz)

FM station (200 kHz station spacing; BW = 150 kHz)

Facsimile (goes over voice-grade lines)

B/W photo (digitized)

Color photo (digitized)

B/W video

Color video (6 MHz station spacing; BW = 4.5 MHz)

High-definition video

Shannon’s Law, 1948: capacity = BW x log2 (1 + SNR); capacity = bits/sec; BW = Hertz.

Example: find capacity of simple twisted-pair wire; BW = 10 MHz; typical SNR = 40 dB

40 dB = 100; capacity = 10 MHz x log2(101) = 10 MHz x 6.658 = 66.58 MHz

Example: find SNR required to send TV over 4.5 MHz BW; required capacity = 20 Mb/s

SNR = log-1(C/BW) -1; SNR = log-1(20Mb/s / 4.5 MHz) -1 = 21.77 - 1 = 20.77, or 26.35 dB

This law is the theoretical limit; most communication channels never achieve this, and some only reach half of it.

Where does one find more bandwidth? (At the high frequencies).

**1.5: Simplex, Duplex, and Half-Duplex Systems**

Simplex: one-way only. Example: broadcast radio, TV

Half-duplex: bi-directional, but only one at a time. Example: two-way radio

Full-duplex, or duplex: bi-directional, both at the same time. Example: human conversations; phones

Analogy to streets:

Simplex = one-way street

Half-duplex = narrowed down for construction, both directions, but only one direction at a time.

Full duplex = 2-lane road

Relationship to bandwidth?

Shannon’s Law examples:

#1: SNR=45 dB = 177.83; BW = 300 kHz; find Capacity: Cap = 2.2447 Mbps

#2: BW=250 kHz; Cap = 3.53 Mbps; find SNR:

cap/BW = log2(1+SNR)

2cap/BW = 1+SNR

2cap/BW -1 = SNR

2(3.53M/250k) -1 = 17,804 = 85.01 dB

Remember:



**CHAPTER 2: FOURIER AND SPECTRUM ANALYSIS**

**2.1: Time and Frequency Domains**

\*Example of a time-domain signal and a frequency-domain signal (\*Fig 2.1, p. 23)

Ways to find the frequency domain signal from a time-domain signal:

1. Perform the actual integration of:

(Equation p. 24)



Problems: not all functions are known (can’t find integral of unknown function); not all known functions have solutions; not at all easy to do.

2. Do the FFT, which requires thousands of calculations on many small pieces (piece-wise integration); very practical on computers or DSPs.

3. Use a spectrum analyzer.

**2.2: The Spectrum Analyzer**

Not practical to use hundreds or thousands of filters to cover all the bands of interest. Also not practical at higher frequencies, especially. A single, tunable filter is very practical, and its bandwidth can also be varied electronically. Or finally, the FFT can be performed on the signal, and the results used to drive the display; very common in instruments today.

**2.3: Fourier Analysis Examples**

\*Compare 2.4(a) and (b) (p. 27); now show for another frequency and amplitude of sine wave.

f = 300 Hz, amplitude = +/-1.25

What is the frequency-domain plot of:

\* Two people all playing at the same time, on the same note, at the same amplitude, on two instruments: flute, violin. (\*Fig 2.9, p. 30)

These additional components, all integral multiples of the *fundamental*, are called *harmonics*.

\*Spectra of the basic waveforms, square wave and triangle wave (\*Figs 2.10, 2.11, pp. 30, 31); compare to spectra of sine wave of same amplitude.

What is the BW necessary to pass a perfect sine wave with fundamental at 100 kHz? Square wave? Triangle wave? What does this say about digital signals?

**2.4: Modulation and the Frequency Spectrum**

Modulation: using the information to change the shape of the carrier; either amplitude, frequency, or phase are modulated.

Significance of modulation: without it, how many audio-frequency signals could be broadcast simultaneously.

\*Spectra of AM and FM signals: compare and contrast. (\*Figs 2.12, 2.13, pp. 32,33)

**2.5: The Spectra of Digital Signals**

What are the spectral implications of high *dv/dt* rates? What does this say about true square waves? What BW is necessary to make the corners of a transmitted square wave truly square?

\*Some cool examples of time/freq. domain signals (\*Figs 2.17, 2.18, 2.19, pp. 36, 37)

**2.6: Superposition**

Any recollections about the basic theorem?

How would it look in time/freq domain to add (superposition) 2 signals of same amplitude, 90° phase shift? (After studying Figs 2.20, 2.21, 2.22, pp 38, 39).

How can you tell if a time-domain signal has no DC component? (Give some examples)

**2.7: Power and Energy Spectra**

\*\*Compare \*Figure 2.26 to \*2.16(b) (pp. 36, 42); these are what transmissions must be concerned about, since all electronic signals are the product of the current and voltage (power).

**CHAPTER 3: DECIBELS AND NOISE**

**3.1: Signal Magnitudes and Ranges**

Received signals range from fW to mW; amplified signals range from mW to kW. It is often desirable to compare one signal strength to another, but the resulting ratios would be unwieldy and unitless. So:

dB = 10 log P1/P2; since P = V2|R, dB = 10 log V22/V12, which = 20 log V1/V2.

**3.2: dB Calculation Examples**

Find the dB of ½-power, for power and voltage.

Find the dB of 10x greater voltage; 10x greater power

Find the ratio of 30 dB for power & voltage.

Estimate the ratio of 50 dB for voltage.

Estimate the dB for a ratio of unity.

**3.3: dB Reference Values**

Several standards have developed as comparison points; the dB subscript is then either explicit or implicit by context.

dBm = referenced to 1 mW; what is -3 dBm?

dBW = referenced to 1 W; what is 30 dBW?

dBV = referenced to 1 V; what is -10 dBV?

dBc = referenced to ideal carrier signal (of different amplitudes; the ratio only is important here)

dB in audio = referenced to the quietest sound that humans can perceive.

**3.4: System Measurements with dB**

Standardized Bode plot

Specifying attenuation or gain

Specifying overall gain of multi-stage amplification system

**3.5: dB and Bandwidth**

\*Where do you draw the limits of the BW? (Figs 3.6, 3.7, p. 50) - at the half-power points, or -3dB.

**3.6: Noise and Its Effects**

Significance and impact of noise cannot be overstated; it is a MAJOR limiting factor.

Impacts:

1. Misunderstanding of transmitted signal

2. Malfunction of receiving/decoding circuit (inter-symbol modulation, distortion out of expected shape, out-of-band noise)

3. Lowers efficiency of communication system.

**3.7: Sources and Types of Noise**

External: impulses, AC line, motors, switches, relays, other similar signals, poorly limited signals, space noise.

Internal: amplifiers, resistors, capacitors, random motion of electrons and atoms (white noise or Johnson noise). Note: white noise Power = kTΔf; k=Boltzman’s constant (1.38 x 10-23J/K); T=temperature in K; Δf=BW in Hertz. How to limit? (reduce T or BW); sometimes specified as *equivalent noise temperture*, or the temp necessary to cause that much noise at a given BW.

**3.8: Noise Measurements**

Usually measured in RMS volts, not p-p or otherwise, due to the random nature of it.

SNR is extremely common in specifying noise levels; gives a measure of its significance.

\*Noise source, or stage of noise, is particularly important (\*Fig 3.13, p. 67)

Good SNR depends on the application: Space: sig=8x10-19W; noise=8x10-10W

Audio: 90 dB, classical; 40 dB rock Video: 60 dB Digital: 35 dB Space: -90 dB

Noise figure: noise added by amplifier, in dB: SNR (in) = 25 dB; SNR (out) = 24 dB; NF = 1 dB

**CHAPTER 4: AMPLITUDE MODULATION**

**4.1: Need for Modulation**

Wavelength of signal (audio would have λ=15,000 km - 15 km)

Allow sharing of spectrum

AM radio: spectrum = 535 kHz - 1610 kHz; BW = 7.5 kHz (with 1.25 kHz guardband).

**4.2: Basics of AM**

\*\*Carrier amplitude modulated by information; results in sidebands (\*Fig 4.1, p. 76); looks like \*Fig 4.2, p. 77. What is the frequency separation of the sidebands from the carrier?

\*What would it look like if you used a 300-3 kHz voice signal? (\*Fig 4.3, p. 77)

\*Spacing of AM stations (\*Fig 4.4, p. 78)

Effect of tuning a radio.

**4.3: Modulation Index and Signal Power**

*m* = (modulated peak V - unmodulated carrier V) / unmodulated carrier V; so it can range from 0 - 1.

Find *m* for modulated peak V = 9 V, unmodulated carrier = 5 V:

*m* = (9-5)/5 = 4/5 = .80

\*See example (\*Fig 4.5, p. 80)

Relationship between *m* and total power: PT = PC\*(1+(m2/2)) (\*Note error in text, p. 81; it is correct twice on the next page) This means that at 100% modulation (*m*=1), a carrier of 1000W also has sidebands of 250W each, for a total of 1500 W. But only 1/3 of the power transmitted (in the sidebands) contains information. And since each sideband is the mirror image of the other, only 250 W of 1500 W contains needed information (1/6). This is one of the negative results of AM, which leads to suppressed carrier AM and SSB AM, although these are much more difficult to transmit and detect (see section 4.5)

Negative effects of overmodulation:

Distortion, loss of information, splatter

**CHAPTER 5: RECEIVERS FOR AM**

**5.9: Amplitude Modulation Features and Drawbacks**

Main drawback: signal greatly affected by noise (directly modifies envelope, therefore becomes data)

Another drawback: amplitude cannot be exactly controlled from source to receiver, therefore exact data cannot be transmitted via AM - only relative data.

Another drawback: not efficient

Advantage: inexpensive transmitter and receiver.

Note: receiving is much more difficult than transmitting. Why?

Original signal unknown

Noise interference

Attenuation of signal; variable attenuation of signal

**CHAPTER 6: FREQUENCY AND PHASE MODULATION**

**6.1: The Concept of Frequency Modulation**

Developed by Major E.H. Armstrong during the 1930s.

For this chapter, statements made about FM also apply to ΦM.

