ECE 375 Introduction to Communications

Course Information

- **Instructor**: **Yadong Wang, Ph.D.**
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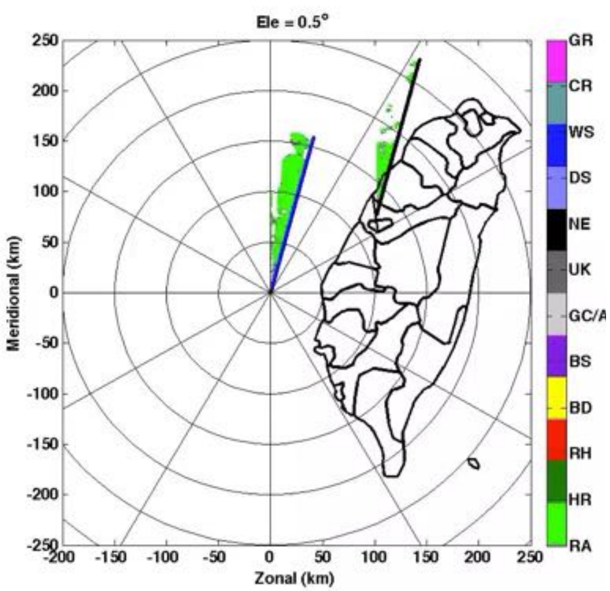
- **Textbook**: L. W. Couch II, ***Digital and Analog Communication Systems***, 8th Edition Prentice Hall
- **Software**: MATLAB
- **Grading**:

Exam 1:	20%
Exam 2:	20%
Quizzes:	20%
Project/Simulation:	10%
Final Exam:	30%

- **Prerequisites**: Declared major in an engineering discipline, grade of C or better in 351 and 352.

About Me



Education

Ph.D., Electrical and Computer Engineering,
Advanced Radar Research Center, University of Oklahoma
Dissertation Title: ***The application of spectral analysis and artificial intelligence methods to weather radar***

M.S.E.E., Electrical and Computer Engineering,
Advanced Radar Research Center, University of Oklahoma

B.S.E.E., Electrical and Computer Engineering,
Sichuan University, P. R. China

Professional Experience

2010-2016, Postdoctoral Research Associate/Research Scientist,
National Severe Storms Laboratory, University of Oklahoma

2003-2010, Graduate Research Assistant,
Electrical and Computer Engineering, University of Oklahoma

1999-2003, Radar Hardware Engineer,
Changfeng Science Technology Industry Group Corp. Beijing, China

Research Interests

Radar signal/imaging processing
Radar engineering
Communication
Remote Sensing

ECE 375 Introduction to Communications

Course Content

- ✧ **Chapter 1: Introduction**
- ✧ **Chapter 2: Signals and Spectra**
- ✧ **Chapter 3: Base Band Pulse and Digital Signaling**
- ✧ **Chapter 4: Band Pass Signaling Principles & Circus**
- ✧ **Chapter 5: AM, FM and Digital Modulated Systems**
- ✧ **Chapter 6: Random Processes and Spectral Analysis**
- ✧ **Chapter 7: Performance of System Corrupted by Noise**

Chapter 1. Introduction

Chapter Objectives

- **How communication system work**
- **Frequency allocation and propagation characteristics**
- **Computer solutions (MATLAB)**
- **Information measure**
- **Coding performance**

1.1. Historical Perspective

The history of communication is the history of human

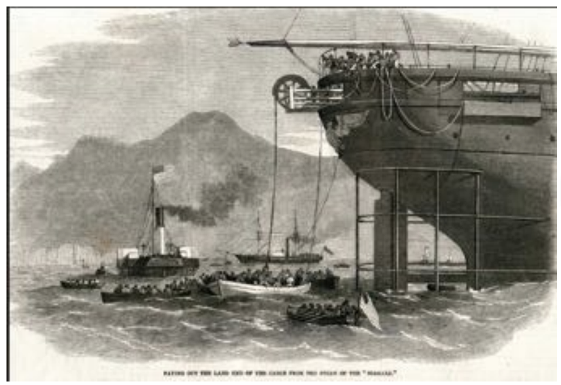
490 BC.

