EEEN 462 – ANALOGUE COMMUNICATION SYSTEMS

FUNDAMENTALS OF ANALOGUE TELEPHONY - STUDY GUIDE/REVISION

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1. LEARNING OBJECTIVES

Upon completing this guide, the student should be able to:

1. Explain the historical significance and basic operational concept of the Public Switched Telephone Network (PSTN).
2. Describe the process of converting sound into an electrical signal and back again, focusing on the carbon microphone and analogue receiver.
3. Analyze the standard frequency range allocated for voice transmission (300 Hz - 3.4 kHz) and justify its limitations.
4. Understand the DC and AC components of the local loop (subscriber loop).
5. Explain the function and basic operation of a telephone hybrid and the problem of sidetone.
6. Describe the principle of circuit switching as the foundation of the PSTN.
7. Differentiate between dial-pulse and dual-tone multi-frequency (DTMF) signalling.
8. Sketch and interpret a basic analogue telephone multiplexing system.

2. INTRODUCTION

Analogue telephony, the technology behind the traditional "landline," formed the backbone of global communication for most of the 20th century. While modern systems are digital, the underlying architecture, protocols, and many fundamental concepts were established in the analogue era. Understanding these fundamentals is crucial for any electrical engineer, as they are the historical and conceptual foundation for today's digital networks.

The core system is the Public Switched Telephone Network (PSTN). Its key characteristic is circuit switching: a dedicated physical circuit (a continuous electrical path) is established between two parties for the duration of a call.

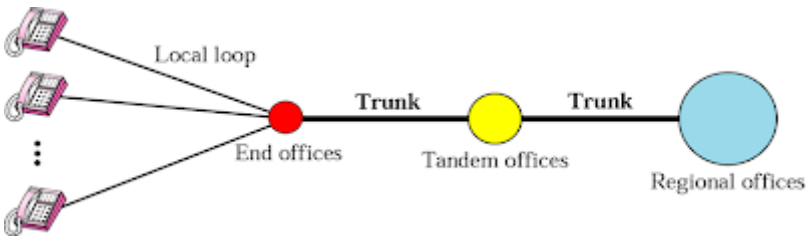

Figure 1. Organization of analogue telephone system

3. CORE COMPONENTS & CONCEPTS

3.1. Voice Signal

3.1.1 Nature of Speech: Human speech produces a complex, time-varying acoustic wave containing a fundamental frequency and harmonics.

3.1.2 Voice Frequency Band: Through analysis, it was determined that intelligible voice communication could be achieved by transmitting frequencies between approximately 300 Hz and 3.4 kHz.

- *Why this band?* It represents a trade-off between voice quality, intelligibility, and the economic need to conserve bandwidth (to allow more calls on a single cable).
- This band is often called the **voiceband** or **telephone band** (ITU G.711 standard)

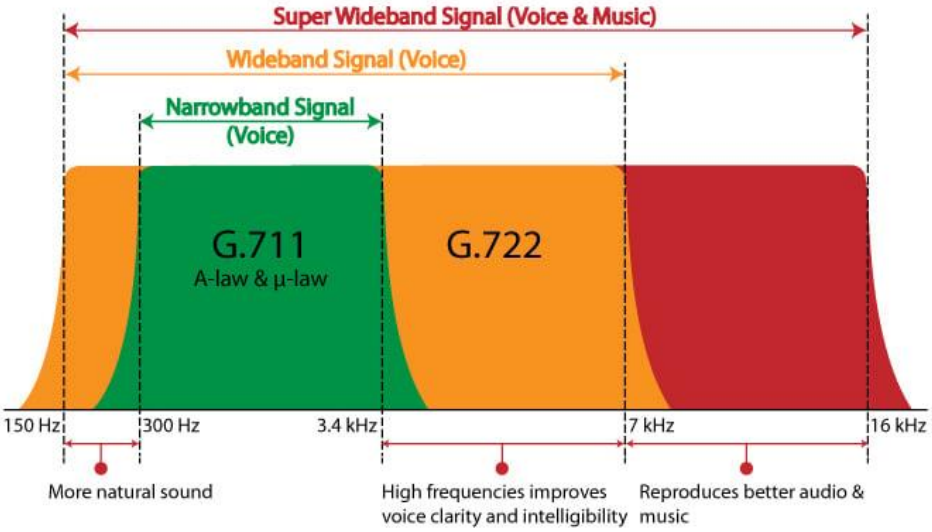

Figure 2. Voice band compared with other bands used in contemporary digital communication systems. Analogue telephone Systems/first generation use 300Hz-3.4KHz.