Most noise signals do not affect the frequency or phase of a carrier; therefore FM = low noise

**6.2: FM Spectrum and Bandwidth**

\*Example (\*Fig 6.1, p. 144)

Δf (of carrier) α signal amplitude; rate of Δf (of carrier) α signal frequency

FM causes a whole range of sidebands, not just the upper and lower sidebands characteristic of AM.

*m* = Δ/fm ; example: Δ=±80kHz; fm = 20kHz; *m* = 4.0

\*Note the Bessel functions that describe the sidebands and their relative amplitudes. (\*Fig 6.2, p. 145)

Carson’s rule allows a simplified approach:

BW = 2(Δ + fm)

Using the rule of thumb that the allocated BW should allow 98% of the sideband energy to be transmitted, find *m* for the consumer FM band:

fm = 0-15kHz BW = 150 kHz

Δ = (BW - 2 fm)/2 = (150 kHz - 30 kHz)/2 = 60 kHz

*m* = 60 kHz/15 kHz = 4.0 (by Carson’s Rule; 5.0 by Bessel functions

Thus FM requires much more BW than AM. Narrowband FM developed for applications which require high noise immunity but do not require high fidelity (police, fire, other emergency)

**6.7: Phase Modulation**

Frequency is the rate of change of phase (derivative).

FM: *m* 1/α fm; ΦM: *m* remains constant with fm; Φ deviation α amplitude and frequency of fm.

**6.8: Comparison of AM, FM, and PM**

Noise sensitivity: AM worse, FM/PM better

BW: AM better

Efficiency: FM/PM better

Frequency-dependent *m*: FM worst; PM and AM unaffected.

Circuit complexity: AM simplest; FM and PM very similar for analog.

**CHAPTER 7: WIRE AND CABLE MEDIA**

**7.1: Wire and Cable Parameters**

*Wire*: strand of (copper/aluminum); *cable*: assembly of wires and insulators plus connectors

Wire at DC or low frequencies: R

\*Wire at high frequencies: \*Fig 7.1, p. 183 - discuss the nature of these elements and the wire.

Function of *shielding* of cables Distributed L ∝lμ/A; C = εoεRA/d

**7.2: Balanced and Unbalanced Lines**

\*Single-ended most common; uses unbalanced lines (\*Fig 7.2, p. 184). Assumes a perfect ground.

\*Alternative: differential, or balanced (\*Fig 7.3, p. 185).

Allows common-mode advantages, including CMRR and noise cancellation, assuming the pair is carefully routed together so that both lines experience the same noise environment.

CMRR of 70 dB (usually a voltage ratio), means a decrease in CM voltage of 3162 times (103.5).

Problems of probing balanced lines?

**7.3: Line Drivers and Receivers**

Line Drivers (buffers, transmitters): why is their job difficult? Why is it hard to quickly change the voltage all along the length of a cable? - Distributed capacitance, which can be 10 to 1000 pF/ft.

Ic = C(*dv/dt*), so to get large (*dv/dt*) = Ic/C, so raise Ic or lower C.

Besides the high currents needed is the limitation known as *slew rate*, usually measured in V/μs. Drivers have a finite slew rate, which limits frequency regardless of current capability.

On a sine wave, where is the max slew rate required? What about on a “square” wave?

\*Clearly, slew rate is a function of load capacitance also (\*Fig 7.6(b), p. 190)

\*Great receivers do *regeneration*, where the original signal is reproduced from decision thresholds (\*Fig 7.7, p. 191)

**7.4: Twisted-Pair and Coaxial Cables**

@Take examples

Twisted pair: 20 - 24 AWG wires; 5 - 15 pF/ft; 1 - 50 MHz

Good for differential signals; less expensive than coax

Shielded (grounded shield) provides significant advantages.

\*Coaxial: more expensive, better frequency performance (\*Fig 7.9, p. 194), up to 1 GHz

**7.5: Time-Domain Reflectometry**

Characteristic impedance (Z0) of a cable; dependent on physical parameters, such as:

Distance between conductors

Dielectric constant of insulating material

Diameter of wire

Physical locations of conductive strands

Change any of these, and you change Z0, which will cause reflections. This is the principle behind TDR

\* (\*Fig 7.11, p. 196). Knowing the velocity of propagation (as a % of the speed of light) tells you just

how far away the discontinuity is.

Example: a TDR tells you the discontinuity is 3.4 μs away in a length of RG59 (prop=.73); how far is it?

Distance = time \* velocity = 3.4 μs \* 3x108 m/s \* .73 = 744.6 meters.

Note that OTDRs also exist for troubleshooting optical fiber.

**CHAPTER 8: TRANSMISSION LINES**

**8.1: Impedance and Line Fundamentals**

Now is when we finally get to cover why a piece of wire is not just a piece of wire at high frequencies. This has been hinted at in your previous classes (I hope), and must now be understood.

We use G and C in parallel, because it allows us to add them directly to the whole.

Z0 is usually specified in units/foot or units/meter.



Note that R and G are usually small enough to ignore, leaving:



Which is a constant V/I transfer ratio, is not frequency dependent, and does not change as long as the physical characteristics of the wire medium do not change. Example:

Find Z0 for C = 35 pF/m and L = 17 nH/m

Z0 = √(17 nH)/(35 pF) = √485.7 = 22.04 Ω

Losses:

I2R heating - can be reduced by reducing I (by increasing V)

Skin effect losses - em field greatest at center of wire, so majority of current flows in skin; increases

effective resistance of wire; can be counteracted by using larger diameter wire, even hollow wire

(more expensive!)

Radiation losses - no shield keeps everything in

Dielectric heating - from leakage that flows through the dielectric

Capacitively coupled to Gnd - function of frequency

Imperfections (in materials, manufacturing)

For coax: from 1.5 to 10 dB/100m, depending on frequency, coax type

**8.2: Microstrip Lines and Striplines**

\*Transmission lines on a PWB (\*Fig 8.2, p. 207); range of Z0 ≈50 to 200 Ω

What does this say about the PWB manufacturing process?

Tolerances on thicknesses, widths must be very tightly controlled

Materials must be of uniform consistency

Multi-layer boards are better for shielded signals

Ground planes (or *virtual* ground planes) are very effective

PWB layout at high frequencies is not a trivial thing

**8.3: Waveguides**

At frequencies in the multiple-GHz range, coax is no longer an effective solution due to the losses. This is where waveguide comes into play.

Waveguide is basically a channel for the EM signal, into which it is launched, and down which it propagates by reflection off the smooth sides. The size of the channel in the waveguide is dependent on the frequency of the signal you wish to propagate. Waveguide is very effective for low and high

\* power, in the multiple 10's of Ghz. (\*Fig 8.3, p. 209)

Waveguide can be rectangular, square, or circular. Physical dimensions, smoothness of interior surface, are critical parameters. It is NOT cheap. No more focus in this class on waveguides.

**8.4: Line and Load Matching**

Maximum power transfer theorem (reminder); for AC, it occurs at complex conjugates; example:

(6 + *j*10 Ω) and (6 - *j*10 Ω).

Effects of mismatches is to change the Z0 dramatically, since Z0 calculations assume an infinitely long

\*\*line. (\*Figs 8.7, 8.8, p. 216). For the open-circuit termination, it looks like an infinite Z composed of C, in which I leads E. For the short-circuit termination, it looks like 0 Z composed of L, in which E

\* leads I. Where you attach a load determines what the load looks like. (\*Fig 8.9, p. 218) This is a function of its electrical length:

Electrical length = physical length/signal λ

Example: 2.5m cable, 150 MHz, velocity = .85 c:

2.5 m / (3x108 \* .85)(150 MHz) = 1.47 λ

Rule of thumb: When electrical length ≈> 0.10λ, you have transmission line characteristics to worry about.

Example: @FM band, 108 MHz: λ = (0.85 c)/108 MHz = 236 cm; 0.1λ = 23.6 cm ≈ 9.3"

Example: @60 Hz, λ = (0.85 c)/60 Hz = 4250 km; 0.1λ = 425 km.

Why is it important to match?

Standing waves: VSWR = Vmax/Vmin; worst case = ∞, best case (matched load) = 1.

Standing waves interfere with driven waves

Standing waves radiate power (power loss)

Standing waves reflect power back into drivers (bad for drivers!)

Γ = Vreflected/Vapplied = (ZL - Z0) / (ZL + Z0)

Example: Z0 = 100 Ω; ZL = 300 Ω; Γ = (300-100) / (300+100) = 200/400 = .5

How to match loads to Z0:

\* 1/4-λ Zn in series with line (\*Fig 8.10, p. 223) - requires custom-made line to give necessary Zn

Open or shorted (preferred due to less radiation) stub. Variables: stub length, stub position, open or shorted stub, and Z0 of stub wire.

Transformers:

**8.5: The Smith Chart**

A very powerful tool still used to allow quick determination of the above variables for given conditions. To really learn it would take at least 3 examples, 2 or maybe 3 lectures, and at least 1 lab. I have really struggled with this, but have decided to skip how to use one.

**8.6: Test Equipment**

Skip lecture on this

**CHAPTER 9: PROPAGATION AND ANTENNAS**

Size α wavelength; matters a great deal

Directional, Omnidirectional

**CHAPTER 10: DIGITAL INFORMATION**

**10.1: Digital Information in Communications**

Characteristics of analog vs digital:

\* Analog can have any value within the range; digital can have only discrete values (\*Fig 10.1, p. 277)

Analog has very limited range of optional processing available; digital has massive options.

Analog quality has significant noise limitations; digital has “perfect” quality or 0 quality

Regeneration of analog signals *extremely* difficult; regeneration of digital signals complicated but

\* well-understood and easily done today. (\*Fig 10.2, p. 279)

Most of the world we live in is inherently analog.

Some things are inherently digital: cost of a product; letter of the alphabet; # people; # CDs you own

Lots of good descriptions of examples of the above characteristic differences between analog & digital.