Philippides, the Greek messenger

From the battlefield of Marathon towards Athens. About 26.2 miles.

"We have won!"

1900s



Across Atlantic Cable

More than 2000 miles

"Europe and America are united by telegraphic communication. Glory to God in highest, on earth peace, Goodwill to men"

After 2000.

Wireless communication

"Hello world!"

1.1. Historical Perspective

Milestones in Communications

- **1837**, Morse code used in telegraph
- **1864**, Maxwell formulated the electromagnetic (EM) theory
- **1887**, Hertz demonstrated physical evidence of EM waves
- **1890's-1900's**, marconi & Popov, long-distance radio telegraph
  -- Across Atlantic Ocean
  -- From Cornwall to Canada
- **1875,** Bell invented the telephone
- **1906**, radio broadcast
- **1918**, Armstrong invented superheterodyne radio receiver (FM in 1933)
- **1921,** land-mobile communication
- **1947,** microwave relay system
- **1957,** satellite communication began
- **1966,** fiber-optical communications
- **1981,** analog cellular system
- **1988,** digital cellular system
- **2000,** 3G network

1.2. Digital and analog sources and systems

Basic Definitions:

Analog Information Source:

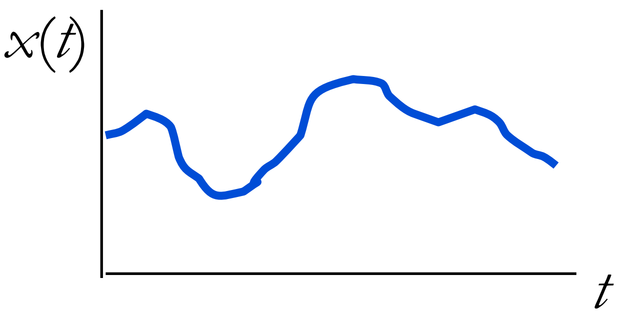
A analog information source produces messages which are defined on a continuum.

E.g.: microphone

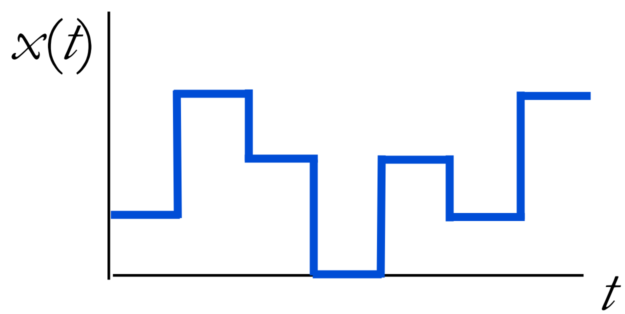
Digital information source:

A digital information source produces a finite set of possible message.

E.g.: telephone touchtone



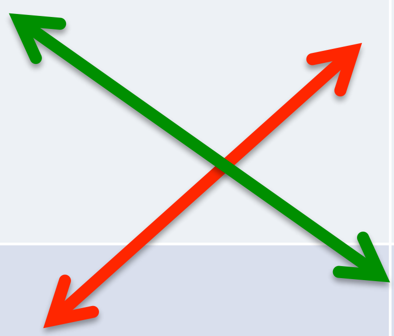
Analog



Digital

1.2. Digital and analog sources and systems

	Analog	Digital
Communication system	Transfer information from an analog source to the receiver (sink)	Transfer information from a digital source to the receiver (sink)
Advantages		• Relative Inexpensive digital circuits • privacy preserved (data encryption) • greater dynamic range, • no noise accumulation, • data resources merged and transmitted over one system • small errors, • errors corrected
Disadvantages		More bandwidth is required, Synchronization is required



1.3. Deterministic and random waveforms

DEFNITION. A deterministic waveform can be modeled as a completely specified function of time.