3.2. The Subscriber Loop (Local Loop)

This is the two-wire copper connection (the "twisted pair") between the telephone set in your home and the **Central Office (CO)** or telephone exchange.

- **DC Circuit:** The Central Office supplies a DC voltage (typically -48V) to power the telephone. When the handset is on-hook, the circuit is open. When taken off-hook, the circuit closes, allowing DC current to flow (~20-50 mA). This **off-hook signal** tells the CO you want to make a call.
- **AC Signal:** Your voice is superimposed on this DC bias as an AC signal. Capacitors in the telephone set block the DC from the microphone and speaker, allowing only the AC voice signal to pass through.

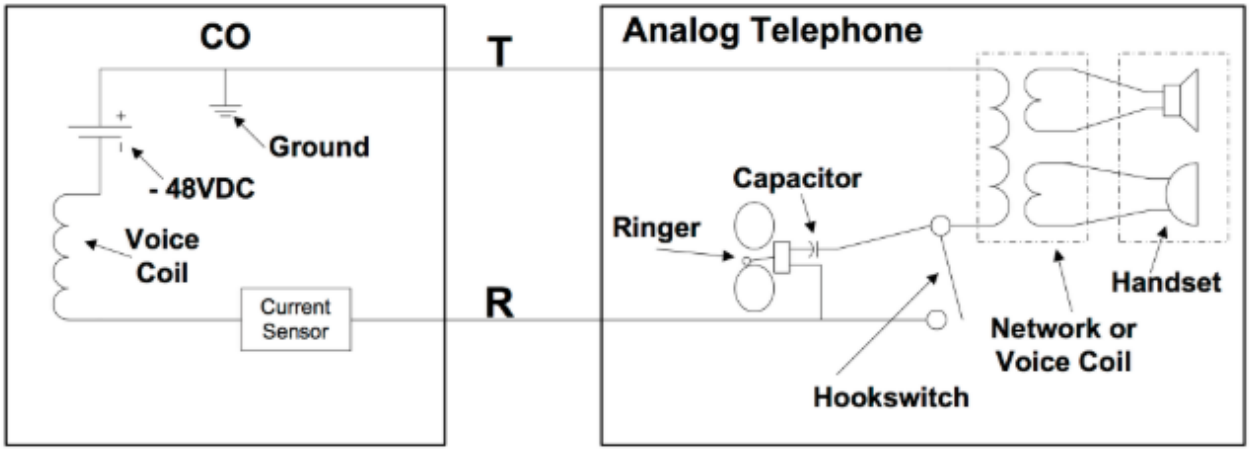

Figure 3. Simplified circuit diagram of analogue telephone local loop.

3.3. The Telephone Set

A classic analogue telephone is a marvel of electro-mechanical engineering.

- **Transmitter (Microphone):** Traditionally a **carbon microphone**. Carbon granules change resistance under sound pressure, modulating the DC current from the CO. The varying current is an analog representation of the sound wave.
- **Receiver (Speaker):** A simple magnetic speaker that converts the varying electrical current back into sound waves.
- **Hybrid Circuit (2-wire to 4-wire conversion):** This is a critical component. The local loop uses one pair of wires for both talking and listening (2-wire). Long-distance transmission uses separate paths for send and receive (4-wire). The hybrid is a special transformer (a **hybrid coil**) that separates the two signals to prevent your own voice (the **sidetone**) from being too loud in your own receiver. A small amount of sidetone is desirable for a natural feel.

3.4. Signalling

How the telephone tells the network what to do.