**10.2: Digital Specifications**

Accuracy: how close it is to the actual value; this is a function of many interrelated things

Resolution: the smallest part into which it can be divided. This, in digital, is a function of the # of bits

\* used to represent the signal. Example: \*Fig 10.4, p. 285 Inaccuracies in actual value in this domain are termed *quantization error*, which is the difference between the actual, analog value and the digitized value; purely a function of resolution. Infinite resolution (=quantum variations) ≈70 bits (270 ≈1.18x1021); CDs use 16-bit resolution, which is about where the ear loses its ability to distinguish a difference. Resolution is also specified as % of full scale, so 12 bits = 4096 parts ≈0.025%.

Dynamic Range: difference between the largest and the smallest signal. Since double = 6 dB, and each additional bit doubles the resolution, then dynamic range (dB) = # bits \* 6; so 16 bits = 96 dB.

Example: a given signal goes from 0 to 4.0 V, and is to be converted to 10 bits digital. Find the maximum quantization error (step size), the resolution in %, and the dynamic range.

Step size = 4V/210 = 4/1024 = 3.9063 mV

Resolution = 1/1024 = 0.097656 %

Dynamic range = 10 \* 6 dB = 60 dB

**10.3: Sampling, Bandwidth, and Bit Rates**

Nyquist criterion: An analog signal can be perfectly reconstructed, solely from its sample values, without any loss of its original information, if the sampling rate is at least twice the bandwidth of the signal (p. 292). Original signal MUST be band-limited to prevent any signal frequencies from being above this limit, or *aliasing* occurs. Aliased signals appear to be correct but in fact are entirely false. Example is the spokes of wheels of a wagon on film, or a strobe light on a wheel.

How can you know if a given signal has aliasing problems, if you only have the signal?

Note the inefficiency of digital versions of the signal:

Voice: 300 Hz - 3.3 kHz = 3 kHz BW (analog)

Digital: 3.3 kHz = 6.6 ks/s \* 8 bits/sample = 52.8 kbps (present system uses 8 kHz sampling @ 7 bits = 56 kbps)

Options: lower required resolution; lower sampling rate as much as possible; use multi-level signals, so that each symbol = > 2 voltage levels = > 1 bit; compression

**My addition:**

Find the # of bits on a 60-minute CD, assuming 16-bit resolution and 44.1kHz sampling rate:

60 minutes \* 60 sec/minute \* 44.1k sample/sec \* 16 bits/sample = 2.5402 Gbits = 317.52 Mbytes (per track; 2 tracks for stereo)

Types of A/D converters: integrating; Δ-Σ; successive approximation; flash

**10.4: Digital Testing**

Logic probes – very useful for digital troubleshooting

Logic analyzer - displays many channels at once, all digital

Network or protocol analyzer - higher level box for specific types of transmission where well-defined protocols exist. Used extensively in testing networking installations.

**CHAPTER 11: DIGITAL COMMUNICATION FUNDAMENTALS**

**11.1: Analog-to-Digital and Digital-to-Analog Converters**

First known as A to D or ADC; second known as D to A or DAC

\*Complete analog signal, digital transmission system: \*Fig 11.4, p. 302; understand function of each block.

Go over the various types: SA, Flash, Σ/Δ, integrating

**11.2: Pulse Code Modulation**

Essential role of the Clock in each of the 3 blocks that use it; without synchronization, glitches can occur

\*P/S and S/P converters: shift registers (\*Fig 11.6, p.305)

\*Criticality of clock synchronization to bit period: (\*Fig 11.7, p. 306)

Companding: based on the principle that lower amplitudes need greater resolution than the greater amplitudes, just like measuring small distances needs greater resolution than large distances.

\* Transfer curves: (\*Fig 11.8, p. 308); μ = 100 is the most commonly used value.

**11.3: Synchronization**

Again, the criticality of identical bit period definitions on both ends (transmit, receive).

What prevents us from simply using two identical clocks on both ends? (variation is inevitable)

Synchronization choices:

1. Send the clock as a separate signal (requires additional bandwidth or additional line)

Common for short distances, such as to printers or other computer peripherals or within a computer

2. Derive the clock timing from the received data bits (clock recovery, usually using PLLs)

VCO set to transmitter center frequency; variations are small, and easily tracked.

3. Use special bits as part of the data bit stream to reestablish sync and timing at receiver

4. Reference a common signal (60 Hz, 50 Hz, other)

#3 is very heavily used. #2 has problems with certain data patterns, particularly those with few transitions.

Frame synchronization - the next step up after bit-frame synchronization. Where is the MSB/LSB? Usually done by sending a special bit sequence, which can also be used as the sync sequence for the PLL.

**11.4: Delta Modulation**

An interesting concept that eliminates the need for framing (bit or frame), but increases the bit rate by 2

\*\* to 5 over the normal method (all bits of all bytes). See \*\*Figs 11.11 & 11.12, pp. 314, 315.

Only useful when the information is in the changes, and not in the absolute values (voice, for example)

**11.5: Troubleshooting**

Skip

**CHAPTER 12: DIGITAL COMMUNICATION SYSTEMS**

**12.1: Complexity of Digital Communications**

\*\*Multiple layers are involved (\*Figs 12.1, 12.2, p. 323). The only way we could ever do so much to the data for so little cost is the advances in VLSI that have made this possible.

Transparency: essential, but we as IT engineers must see all these “transparent” layers. When do these layers become opaque to the public? (When the communication systems fails in very unique ways).

**12.2: Coding**

ASCII (American Standard Code for Information Interchange) (see Appendix C, p. 795-797) - note that it is a 7-bit code; 8-bit ASCII does exist, but is not widely standardized. You can actually enter ASCII characters directly on most word processors (and email) by typing Alt + the decimal # (on num pad): A=65 (100 0001); a=97 (110 0001); 0=48 (011 0000). 253(FD)=²; 248(F8)=°; 168(A8)=¿; 171(AB)=½; 172(AC)=¼; ñ=164(A4).

Note that ASCII defines sequence as LSB first.

Define the waveform to transmit, in ASCII, BYU:

B=100 0010; Y=101 1001; U=101 0101; = 0100 001 1001 101 1010 101

Note that 16-bit ASCII has also been defined and internationally standardized (Unicode), to accommodate characters from almost all languages with alphabets; gives 65,536 possibilities.

**12.3: Format**

Many formats have been defined for many specialized applications. Standard pieces:

header/preamble terminator/postamble

message length EOF

message #

address of receiver

SOM character

Message lengths can be fixed or variable; each has its advantages and disadvantages for different types of data.

Example of a very fixed format: T-1; T-3 = 28 T-1s (≈45 Mbps); BYU had 3 T-3s in 2002; as of 2007,

we use a single gigabit fiber connection capped at 700 Mbps at the ISP’s router. Connection to

Aspen Grove is still a T-3 line.

\* 24 TDM signals, each at 8k samples/sec, 7 bits/sample (+1 line status bit) = 64k bps, +1 framing bit/frame; this gives 193 bits/frame, and 8k frames/sec = 1.544 M bps. (\*Fig 12.4, p. 330)

T-3: 28 T-1s (≈45 Mbps); BYU has 3.

**12.4: Physical Interface and Throughput**

Many types exist, with many differences.

Voltage levels: TTL (for limited applications & distances). Remember that drivers & receivers must be able to withstand hot connections, miswiring, shorts to power supplies, & ESD events, plus drive the substantial capacitance of the line.

Unipolar problem: a string of 0's looks the same as a dead line.

Bipolar (RS-232, for example) uses ±5V to ±15V. Bipolar also has a long-term average of 0V (no DC component), which is desirable for AC coupling.

\*NRZ vs. RZ (Manchester encoding uses this) \*Fig 12.7, p. 334 - the RZ data includes clocking data, since every bit period is guaranteed to have a transition. Also, the difference between the highest (fundamental) frequency and the lowest is only 2:1; with NRZ, the difference can be infinite, limited only by the # of 1's or 0's that occur in a row. Drawback: 2x BW required for 1x data.

Data rates: bps ≠Baud, since 1 Baud can = multiple bits (with encoding).

Another reason bps ≠ data bps is the overhead (see **12.3: Format** above)

**12.5: Protocol and State Diagrams**

Protocol: a definition of a rule for communication. Defines the normal situation (simple), and what to do

in the event of special conditions (complex), such as loss of power; errors in data, preamble, postamble, ECC; loss of connection; etc.

\*Common example: ACK and NAK signals returned by receiver (\*Fig 12.9, p.339); protocol must also cover what to do if these are garbled as well.

**12.6: Asynchronous and Synchronous Systems and Effective Throughput**

\*Asynchronous: undefined time between characters. Example: \*Fig 12.12, p. 342.; commonly used for keyboards and other applications where the generation of data is sporadic.

Asynchronous requires definition of a *start bit* and a *stop bit*, which are also overhead.

Requires minimal complexity and protocol processing.

Maximum character rate a function of # bits/character plus overhead:

RS-232 defines 7 character bits, 1 parity, 1 start and 1 stop bit; 56 kbps = 5600 chars/sec.

\*Chip for implementation: \*Fig 12.13(a), p. 344

Synchronous: constant bit and character stream; higher-performance, more protocol, less overhead.

Long block lengths = high efficiency (for large chunks of data; lower efficiency for small chunks).

\* Example: HDLC/SDLC (High-level Data Link Control/Synchronous Data Link Control) (\*Fig 12.14, p. 347)

**12.7: Error Detection and Correction**

Gross errors: # of bits expected not received; clock not able to be recovered - send NAK

Smaller errors:

Add redundant bits which tell something about the previous bit stream (error detection - parity;

\*\* CRC) \*Fig 12.16, 12.17, pp. 351, 352 Add carefully calculated redundant bits, which tell much more about the previous bit stream, such as

the location of the bit in error (now you can FIX the bit - forward error correction). Advanced methods can handle 2 or 3-bit errors. Common ones: Hamming; Reed-Solomon; Tornado.