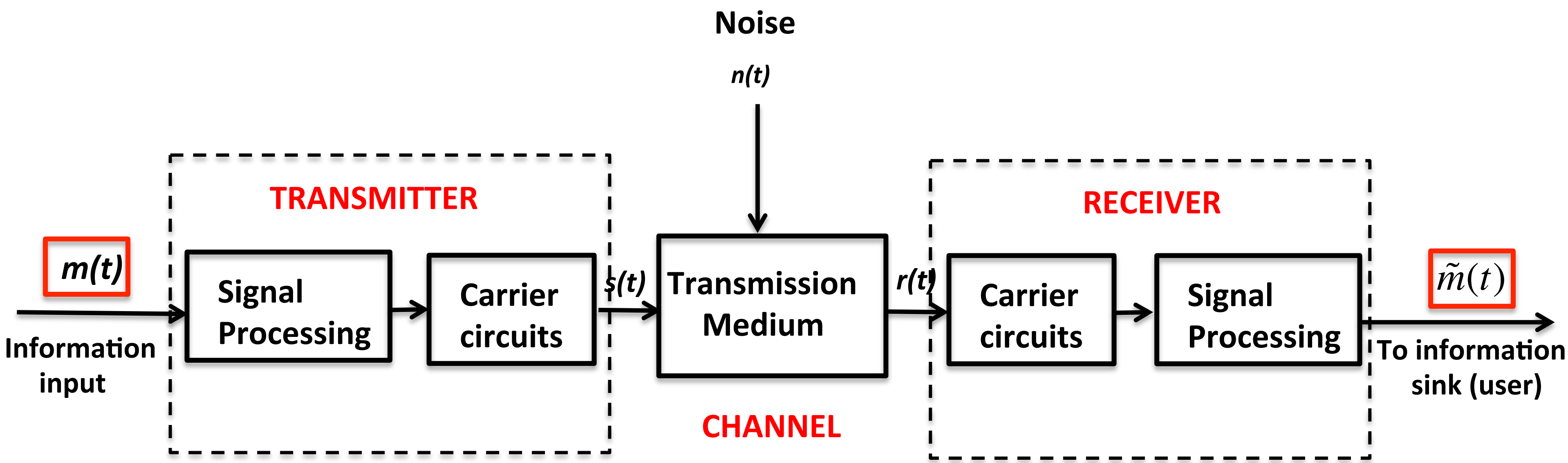
$$w(t) = A\cos(\omega_0 t + \varphi_0)$$

For given A , ω_0 , and φ_0, the w at t is determined.

If any of constants are unknown, then the *w(t)* is not deterministic

DEFNITION. A random waveform (or stochastic waveform) cannot be completely specified as a function of time and must be modeled probabilistically. (ECE 352)

1.6 Block Diagram of a Communication System



Three basic elements

Transmitter: convert message into a form suitable for transmission

Channel: the physical medium, introduces distortion, noise, interference

Receiver: reconstruct a recognizable form of the message

1.6 Block Diagram of a Communication System

Transmitter

✧ **Signal-processing block:**

- **Purpose:** for more efficient transmission. The output of transmitter is baseband signal
- **Examples:**
  - In an analog system, the signal processor may be an analog low-pass filter to restrict the bandwidth of $m(t)$.
  - In a hybrid system, the signal processor may be an analog-to-digital converter (ADC) to produce digital signal that represent samples of the analogy input signal

✧ **Transmitter carrier circuit:**

- **Purpose:** converts the processed base band signal into a frequency band that is appropriate for the transmission medium of the channel.
- **Example**
  - An amplitude-modulated (AM) broadcasting station with an assigned frequency of 850 kHz has a carrier frequency fc=850 kHz. The mapping of the base band input information waveform $m(t)$ into the band pass signal *s(t)* is called modulation. It will shown that any band pass signal has the form

$$s(t) = R(t)\cos(\omega_c t + \theta(t)) \qquad \omega_c = 2\pi f_c$$

If $R(t)=1$ and $\theta(t)=0$, $s'(t)$ would be a pure sinusoid of frequency $f=f_c$ with zero bandwidth

1.6 Block Diagram of a Communication System

Channel

- **Channels represent the path (or multiple paths) in which signals travel from transmitter to receiver :**

- **Classification:**

  - **Wire:** Twisted-pair telephone line, coaxial cable, waveguide, and fiber-optic cable.
  - **Wireless:** air, vacuum, and seawater

In general, the channel medium attenuates the signal so that the delivered Information $\tilde{m}(t)$ is deteriorated from that of the source. The channel noise May arise from natural electrical disturbances or from artificial sources.