\* Example of a new one: \*March 2004 IEEE Spectrum, p. 36 - Turbo Codes

Example at IBM: raw error rate = 1 in 4 x106 (@ 3 Mbytes/sec = .17 sec/error); 18% overhead (82 data, 18 FEC) for EDC = 1 in 2 x 1012 = 83,333 sec/error = 23.15 hrs/error (≈1/day)

Interleave the data so that burst errors (the most common type) will be spread over many blocks, and

each block will have only a few bits in error. (Read box on p. 356: CD Players and EDC)

Bit Error Rate:

A primary measure of overall quality of a digital communication system.

Good: 1 in 1012; bad: 1 in 106.

\* Relationship between BER and SNR, also with/without EDC (\*Fig 12.21, p. 357)

Example of FEC, using simple Hamming code: (from Miller: Modern Electronic Communication, p. 374)

Where m = # of bits in string to be encoded; n = # of bits in Hamming code, n must be

the smallest number such that 2n ≥m + n + 1

For nibble 1101, n must = 3 or greater. Can be encoded in many ways; one example (even parity) is:

P1 P2 D1 P3 D2 D3 D4 P1 = parity on 3,5,7 P2 = parity on 3,6,7 P3 = parity on 5,6,7

1 2 3 4 5 6 7 Note: P1 = LSB, P3 = MSB

1 0 1 0 1 0 1 for even parity on each

If error occurs such that bit 5 (D2) is wrong:

1 0 1 0 0 0 1 which gives P1 is wrong (odd), P2 is OK (even), P3 is wrong; assigning a 1 for wrong parity and a 0 for even parity gives 101, or bit 5 is in error. Works no matter which bit is in error, even the parity bits.

P2 is wrong:

1 1 1 0 1 0 1 which gives P1 is OK (0), P2 is wrong (1), P3 is OK, which = 010.

P3 is wrong:

1 0 1 1 1 0 1 which gives P1 is OK (0), P2 is OK (0), P3 is wrong (1), which = 100.

Overhead: 3/7 (=43%, or an extra 75%)

**CHAPTER 13: DIGITAL MODULATION AND TESTING**

**13.1: Basic Modulation & Demodulation**

Detection greatly simplified, as compared to analog; it’s a problem of detecting and determining

(deciding) what the original signal was (since only a few discrete values are permissible), instead of

being a problem of reproducing the original signal. But it takes a lot more BW; so... it’s complicated!

Multi-level modulation:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Binary | Di-bits | Tri-bits | Quad-bits |
| Data bits | 16 | 16 | 16 | 16 |
| Bit periods | 16 | 8 | 5.333 | 4 |
| Baud rate | 16 | 8 | 5.333 | 4 |
| Noise separation  (@ 0-4V, ±10%) | 3.2 V | 1.6 V | .8 V | .4 V |
| Detection circuitry | simple | fairly simple | somewhat complex | complex |

\*AM: 0=½ level; 1=full level. Detection of a 4-level signal (\*Fig 13.3, p. 366 - note error on output)

\*\*FM: FSK was very common (modems) Detection (\*Fig 13.4, 13.5, pp. 367, 368). These filters are tricky, expensive,

non-ideal, and drifty.

PM: 0-90° phase shift; detector similar to FM detectors (PLLs), whose amplitude α phase difference.

This signal then goes to a bank of comparators, as in AM. PLL extracts the original clock as the

reference.

**13.2: Quadrature Amplitude Modulation** - commonly used in modern modems, other apps

\*Uses a combination of AM & PM. Uses I & Q components, summed together (\*Fig 13.6, p. 370). Uses

equation (p. 374) to form sum: s(t) = i(t) sin 2πft + q(t) cos 2πft . This = one signal with both AM & PM.

QAM allows dibits with digital (binary) separation in both amplitude & phase. 4x4 levels gives quadbits.

\*\*Constellation plots show the I/Q points (\*Fig 13.7, p. 371). I channel noise = horizontal movement (\*Fig

13.8, p. 372); Q channel noise = vertical; noise on both = fuzzy spots with diameter α noise amplitude.

Popular are 2x2, 4x4, 8x8 QAM for 2, 4, & 6 bits/Baud. Very BW efficient, but very complex. Today’s modems:

|  |  |  |  |
| --- | --- | --- | --- |
| ITU-T | Baud Rate | Bit Rate | Modulation |
| V.21 | 300 | 300 | FSK |
| V.22 | 600 | 1200 | 4-PSK |
| V.23 | 1200 | 1200 | FSK |
| V.26 | 1200 | 2400 | 4-PSK |
| V.27 | 1600 | 4800 | 8-PSK |
| V.29 | 2400 | 9600 | 16-QAM |
| V.32 | 2400 | 9600 w/ ECC | 32-QAM |
| V.32bis | 2400 | 14,400 | 64-QAM |
| V.32terbo | 2400 | 19,200 | 256-QAM |
| V.33 | 2400 | 14,400 w/ ECC | 128-QAM |
| V.34 | 2400 | 28,800 | 4096-QAM |

Note: the capacity of a phone line is given by its BW of 3kHz and SNR of 35 dB to be:

C = 3 kHz \* log2 (3162+1) = 3 kHz \* 11.6271 = 34.881 kbps (@45dB, Cap = 44.846 kbps)

**13.3: Loopbacks, Error Rates & Eye Patterns**

Loopback simply re-sends the received signal back to the source. Any bit differences from the original

signal = error.

BER in loopback = worst-cast, since it includes noise in both paths.

Loopback is usually a built-in diagnostic mode, remotely triggerable by a simple command.

BER must be tested with EDC disabled, else the EDC masks the diagnosis.

Common test patterns: all 1's, all 0's, alternating 1/0's, and PRBS.

2 other common measurements: %age total seconds w/o errors

%age total frames w/o errors

These two (either or both), along with BER, help greatly in troubleshooting a channel. Discuss what

one tells you that the other does not. (Burst characteristics of noise)

\*Eye patterns: show all the analog variations in the channel (\*Fig 13.12, p. 378)

For QAM, 2 eye patterns, one above the other; one for I, other for Q.

**13.4: Random Bit Generation & Data Encryption**

PRSQs meet all the main criteria for randomness, but are repeatable and predictable, if you know the

\* key. Examples: (\*Fig 13.15, p. 382)

\*\*Encryption: need, & some methods (\*\*Figs 13.16, 13.17, pp. 383, 384)

**CHAPTER 14: TV/VIDEO AND FACSIMILE**

**14.1: Imaging Basics**

\*Basics of a monochrome TV image conversion to a time-varying voltage (\*Fig 14.1, p. 389)

To convert to signal, we used a vidicon (a vacuum tube detector of light, scanned like a CRT); now we use CCDs (charge-coupled devices) or CMOS sensors - inherently pixellated.

Resolution: 525 lines/screen (frame); x resolution approximately 384 pixels.

\*Image reconstructed in reverse, using another type of vacuum tube, the CRT (\*Fig 14.2, p. 390)

Need for sync in vertical frame and horizontal line. Sweep is done at 60 Hz \* 525/2 = 15.75 kHz (which accounts for the high-pitched whine some people can hear in some TVs.)

The eye perceives a continuous image, because of the image retention of the eye (look at something, then

close your eyes; notice a small delay from when you close your eyes to when the image disappears).

Interlacing: solution to insufficient BW for 525 frames @ 60 Hz; lower refresh rate = flicker. The mind stitches the interlaced signals together, since there is very little difference between the adjacent lines.

**14.2: The TV Signal**

Electronic Industries Association (EIA) defines RS-170, the exact timing and voltage levels for a TV

\* signal (\*Fig 14.3, p. 394)

Each visible field has 485 lines; the vertical blanking interval occupies the remaining lines. Since no video signal is needed in these lines, they are used for transmitting closed-captioning and occasionally other services

\*Bandwidth required (\*Fig 14.4, p. 395)

Video uses AM, vestigial sideband, as opposed to:

SSB-SC: complex to create, even more complex to demodulate

DSB-SC: more BW, but less wasted carrier power; difficult to demodulate

Conventional AM (DSB-AM): more BW, more wasted carrier power, easy to demodulate

Audio uses narrowband FM (±25 kHz)

Different types of modulation between video and audio prevents intermodulation artifacts

Digital TV:

256 gray levels = 8-bit resolution; 485 lines @ 384 pixels/line, 8-bit resolution, 30 frames/sec =

44.7 Mbps, which ≈89 - 223 MHz BW; ergo, digital TV = impossible in given 6 MHz BW slots.

**14.3: Color TV**

Amazing things went into modifying RS-170 to allow for color; had to be downward compatible, also.

The new definition was NTSC color (National Television Standard Committee), in 1953; the US standard. The actual complexity is far beyond this class.

RGB: an AM signal for each color; high frequency, short distance only; goes directly to circuitry which

modulates intensity of each color.

Pixels on screen made up of 3 dots (check out with a magnifying glass)

Other countries developed their standards later, when better technology was available, but still using the

6-MHz BW; these are PAL and SECAM, and are incompatible with NTSC.

Set-top boxes: use from 10 MHz to several 100 MHz, allowing for many channels; convert tuned channel to channel 3 or 4 for TV.

**14.4: TV Receivers**

Reiteration of author’s point: TVs may be cheap, but they are far from simple. The circuitry required must have excellent frequency response, tight filtering, low drift, high stability, precision of amplitude frequency and phase, and tight matching. That we figured out how to do this for a reasonable price 50 years ago is absolutely amazing.

\*Demodulator (\*Fig 14.6, p. 402) - excellent discussion in the book, but beyond this class.

**14.5: Facsimile**

Uses digital, not analog, transmission, but uses 3kHz BW of phone lines. Standard was 200 pixels/inch,

or 1700 bits/line. No gray scale used; all off or all on for each point on the image.

Vertical resolution = 100, 200 or 400 lines/in. 8½ x 11" = 1700 bits/line \* 1100 lines (at lowest resolution) = 1.87 Mbits; at 2400 Baud, = 13 minutes (impractical).

Compression techniques make this manageable.

Long sequences of identical information (white space, especially)

Frequently repeating codes can be encoded

Similarity between lines can be exploited, and only the changes transmitted

Results in more complexity in the fax machines (both for compression and de-compression), but dramatically reduces the transmit time.

Book has great box on early fax machines.

**14.6: MPEG Encoding, Digital TV, and Broadcast Direct Satellite TV**

MPEG (Moving Picture Experts Group) standardized video compression into MPEG-2, and later MPEG-3, which also included a standard for audio compression (now known as MP3).

Only transmits the changes between frames; reference frames sent occasionally for new scenes and

to allow for recovery.

Is a *lossy* (not *lousy*) compression technique, creating some artifacts.

Artifacts of digital images:

Failure is digital; either the picture is perfect (no snow, etc.), or it freezes (keeps last known good picture until next good one arrives), or no signal is displayed at all (the infamous blue screen).

HDTV: in your store today! Only $2000-$5000. Uses lots of compression; depends on excellent SNR; not yet as robust as it needs to be; uses 16:9 aspect ratio of movies; has about 4x more pixels than NTSC, but is all digital and (presently) incompatible with NTSC (just has an NTSC tuner, also). Shows how far we have come since the author finished this edition (1999; I think he didn’t update this part since his 1996 edition, since it seems about 6 years old).

HDTV @ 1080 x 1920 p = 2,073,600 pixels x 3 colors/pixel = 6,220,800 subpixels

X 60 frames/sec = 124,416,000 pixels/sec x 24 bits/pixel = 2.986 Gbps (over a 6 MHz BW?!)

**CHAPTER 15: FREQUENCY SYNTHESIZERS AND DIRECT CONVERSION**

**15.1: Direct and Indirect Synthesis**

Direct synthesis (creation of the clock for demodulation) was used for decades, using crystals as the

reference source, but this had many drawbacks.

Indirect synthesis uses PLLs in various arrangements to create the desired frequencies, with very little

extra circuitry, and making the tuner microprocessor controllable. Uses a single crystal as the

reference, from which all others are generated. The heart of digital tuners.

**15.2: Basic Indirect Synthesis**

\*Using the basic circuitry of \*Fig 15.3, p. 426 (note error on mixer), the PLL can be used to generate essentially

any frequency. Example: with Fref = 50 Hz and modulo = ÷ 20,000 to 40,000, the VCO steps from

1,000,000 Hz to 1,000,050 Hz to 1,000,100 Hz, etc.

The way in which the PLL operates is a function of several analog parameters, depending on the VCO,

the reference oscillator, the phase detector, and the feedback filter; and also the divider somewhat.

**15.3: Extending Synthesizers**

PLLs have a practical frequency range of only about 100 MHz, which would severely limit their applica-

\* tion in modern digital tuning. Use of a fixed *prescaler* (\*Fig 15.6, p. 431), implemented in a very fast logic

such as ECL, allows operation up to the multiple GHz. If the entire PLL and modulo N divider were

implemented in ECL, it would take far too much power.

Dual-modulus prescalers solve the problem of the increased step size that the above creates.

**15.4: Synthesizers and Microprocessor Systems**

The addition of a microcontroller significantly adds to the flexibility of such a tuning system. The text

gives an example of using the National DS8907 synthesizer w/ a microcontroller to accomplish this.

**15.5: IF-to-Baseband Conversion, Undersampling, and Wideband Digital Receivers**

Undersampling the carrier, but Nyquist sampling of the modulating signal, in phase with carrier, gives

the demodulated signal directly; no mixer, IF, or demodulating circuit needed!

Can’t get something for nothing (as usual); such a converter needs a BW equal to the carrier freq, which

can be hundreds of MHz or a few GHz. Sampling rate only needs to be appropriate for modulating

signal.

**CHAPTER 16: THE TELEPHONE SYSTEM**

**16.1: Overview of the System**

Uses switched circuits. What would happen if a dedicated line were needed for each call from each person to each potential receiver? Uses the analogy of roads: low-speed, small capacity roads in the residential areas; higher-speed, higher-capacity arteries in larger areas; high-speed, high-capacity interstates for the long haul. Similarity ends there.

Uses a *hierarchy* of small, medium, and large switching centers. Lowest level: *local loop*, connecting to

the *central office*, one central office per *exchang*e (first 3 digits of phone #). Provides BORSHT

(Battery feed, Overvoltage, Ringing, Supervision, Hybrid, Test, or BORSHT). Next level is the  *trunk*, connecting the exchange to other exchanges. Next level is the *supertrunk*, combining many trunks. Each area code is a different major center.

Routing is the tricky thing, but in general, there are many redundant choices for routing a connection,

depending on traffic, noise, outages, etc. Results in a vastly complex infrastructure which is extremely robust.

**16.2: The Telephone Instrument and the Local Loop**

\*POTS: plain old telephone service, no frills. Signals: (\*Fig 16.4, p. 451)

A great variation in signal levels and line impedances must be tolerated (0 dBm to -42 dBm; 200 to

1200 Ω).

\*Pulse dialing: reliable and cheap, but allows no special codes or signals (\*Fig 16.5, p. 453). Example of my

dialing a # with the hangup button only.

\*Tone dialing: much faster, but requires PLLs to detect tones, and logic to decode the PLL outputs. (\*Fig 16.6, p. 454). This is termed *dual-tone multi-frequency* (DTMF) dialing. Note the advantage of transparency of signals available in DTMF (try pushing a button while talking), and the absence of the availability of transparency in make/break pulse dialing.

Methods of generating the DTMF tones: 8 analog oscillators (we know those problems!), or 1 master

\* oscillator with crystal stability, and variable ÷N ratios (\*Fig 16.7, p. 456)

Line grades: anything better than POTS (which has a large variation) is termed *leased, conditioned, or dedicated*; POTS is *dial-up* or *switched*.

Why does all this matter, if we are only interested in sending digital information?

**16.3: The Central Office and Loop Supervision**

Home of the SLICs (subscriber loop interface circuit); one for each subscriber. Provides BORSHT. A

\* rather complex series of events (\*State machine: Making a Phone Call)

All the functions of the SLIC, which used to occupy a good-sized PWB, are now on a single IC, such as the Motorola MC3419.

**16.4: The Central Office and Switching**

The actual switching used to be done by the operator (switchboard operator), using plugs. Then it progressed to relays, then reed relays. Now we use a single CMOS IC with decode logic and a large switch matrix (12 x 8). This can steer any of the 8 incoming lines to any12 of the outgoing lines. Can be combined with more to form any array needed.

The transition from 2-wire to 4-wire (for full-duplex) is also at the central office.

Trunks (connections between central offices) are a much more tightly controlled channel than the local

loop, with much better performance. Also include repeaters (analog) or regenerative amps (digital) to

keep SNR and signal quality high.

Direct Distance Dialing and the Worldwide Numbering Plan - fascinating reading, but not required. Explains the history of direct dialing and area code assignments, plus each part of a phone number.

**16.5: Electronic Switching Systems**

As you might expect, these came with all the advantages of all electronic things replacing mechanical

\* ones: reliability, lower power, much greater flexibility, many more features. Operation: (\*Fig 16.15, p. 471)

Features include the very popular *camp-on, speed dialing, call forwarding, call blocking, caller ID*, and many others for highly specific applications.

A PBX (private branch exchange) or a PABX (private automated branch exchange) is one within a company or organization.

Problem created by using a talking trunk for the signaling information; solution by using out-of-band signaling on separate high-speed channel, to prevent occupying the talking trunk.

Call tracing with an ESS, compared to the old switch systems

**16.6: Echoes and Echo Cancellation**

Echo is a reflection of the original signal, due to an imperfect match between impedances (TDR!) Actual line distances can be significantly longer than physical distance, due to routing. Echo is annoying to talkers, but highly perturbing to digital data.

\*Echo suppression by signal subtraction (\*Fig 16.18, p. 478). Requires continuous adapting of signal levels and

delay times to effectively cancel echo.

DSP is a relatively new approach, and is very effective.

4-wire all the way also works, but requires absolutely no hybrids (2-4 wire conversions) along the way.

**16.7: Digital Signals and Switching**

The long transition from analog, to mixed digital and analog, and finally to straight digital, is underway.

ISDN (Integrated Services Digital Network) is a protocol for managing a purely digital network.

(8 ksps = 125 μs/sample)

**CHAPTER 17: THE RS-232 INTERFACE STANDARD, MODEMS, AND HIGH-SPEED POTS LINKS**

**17.1: Role of the Interface Standard**

EIA (Electronic Industries Alliance - merged with Telecommunications Industries Alliance in 1991) RS (recommended standard) 232: probably THE most common low-to-moderate performance interface standard.

DTE: source or sink of data

DCE: takes signal from DTE and makes it compatible with physical link.

Specifies a link capable of 50 ft and 20 kBaud, although longer ones have been implemented.

Usually uses ASCII, but not necessarily.

**17.2: RS-232 Operation**

\*+3V to +25V = 0; -3V to -25V = 1 (received end); transmitted end = +**5**V to +25V = 0, -**5**V to -25V = 1

(\*Fig 17.2, p. 487)

\*25 pins defined, 22 defined (\*Fig 17.3, p. 489). Most heavily used = 2,3,7. Four groups: data, control, timing,

\* secondary functions (\*Fig 17.4, p. 490; note Control error)

Baud rates: 110, 300, 600, 1200, 2400, 4800, 9600, 14,400, 19,200; some exceed the specification at 38.4 kBaud for a given implementation.

Connectors: DB-25, DB-9; as needed in a specific implementation (setup at Snow College)

Control lines allow for handshaking, for interface between intelligent devices. Use of a buffer for faster

(more efficient) transfer

**17.3: RS-232 ICs**

UART for interface management

1488 (line driver) and 1489 (line receiver) for translating from TTL (common signal levels) to RS-232

\* levels (\*Fig 17.11, p. 497)

**17.4: RS-232 Examples and Troubleshooting**

Example of digital voltmeter connected to computer; audio frequency spectrum analyzer output to computer; file format

*Null modem*: a simple cable with pins 2 & 3 crossed, to allow a very simplistic interface.