1.6 Block Diagram of a Communication System

Receiver

- The receiver takes the corrupted signal at the channel output and convert it to be a baseband signal that can be handled by the receiver's baseband processor.

- The baseband processor cleans up this signal and delivers an estimate $\tilde{m}(t)$ of the source information $m(t)$ to the communication system output.

- In digital systems, the measures of signal deterioration is usually taken to be the probability of bit error $P(e)$, also called **Bit Error Rate (BER)** of the delivered data $m(t)$.

- In analog systems, the performance measure is usually taken to be the **Signal-to-Noise Ratio (SNR)** at the receiver output.

1.7 Frequency Allocations

- Regulations specify, modulation type, bandwidth, power, type of information and etc. that a user can transmit over designed frequency bands.
- Frequency assignments and technical standards are set internationally by International Telecommunication Union (ITU).
- Each nation of ITU retains sovereignty over spectral usage and standards adopted in its territory.
- Each nation is expected to abide by the overall frequency plan adopted by ITU.

1.7 Frequency Allocations

TABLE 1–2 FREQUENCY BANDS

Frequency Band[a]	Designation	Propagation Characteristics	Typical Uses
3–30 kHz	Very low frequency (VLF)	Ground wave; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
30–300 kHz	Low frequency (LF)	Similar to VLF, slightly less reliable; absorption in daytime	Long-range navigation and marine communication radio beacons
300–3000 kHz	Medium frequency (MF)	Ground wave and night sky wave; attenuation low at night and high in day; atmospheric noise	Maritime radio, direction finding, and AM broadcasting
3–30 MHz	High frequency (HF)	Ionospheric reflection varies with time of day, season, and frequency; low atmospheric noise at 30 MHz	Amateur radio; international broadcasting, military communication, long-distance aircraft and ship communication, telephone, telegraph, facsimile
30–300 MHz	Very high frequency (VHF)	Nearly line-of-sight (LOS) propagation, with scattering because of temperature inversions, cosmic noise	VHF television, FM two-way radio, AM aircraft communication, aircraft navigational aids

[a] kHz = 10^3 Hz, MHz = 10^6 Hz, GHz = 10^9 Hz.

1.7 Frequency Allocations

TABLE 1-2 (cont.)

Frequency Band[a]	Designation	Propagation Characteristics	Typical Uses
0.3–3 GHz	Ultrahigh frequency (UHF)	LOS propagation, cosmic noise	UHF television, cellular telephone, navigational aids, radar, GPS, microwave links, personal communication systems
	Letter designation		
1.0–2.0	L		
2.0–4.0	S		
3–30 GHz	Superhigh frequency (SHF)	LOS propagation; rainfall attenuation above 10 GHz, atmospheric attenuation because of oxygen and water vapor, high water-vapor absorption at 22.2 GHz	Satellite communication, radar microwave links
	Letter designation		
2.0–4.0	S		
4.0–8.0	C		
8.0–12.0	X		
12.0–18.0	Ku		
18.0–27.0	K		
27.0–40.0	Ka		
26.5–40.0	R		
30–300 GHz	Extremely high frequency (EHF)	Same; high water-vapor absorption at 183 GHz and oxygen absorption at 60 and 119 GHz	Radar, satellite, experimental
	Letter designation		
27.0–40.0	Ka		
26.5–40.0	R		
33.0–50.0	Q		
40.0–75.0	V		
75.0–110.0	W		
110–300	mm (millimeter)		
10^3–10^7 GHz	Infrared, visible light, and ultraviolet	LOS propagation	Optical communications

[a] kHz = 10^3 Hz; MHz = 10^6 Hz; GHz = 10^9 Hz.

1.8 Propagation of Electromagnetic Waves

- The propagation characteristics of electromagnetic waves used in wireless channels are highly dependent on the ***frequency***.