Troubleshooting RS-232 interfaces: (see box, p. 503)

First check the settings to verify they are both the same (on Rx & Tx ends) (baud rate, parity, # of stop bits)

Next check the cable and connectors; verify proper signal lines and physical connections

Next check the signal levels and interface lines

Check for message terminator definition

**17.5: Modem Functions**

\*Major functional blocks of a modem (\*Fig 17.16, p. 505)

FIFOs eliminate the need for handshaking between each character, and allow blocks of data to be sent

between handshakes.

Checksums and EDC allow for even more improvement in data transfer rates.

**17.6: Standard Modems for POTS Lines**

Bell 103 and 212 modems: a standard for decades

Note that fax modems differ in function and are not inherently compatible with data modems.

Most modem standards, for many years, have been defined by the CCITT of the ITU (International

Telecommunications Union). Fig 17.23 has a great summary.

56k modems: utilize a fully digital front end, bypassing the A/D stage at the local loop send end; it is

converted back to analog for the receive end local loop.

**17.7: Other “RS” Communications Standards**

\*Summary of RS-232: 50 ft, 20kBaud, point-to-point, single ground, ±25V. Each is a limitation. (\*Table) (1969)

RS-423: 4000 ft, 100kbps, 10 receivers for 1 driver, ±3.6V to ±6V, single-ended. (1979)

RS-422: 4000 ft, 10 Mbps, 10 receivers for 1 driver, ±2V to ±6V; differential signals. (1978)

RS-485: 4000 ft, 10 Mbps, 32 receivers and 32 drivers (only one active at a time; others are three-stated), ±1.5V to ±6V; differential signals. (1983)

**17.8: High-Speed POTS Links Using xDSL**

What? 100k or 1M on POTS? Out-of-band signals can actually pass, up to MHz, but these will be:

Low amplitude Distorted Corrupted by noise

All the above are time-varying, depending on other conditions.

Solution? DSP! Plus known reference signals which are monitored to determine time-varying conditons

\* on the line. Summary of options (\*Fig 17.28, p. 521) Also used: FEC, echo cancellation, complex coding and modulation patterns.

What did you think of DMT, and the analogy to moving lots of bricks with 256 workers? I hope it gives

you some appreciation for the complexity of today’s digital transmissions! (P. 522, in main text)

From: “DSL Dominates Broadband Worldwide”, by Louis E. Frenzel; *Electronic Design*, Mar 29, 2007

The real limiting factor is the length of the local loop. Typical length of local loop = 5000 feet (about

1500 meters) to as much as 18,000 feet (about 5500 meters) in rural areas.

Uses OFDM (orthogonal frequency-division multiplexing).

Existing local loops have loading coils (inductors), bridge taps (act as transmission line stubs), and

lots of crosstalk.

Divided into 256 voice channels, each 4.3125 kHz wide.

DSLAM = DSL access multiplexer.

VDSL2 (very high data rate DSL) can do 100 Mbps, dividable as needed for asymmetry.

|  |  |  |  |
| --- | --- | --- | --- |
| Common Versions of ADSL | | | |
| Type | ITU Standard | Maximum downlink speed | Maximum range (ft/m) |
| ADSL | G.992.1, G.992.2 | 768 kbps to 8 Mbps | 18,000 / 5500 |
| ADSL2 | G.992.3, G.992.4 | 5 to 12 Mbps | 12,000 / 3600 |
| ADSL2+ | G.992.5 | 10 to 24 Mbps | 8000 / 2400 |
| G.SHDSL | G.993.1 | 5.6 Mbps up/down | 12,000 / 3600 (data only) |
| HDSL | G.991.1 | 2.3 Mbps up/down | 12,000 / 3600 (two pairs) |
| VDSL | G.993.1 | 13 to 55 Mbps | 4500 / 1375 |
| VDSL2 | G.993.2 | 10 to 100 Mbps | 5000 / 1525 |

**CHAPTER 18: LOCAL AND WIDE AREA NETWORKS; SPECIAL-PURPOSE LINKS**

**18.1: Network Applications**

Think of the network applications we have today, which we did not have 15 years ago.

Access to all university libraries nationwide, and more

Searchable indices to nearly all important databases for research

Tracking of satellites worldwide, regardless of orbit & location on Earth

Tele-commuting; having workers world-wide, to allow 24-7 support.

4 elements of an interface standard:

Mechanical (physical cable) Electrical (voltages & currents, patterns)

Functional (interface signals) Operational (messages)

Differences from phone system

Users usually united by something

Users share single connecting medium, instead of each having a dedicated line

Requires much more elaborate headers

Requires a more elaborate protocol (rules of the connection)

**18.2: Topologies** (Dictionary: topology = basic geometric shape, unchanged by stretching or bending)

4 basic topologies: 1-to-all star bus ring

Evaluation criteria:

Required cabling or paths Flexibility for sending messages

Expansion potential Reliability in case of problems

Ease of protocol management

Node: point at which a user is connected to the network

Hub: interconnection point for multiple users

\*Comparison of 4 topologies (\*Figs 18.1-18.4, pp. 530, 531, 532)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Criteria | One-to-all | Star | Bus | Ring |
| Required cabling | Grows quickly with # of nodes:  (n²-n)/2 | Only requires one connection for each node | One common bus connection, shared | One cable for each node |
| Expansion potential | Very impractical for large # nodes | Very practical for large #; phone system uses it. However, new line for each user | Very practical for large #; Ethernet uses it | Very practical; requires briefly breaking ring to add node |
| Ease of protocol management | Simple protocol (no collisions!) | Simple; no collisions! | Much more complex to handle collisions | Complexity simpler than bus (uses *token*) |
| Flexibility for sending messages | Software must be modified for each addition or change | Hub-central, but robust otherwise | Very flexible but cannot guarantee  response time | Highly flexible; guaranteed response time |
| Reliability in case  of problems | Robust; 1 failure affects only a few | Easy to fix; hub failure affects all unless more paths are installed | With *watchdog*, very robust, but bus-central | One failed node can stop ring; sol-utions available, however |

**18.3: Protocols and Access**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Protocol→**  **Characteristic** | **Command/Response (aka Master/Slave)** | **Interrupt-Driven** | **Token-Passing** | **Collision Detection** |
| **Message passing** | Requires 2 for each transmission, 4 for slave-to-slave | Master waits for interrupts, then quickly responds | Any node may originate, when token comes | Any node may originate using CS then CD |
| **Simplicity** | Very simple | Very simple | Relatively simple | Relatively simple |
| **Effectiveness** | Very high for small # of nodes | Very high for small # of nodes | Very high | Very high |
| **Master dependency** | Completely | Completely | No | No |
| **Example** | Central computer requests information from POS terminals | Keyboard, mouse, sensors | Ring topology | Ethernet |
| **Advantages** | Simple, fast | Simple, fast | Deterministic | Widely adopted |
| **Disadvantages** | Not practical for large # of nodes | Not practical for large # of nodes | Wait time depends on # of nodes | Nondeterministic |

**18.4: Network Examples**

Some standards are open (published), others proprietary (not published).

IEEE: 802.3 = CSMA/CD for baseband and broadband systems

802.4 = token passing for baseband and broadband bus

802.5 = token passing for baseband rings

AppleTalk (see summary table)

Bus, with up to 32 nodes 17 Ω/300 m Variation of RS-422

Serial Zo = 78 Ω 230.4 kbps

Single twisted pair, shielded C = 68 pF/m FSK

Max distance = 300 m Frame format = SDLC Message length = 1 - 1000s

MAP - Manufacturing Automation Protocol

Developed primarily to tie manufacturing equipment together

Ethernet - developed as a moderate alternative to IBM’s Token Ring and other network standards; has become almost a defacto standard for networking

IEEE-488 - aka GPIB, or General Purpose Interface Bus, developed primarily to tie together test equipment. Up to 15 devices on bus; baseband; device addresses for each instrument (set on each)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | AppleTalk | MAP | Ethernet | IEEE-488 |
| Topology | Bus | Ring | Bus | Bus |
| Protocol | SDLC | Token passing | CSMA/CD | Controller/Talker/Listener |
| Modulation | FSK | FSK | Manchester | Baseband |
| Data Rate(s) | 230,400 bps | 5, 10 Mbps | 10M,100M,1G | 1 Mbps |
| Max Distance | 300 m |  | 500 m | 20 m |
| Cable | Single twisted pair, shielded |  | CAT-5; Coax;  Fiber | Special 24-conductor cable |
| Serial/Parallel | Serial |  | Serial | Parallel (8 bits) |
| Msg Length | 1-1000s bits |  | Variable | Variable |

Test equipment for networks: network analyzers; get ‘em in IT 347!

**18.5: Wide Area Networks and Packet Switching**

Geographic separations: EAN (in 1 building), LAN (only local buildings), MAN (city-wide), and WAN

(spanning multiple cities).

Here, separate lines for each connection are essentially impossible, so the data stream is split up into packets, each separately addressable. Analogy of mail system (messages split up into paragraphs, each in a separate envelope), versus dedicating one circuit. One big difference: you can increase the % utilization of the communication link, since you don’t have to transmit the lulls in converstation, etc. Such systems have no guaranteed delivery time, and are quite complex. Known as *store-and-forward* systems.

One very big issue in today’s networks: QOS. Very complex to implement, but being aggressively pursued due to its tremendous advantages and cost rationale. Those who need guaranteed delivery times can pay for it; if you only need an email sent, it’s cheap!

Five elements: 1) delay (latency), 2) delay variation (jitter), 3) PLR (pakt loss r), 4) availability (uptime), 5) data transfer rate (throughput).

“For example, based on experimental results, for an acceptable voice conversation over the Internet, one reference recommends a latency below 200 ms, a delay variation of about 30 ms, and a PLR below 1%. When looking at InternetTrafficReport.com, the average global Internet response time (round-trip time) over 30 days (Aug 16 – Sept 15, 2008) is 130 ms, which means that latency is roughly 65 ms. On the other hand, the average PLR is about 2%. The maximum values are 85ms for latency and 27% for PLR. These values indicate that while latency is generally acceptable, the PLR is too high for voice conversations over the Internet. Unfortunately, jitter is not reported.” (Aref Meddeb, “Internet QoS: Pieces of the Puzzle”, *IEEE Communications Magazine*, Jan 2010, p. 87.)

\*The ISO (International Organization for Standards) OSI (open systems interconnection) model (\*Fig 18.15, p. 552). This class covers only layers 1 & 2. IT 347 reviews these, then moves into all the subsequent layers. Note: this class also covers many details under layer 1! Note also the relationship

\* between a *gateway,* a *router,* and a *bridge* (\*Fig 18.16, p. 553)

**18.6: Advanced Networks: ISDN, SONET, FDDI, and ATM**

ISDN: Integrated Services Digital Network. Available from most phone companies at a premium; another phone line to your house, without any analog between you and the PBX.

SONET: Synchronous Optical Network. OC-1 is high enough that it is usually made up of many muxed

lower-rate data streams. Up to 500 nodes

FDDI: Fiber Distributed Data Interface - for very fast LANs

ATM: Asynchronous Transfer Mode. Made for many types of payloads. Specifies only the packet, and switching protocol; does not specify the physical layer at all.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ISDN | SONET | FDDI | ATM |
| Topology | Bus | Bus | Ring |  |
| Protocol |  |  | Token passing |  |
| Modulation |  |  | 5/4 encoding |  |
| Data Rate(s) | 192,000 bps (64+64+16+48) | OC-1=51.84Mbps; other multiples | 100Mbps |  |
| Max Distance | 2500-6500 m |  | 100 km |  |
| Cable | Dual twisted pair, shielded | Optical fiber | Optical fiber |  |
| Serial/Parallel | Serial | Serial | Serial | Serial |
| Msg Length | Variable | Variable | Variable |  |

**18.7: The Internet and the World-Wide Web**

The Internet

The WWW: rides on the Internet

Uses TCP/IP (Transmission Control Protocol/Internet Protocol), a highly adaptable specification for breaking messages into packets, which can then be sent anyway we wish.

**18.8: Special Networks: Firewire, Universal Serial Bus, IrDA, and Home Automation**

Each network is a mix of tradeoffs between speed, reliability, COST, data rates, achievable distance,

power consumption, flexibility, ruggedness, other factors.

Firewire: (IEEE 1394) - intended for interconnecting digital consumer devices, live. Autoconfiguring; up to 63 devices;6 lines (two differential pairs, Data [NRZ] and Strobe plus 2 power). XOR of Data and Strobe gives recovered clock. 100 M, 200 M, and 400 Mbps. Maximum distance about 15 ft.

USB (Universal Serial Bus) - intended for interconnecting consumer computer devices, live. Up to 127

devices; 4 lines (signal pair, power, ground). Maximum distance about 16 ft (5 meters); USB 3.0 = 4 Gbps, 1V, 8 wires (4 differential pairs).

IrDA (Infrared Data Association) - wireless interface, distances 1-3 m, 115.2 kbps up to 4 Mbps now. A

point-to-point link.

Home automation: CEBus, Smart House, X-10

**18.9: Spread-Spectrum Systems**

No longer need be only narrow-band! Turns the entire concept on its ear.

Where used: military (for many years); other more common apps in cell phones, even home portable phones.

Two methods: FHSS (frequency-hopping SS) and DSSS (direct-sequence SS). Both difficult to detect

and jam; this also means more immunity to noise.

FHSS: transmitter changes frequencies in a pseudo-random manner; only a receiver following the

same hopping pattern catches all the signal.

\* DSSS: (\*Fig 18.28, p. 578) - also spreads out the signal in spectrum, and also cannot be recovered without

having the pseudorandom chirping pattern used at the transmitter. Receiver reverses this.

Another big advantage of SS techniques is the spectral sharing it allows via CDM (code division multi-

plexing). If two transmitters used completely uncorrelated pseudorandom sequences, they would never transmit on the same frequency at the same time, and could thus share the spectrum simultan-

eously. The degree to which PR codes in the same band avoid overlapping is termed their  *orthogonality*, and only a very few codes are completely orthogonal. However, some non-orthogonality can be tolerated with ECC.

IEEE 802.11 defines FHSS and DSSS, layers 1-3.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Channel Capacity Problem:

**A -------------------→** Noise = 275 µW; Attenuation = 46 dB (wattage) --------------------→**B**

Tx power = 50 dBm Find: 1. Rx power (mW)

Tx channel: 964 – 972 MHz 2. Rx SNR (dB)

3. Capacity (Mbps)

1. Rx power = 50 dBm – 46 dB (wattage) – 4 dBm = 2.512 mW
2. Rx SNR = 2.512 mW / 275 µW = 9.134 = 9.607 dB
3. Capacity = BW \* log2 (1+SNR) = 8 MHz \* log2 (1+9.134) = 8 MHz \* 3.34 = 26.729 Mbps

**CHAPTER 19: SATELLITE COMMUNICATION, NAVIGATION, AND THE GLOBAL POSITIONING SYSTEM**

**19.1: Communications and Orbits**

Overcome limitations of *line-of-sight* communications links. Each has a separate *uplink* and *downlink*.

Terms to know:

line-of-sight

uplink and downlink

footprint

LEO (typically ≈**17,000 mph**, from 150 - 500 miles altitude; some much more - GPS = 10,900 mi)

geosynchronous (GEO) (@23,000 mi, or ≈27,000 mi radius, ≈170,000 mi circumf = **7070 mph**)

Orbits: from 50 miles to 23,000 miles, with orbital time proportional to height.

Frequencies: 1 GHz to tens of GHz. Reasons:

Greater BW Consistent propagation characteristics Lower external noise

Short λ = small antennas

\* Note frequency bands (\*Fig 19.4, p. 592)

**19.2: Satellite Design**

VERY complex systems, including applications of rocketry, high-freq electronics, mechanics, antennas, and a complex earth-based support system. Typical satellite: 100s to 1000s of lbs, $50M-$100M, plus launch fees of about $5,000 - $10,000/lb, 10-year design life (usually limited by thruster rocket fuel)

Orbits: <http://liftoff.msfc.nasa.gov/RealTime/JTrack/3D/JTrack3D.html> - awesome!

Communications channel is a classic application of the amplifier/repeater scenario; received data is simply retransmitted (after processing) for the downlink.

**19.3: Ground Stations**

\*Diagram of ground station (\*Fig 19.7, p. 600)

\*Sample link budget (\*pp. 601, 602)

Read the box about Voyager 2 - absolutely fascinating!

**19.4: LORAN Navigation**

Long-Range Navigation: developed during WW2; major aid for many years. Now being phased out as

GPS has replaced it quite effectively. (GPS is 24 satellites; 3 needed, 4th provides additional accuracy

and elevation).

There is a MASSIVE need for effective navigation aids. It is absolutely amazing the long-distance voyages made long ago, with nothing more than compasses and sextants.

**19.5: Satellite Navigation**

Global Positioning System: 18 satellites; 4 always in view, each with a transmitter of ID, its location, &

current time. Redundancies exist, and X,Y,Z position can be fixed within about 3 meters.

Uses PRBS patterns to transmit timing information. Line the patterns up, correlate the phase, and you

have an exact time reference. (Refer to Fig 19.12, p. 605)

From “GPS Takes a Global Position in the Portable Market”, by Louie E. Frenzel; *Electronic Design*,

May 10, 2007, pp 47-54. (In Classes\327\GPS article.pdf)

AKA Navstar; in operation since early 1990s. Continual upgrades have repeatedly improved resolution.

Specs: 24 operational satellites, at least 3 spares; orbit = 12,548 mi, or 20,200 km; 6 orbits with 4

satellites each; rotational period = 2 minutes < 12 hours; at least 5 (up to 8) satellites always in view

from anywhere on Earth. Each satellite has 4 atomic clocks; each has its own PRC, repeating every 1023 bits; navigation data sent at 50 bps (!); L1 (public) and L2 (military; sometimes encrypted)

signals; longitude and latitude needs 3 satellites; velocity and altitude needs 4; enhancements include

differential (DGPS), wide-area augmentation system (WAAS), assisted (A-GPS), all of which improve on the basic 10-meter resolution for commercial receivers (1 meter for military)

Note: one receiver’s sensitivity is spec’d at -158 dBm! (P. 50, col 2).

**CHAPTER 20: CELLULAR TELEPHONE AND ADVANCED WIRELESS SYSTEMS**

**20.1: The Cellular Concept**

\*Fig 20.2, p. 619, using higher-powered base station at center of each cell. (Highlight each cell type)

Trickiest part of the system: handovers

Issues: available channels; direction of movement; when to handover; maintaining connection

Drawbacks: no service where there are no base stations, and no base stations where there are few people.

Note the difference between a portable home phone and a cell phone

More channels? Just split the cells into smaller cells, and reduce the power!

Cell shapes: determined by antenna design, geographical interference features, other factors

**20.2: Cellular System Implementation**

Uses digital setup channel. Creates a system which is nearly the same to the user as the POTS we’re all

accustomed to.

Base station issues signal strength commands to handsets, from 3W (max) to .7W (min) in 1-dB steps.

MTSO: mobile telephone switching office - links together all the base stations.

Transmit frequencies from 825 to 845 MHz; receive frequencies from 870 to 890 MHz; 45 MHz separation between tx & rx frequencies. Narrowband FM, ±12 kHz, BW=30 kHz; no guardbands

used.