- Based on ***carrier frequency*** EM wave propagations can be classified as:
  - **GROUND-WAVE** Propagation (**below 2 MHz**)
    VLF, LF, MF
  - **SKY-WAVE** Propagation (**between 2 ~ 30 MHz**)
    HF
  - **Line of Sight (LOS)** Propagation (**above 30 MHz**)
    VHF, UHF, SHF, EHF

- Ionization (i.e. free electrons) of the rarified air at high altitudes has a dominant effect on wave propagation in the **MF** and **HF** bands.

1.8 Propagation of Electromagnetic Waves

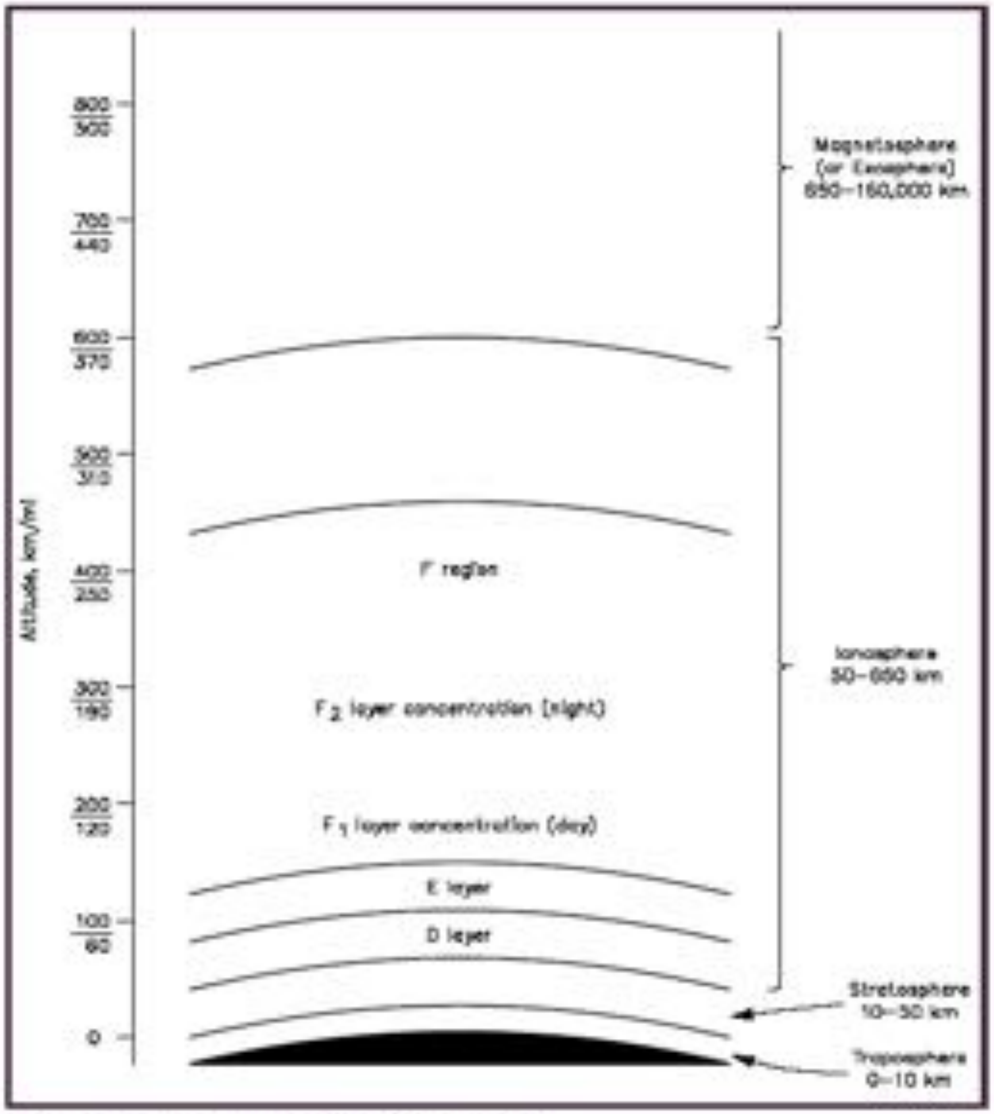


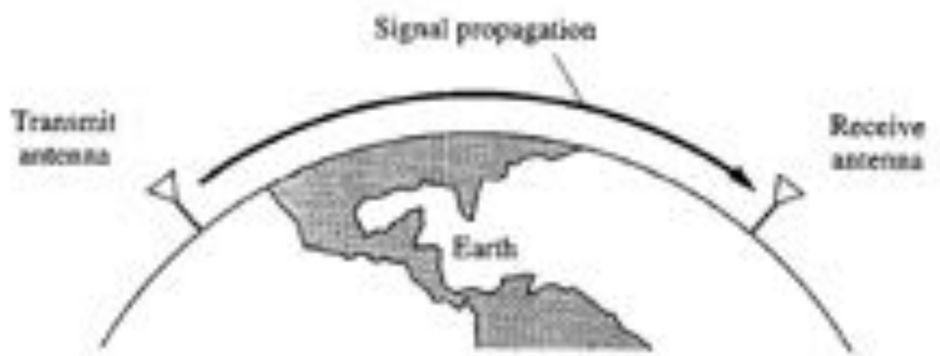
Figure 1—Areas of the atmosphere.

- Ionization is caused by Ultraviolet radiation from the sun.
- Ionized air shows different properties at different levels (Density and pressure).
- Speed of the wave differs with the changing properties.
- Dominant regions are named as D, E, F_1 and F_2 .
- D: about 45 or 55 miles
- E: between 65 to 75 miles
- F: between 90 to 250 miles

1.8 Propagation of Electromagnetic Waves

Ground-wave Propagation

- Dominant mode of propagation for frequencies **below 2 MHz.**
- Diffraction of the wave causes the wave to propagate **along the surface of the earth.**
- This propagation mode is used in **AM Radio Broadcasting.**
- Diffraction of waves in "D" layer helps propagation along the surface of earth.

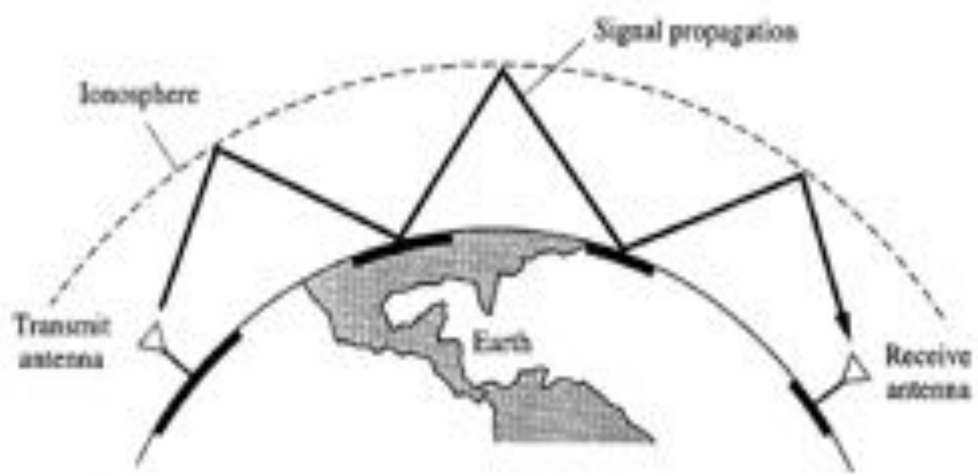


(a) Ground-Wave Propagation (Below 2 MHz)

1.8 Propagation of Electromagnetic Waves

Sky-wave Propagation

- Dominant mode of propagation for frequencies range of **2 MHz ~ 30 MHz**
- **Long coverage** is obtained by reflection of wave at the ionosphere and at the Earth's boundary.
- This mode is used in **HF** band **International Broadcasting (Shortwave Radio).**
- Sky-wave propagation is caused primarily by reflection from the **F** layer.



(b) Sky-Wave Propagation (2 to 30 MHz)

1.8 Propagation of Electromagnetic Waves

Sky-wave Propagation

- The refraction index of the ionosphere can be approximated as

$$n = \sqrt{1 - \frac{81N}{f^2}}$$

Where,
n -- Refractive index,
N -- Free electron density (number of electrons/m^3) (~ $10^{10}/m^3$)
f -- Frequency of the wave (Hz).

- Refractive index will change gradually with the altitude.

- Traveling waves will gradually bend according to Snell's law.