Recent allocations: (Wikipedia: GSM frequency bands)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **System** | **Band** | **Uplink (MHz)** | **Downlink (MHz)** | **Channel number** |
| T-GSM-380 | 380 | 380.2–389.8 | 390.2–399.8 | dynamic |
| T-GSM-410 | 410 | 410.2–419.8 | 420.2–429.8 | dynamic |
| GSM-450 | 450 | 450.6–457.6 | 460.6–467.6 | 259–293 |
| GSM-480 | 480 | 479.0–486.0 | 489.0–496.0 | 306–340 |
| GSM-710 | 710 | 698.2–716.2 | 728.2–746.2 | dynamic |
| GSM-750 | 750 | 747.2–762.2 | 777.2–792.2 | 438–511 |
| T-GSM-810 | 810 | 806.2–821.2 | 851.2–866.2 | dynamic |
| GSM-850 | 850 | 824.2–849.2 | 869.2–894.2 | 128–251 |
| P-GSM-900 | 900 | 890.0–915.0 | 935.0–960.0 | 1–124 |
| E-GSM-900 | 900 | 880.0–915.0 | 925.0–960.0 | 975–1023, 0-124 |
| R-GSM-900 | 900 | 876.0–915.0 | 921.0–960.0 | 955–1023, 0-124 |
| T-GSM-900 | 900 | 870.4–876.0 | 915.4–921.0 | dynamic |
| DCS-1800 | 1800 | 1710.2–1784.8 | 1805.2–1879.8 | 512–885 |
| PCS-1900 | 1900 | 1850.2–1910.2 | 1930.2–1990.2 | 512–810 |

665 tx and rx channels assigned (per cell).

Cell phones have come WAY down in cost and up in features, and will continue to for some time.

**20.3: Cellular System Protocol and Testing**

Digital cellphones have been around for about 25 years (book says cellphones are analog).

No single phone company may own more than half the available channels per cell. This gives 333 (or

332) channels per company per supercell, and 45 user channels/company/cell, with 17 or 18 used for

control channels (again per cell).

Each full-duplex call requires two full-duplex channels (tx & rx, plus control)

The actual protocol for the control channels is quite complex (covered on p. 624 & Figure 20.7)

Digital color code (DCC) identifies the control channel uniquely, for handover control.

Note that companies such as HP (now Agilent) make complete test equipment for cell phones.

**20.4: Advanced Wireless Systems**

\*Digital cellular phone (\*Fig 20.9, p. 637)- see anything we recognize?

GSM (Global System for Mobiles) standard (Europe & elsewhere):

8 ksps, 13-bit resolution = 104 kbps

Compression reduces this to 13 kbps (GPRS = General Packet Radio Service)

EDC bits increase this to 22.8 kbps

Many functions implemented with DSPs

GSMA now developing better SMS, 3 & 4GSM; wider deployment EDGE (Brazil, Nairobi, per Dec 03)

IS-54 TDMA standard (North America):

Same basic concepts as GSM, but different compression and EDC algorithms.

Allows users to “hold” a channel only as long as they are using it; in the lulls, the channels are shared

with other users.

IS-95 CDMA standard

Uses approach 1 of spread-spectrum approach (summed with PRBS).

Requires that all phones within a cell have the same received power (at base station), to avoid domi-

nation by one phone.

A very robust system, otherwise.

\*Fig 20.10, p. 638 - note the forever tradeoff between distance and datarate.

Figures 20.11 and 20.12 - excellent comparison of all the advanced (digital) wireless communication

standards. cdma2000 1EV-DO: near-3G; 120 kbps. EDGE (enhanced datarate for GSM evolution):

8PSK modulation; max of 180 kbps

Bluetooth: invented in 1994 by Ericsson (Sweden), later acquired by Sony. King Harald “Bluetooth” Gormsson of Denmark; died 985 AD. Credited for uniting Denmark & Norway and turning the Danes to Christianity; generally thought of as a good king. Loved blueberries, which stained his teeth. Bluetooth logo is the runic alphabet characters for H B.

MIMO

UWB

SDR & Cognitive Radio

**CHAPTER 22: MULTIPLEXING**

**22.1: Introduction to Multiplexing**

Multiplexing allows multiple signals to occupy the same space or frequency or time; change one of these

and sharing is possible.

Space division multiplexing (SDM): transmitters spaced physically far enough apart so as to not interfere. Examples: phone system links; satellite channels; TV and radio stations; cells in cellphone systems

Frequency division multiplexing (FDM): transmitters spaced spectrally far enough apart so as to not

interfere. Examples: Cable TV; TV and radio stations in a population center; cell channels within a cell; multiple satellite channels in a satellite; wave-division multiplexing in optical fiber; allocation of the electromagnetic spectrum. Note that **code-division multiplexing** is a very special case of this.

Time division multiplexing (TDM): sharing of a single channel by allocating a time slice to each user.

Examples: the Internet; all networking protocols; T-1, T-3 lines; digital cellphone channels; single frequency channel within optical channel; any very high-speed link using packets.

Discuss the difference between multiplexing and modulation

Any signal which has been multiplexed for transmission must be de-multiplexed by the receiver.

**22.2: Space-Division Multiplexing**

Each addition requires an entirely new channel, which expands capacity, increases redundancy, but also

adds cost (significantly).

**22.3: Frequency-Division Multiplexing**

\*Example, Figs 22.4, 22.5, pp. 685, 686 Classic examples: TV signal; Cable TV

Makes more full use of the available BW of a given link, and is thus less expensive than an entirely new

link. However, offers no redundancy, so a problem in the channel affects all the multiplexed signals.

In fiber, this is called WDM

**22.4: Time-Division Multiplexing**

Everybody gets their turn (raising your hand to speak in class)

Two major issues: framing and clock synchronization; if not in sync, you’ve got nothing; not even a better SNR or more EDC can help here.

Cannot increase indefinitely, since the needed BW goes up with the data rate, and the data rate goes up

with the # of channels multiplexed. Example of a T-1 line@1.544 Mbps; 2 T-1 lines = 3.088 Mbps.

TDM used on microprocessor and computer buses; only one device at a time gets to use the bus.

**22.5: Multiple-Stage Multiplexing**

Multiple stages of multiplexing can be used. Examples abound: cellphones with SDM and FDM, also TDM in digital cellphones; TV signals with SDM and FDM; Ethernet with TDM and SDM; computer buses with SDM and TDM; etc.

Three T-1s are combined into a 4.632 Mbps signal; this is TDM with TDM

Comparison:

Adding more channels

Robustness

Cost for adding capacity

BW required

Capacity

**CHAPTER 24: FIBER OPTICS**

**24.1: Fiber Optic System Characteristics**

Advantages of light and fiber optics:

1. Tremendous BW (Cap = 400 THz \* log2(1+100,000) = 6.644 Pbps (for 1 λ); @1000λ/fiber =

2. Very well contained signal; causes no EMI 6.644 Ebps; for Earth population =

3. Essentially immune to interference from EMI 7G; this = 949 Mbps/person!

4. Lowest attenuation of all media

5. Provides complete electrical isolation (can also be a disadvantage)

6. High security; always tamper-evident *2007 Record: Bell Labs did*

7. No danger from sparks *2.5 Gbps over 7500 km w/o*

8. Much lighter than coax (per foot, and per GHz of BW) *repeater!*

Present limitations:

1. Still a bit more expensive than copper, per foot (compared to coax)

2. Much more difficult to splice

3. Connectors much more expensive, due to high precision required

4. Switching and routing difficult and expensive

5. Very different test equipment

Warning: NEVER look into a fiber, unless you KNOW about the other end. Light intensity several times

greater than looking at the sun, but only in a very limited region; retinal damage very quick, possibly

very severe. If source is IR, you’ll never even see it anyway.

**24.2: The Optical Fiber**

\*@Cross-section of fiber (\*Fig 24.1, p. 733; @preforms)

Review the concept of refraction; different frequencies travel at different speeds if the index of refraction

>1.000 (causes refraction effect of prisms). Review what index of refraction is (ratio of speeds)

Concept of total internal reflection (actually *refraction* until critical angle); for fiber, it depends on the index of refraction of the core being greater than that of the cladding. *n* for coating is not important.

\*Fiber types (\*Fig 24.3, p. 736) - cover *dispersion*

POF (Polymer Optical Fiber): >1Gbps@50+m; >100 Mbps@200+m, step-index. PMMA fiber: atten-

uation <160 dB/km@650 nm; <90 dB/km@510 nm (*IEEE Communications*, “Plastic Optical Fiber

Technology for Reliable Home Networking: Overview and Results of the EU Project POF\_ALL”,

Ingo Möllers et al, Aug 2009, pp 58, 66.

Optical fiber performance: best-can-do is presently at about λ=1300 nm, where attenuation <0.3dB/km

(Early fibers had 200 to 700 dB/km)

Losses are due to Rayleigh scattering (95%), imperfections, and impurities, causing scattering & absorption. Also microbending, connectors, and splices.

Rayleigh scattering: a quantum effect, it is the scattering of light by particles smaller than the

wavelength of light; it makes the sky blue due to its dependence on wavelength.

**24.3: Sources and Detectors**

Note that LEDs and laser diodes emit according to λ = *hc/E*, where *h* = Planck’s constant (6.63x10-34

joulesec), *c* = speed of light, *E* = bandgap energy of semiconductor material; essentially monochro-

matic. (GaAsP ≈red; InGaAsP ≈yellow; GaP ≈ green; SiC ≈ blue)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Sources** | Monochromatic\*(Fig 24.8) | Colli-mated | In-phase | Inex-pensive | Power Output | Modula-tion | Reliable |
| LED | OK to poor | poor | poor | very good | low | direct  100 GHz | very good |
| Laser diode | good | good | good | good | medium | direct  100 GHz | good |
| Gas laser | excellent | excellent | excellent | poor | high | indirect  10 GHz | poor |

Notes: n(water) = 1.330 n(pyrex) = 1.474 n(air) = 1.0008 n(diamond) = 2.417

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Detectors** | Sensitivity | Gain | Bandwidth | Low noise | Inexpen-sive | Small Size | Reliable |
| Photo-conductors | fair | fair | fair | poor | very good | excellent | very good |
| PIN diodes | good | good | very good  (10 GHz) | good | good | excellent | good |
| APDs | very good | very good | very good | poor | good | very good | good |
| PMTs | extremely good | extremely high | very good | very good | bad | bad | bad |

**24.4: Complete Systems**

Mostly for long hauls; transAtlantic, transPacific, etc. Using WDM, current records stands at about 100 channels/fiber, each at 100 Gbps, for 10 Tbps performance.

**24.5: Fiber Optic Testing**

OTDRs also exist!

Dark fiber

Optical amplification