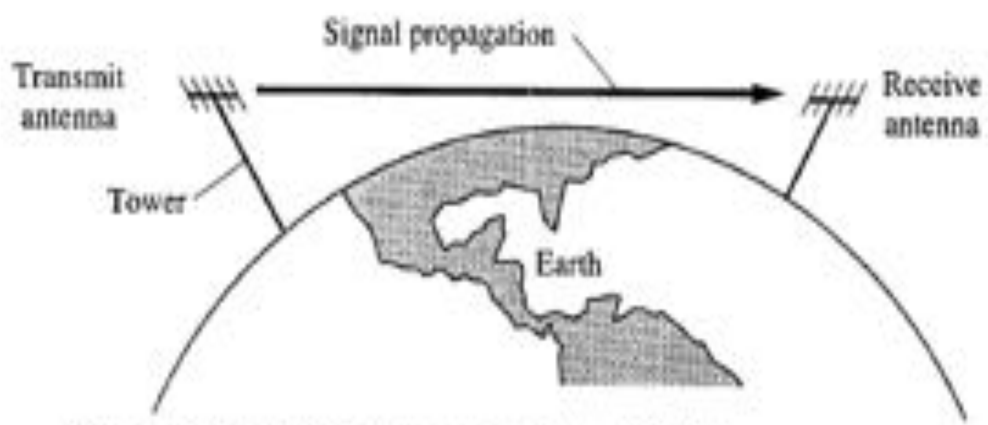
$$n_r \, Sin\ \varphi_r = n_i \, Sin\ \varphi_i$$

- Waves will be bent back to earth. Ionosphere acts as a reflector. Transmitting station will have coverage areas along the surface of earth.

1.8 Propagation of Electromagnetic Waves

Line-of Sight (LOS) Propagation

- Dominant mode of propagation for EM waves **above 30 MHz.**
- The EM wave propagates in a straight line, and the signal will propagate ***through*** the ionosphere.
- This mode can be used in **Satellite Communications.**
- The disadvantage of LOS is that the signal path has to be above the horizon and the receiver antennas need to be placed on ***tall towers*** so that they can see each other.



(c) Line-of-Sight (LOS) Propagation (Above 30 MHz)

1.9 Information Measure

DEFNITION. The ***information*** sent from a digital source when the j^{th} message is transmitted is given by

$$I_j = \log 2\left(\frac{1}{P_j}\right) bits$$

Where P_j is the **probability** of transmitting the j^{th} message

- Messages that are less likely to occur (smaller value for P_j) provide more information (large value of I_j).
- The information measure depends on only the likelihood of sending the message and does not depend on possible interpretation of the content (make sense??).
- For units of **bits**, the base 2 logarithm is used;
- if natural logarithm is used, the units are "**nats**";
- if the base 10 logarithm is used, the units are "**hartley**".

1.9 Information Measure

DEFNITION. The ***average information (Entropy)*** measure of a digital source is

$$H = \sum_{j=1}^{m} P_j I_j = \sum_{j=1}^{m} P_j \log 2\left(\frac{1}{P_j}\right) bits$$

Where *m* is the number of possible different source messages

DEFNITION. The ***source rate (R)*** is given by:

$$R = \frac{H}{T} bits / s$$

Where *H* is the average information (entropy), T is the time required to send a message.

1.9 Information Measure

Example 1-3: Evaluation of information and entropy

1.9 Channel Capacity and Ideal Communication Systems

- For digital communication systems, the **"Optimum System"** may defined as the system that minimize the probability of ***bit error*** at the system output subject to **constraints on the energy and channel bandwidth.**

- ***Thus, bit error and signal bandwidth are of prime importance***

1.9 Channel Capacity and Ideal Communication Systems

Is it possible to invent a system with no error at the output even when we have noise introduced into the channel?

Yes under certain assumptions...

According **Shannon** the *probability of error* would approach **zero**, if

R* < *C

Where

R - Rate of information (bits/s)

C - Channel capacity (bits/s)

$$C = B\log 2\left(1 + \frac{S}{N}\right)$$

B - Channel bandwidth in Hz and

S/N - the signal-to-noise power ratio