- **Loop Start:** The basic off-hook/on-hook signaling described above.
- **Address Signaling (Dialing):**
    1. **Pulse Dialing (Rotary Dial):** Rapidly breaking the local loop circuit to create pulses (e.g., 10 pulses per second). The number of pulses corresponds to the digit (except '0' which is 10 pulses).
    2. **Dual-Tone Multi-Frequency (DTMF - Touch-Tone):** A more modern method. Each keypress sends a unique combination of two sine waves (one from a low-frequency group and one from a high-frequency group). For example, the '5' key is 770 Hz + 1336 Hz. This is faster and more reliable.

3.5. The Central Office (CO) and Switching

- **Function:** The CO is the local hub. It detects off-hook conditions, collects dialled digits, and establishes a connection to the called party's line (if local) or to another CO (if long-distance).

- **Circuit Switching:** The CO's switch (originally electromechanical, now digital) creates a dedicated, end-to-end electrical path. This path is held open, consuming resources, until the call ends.

4. MULTIPLEXING: SHARING THE TRUNKS

It is impractical to run a dedicated pair of wires for every possible long-distance call. **Multiplexing** allows multiple conversations to share a single high-capacity trunk line.

4.1 Frequency-Division Multiplexing (FDM)

- Each voice channel (300-3400 Hz) is modulated onto a higher carrier frequency.
- Channels are spaced 4 kHz apart to avoid interference (with guard bands).
- Groups of 12 channels were combined into a **Basic Group** (60-108 kHz).
- Groups could be further combined into Supergroups, Mastergroups, etc. This was the basis for analog microwave and coaxial cable systems.

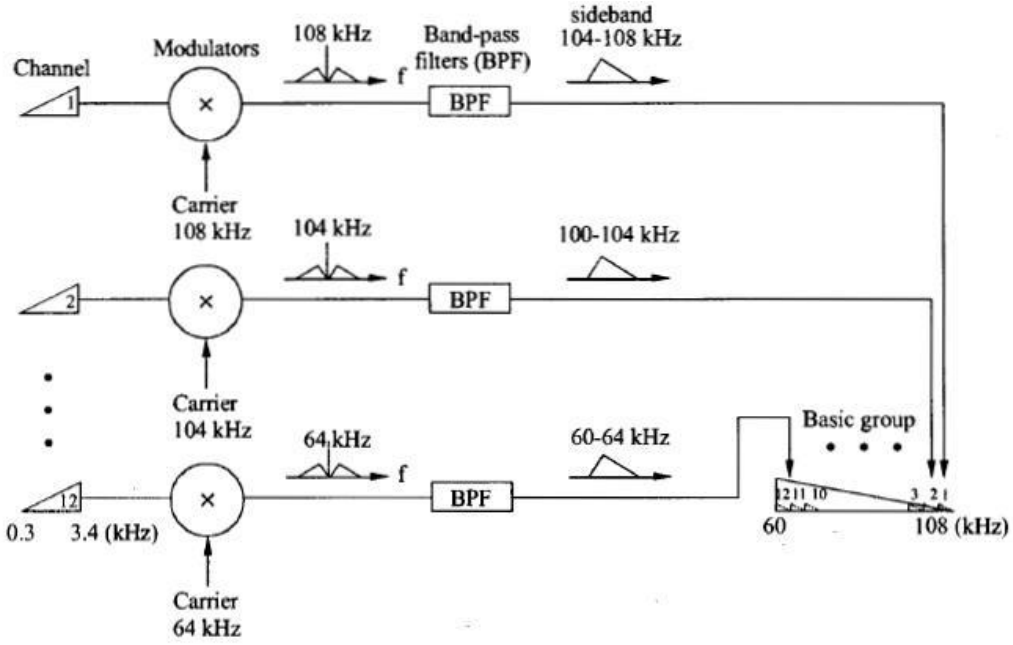

Figure 4. Standard analogue telephone multiplex combining 12 voice channels into one basic group in 60-108 KHz frequency band using Single-Sideband Suppressed Carrier Amplitude Modulation (SSB-SC AM).

4.2 Time-Division Multiplexing (TDM) - The Digital Transition

While initially analogue, the move to digital was fundamental. TDM is the cornerstone of digital telephony.

5. KEY TERMINOLOGY

1. **PSTN (Public Switched Telephone Network):** The worldwide circuit-switched telephone network.
2. **Local Loop / Subscriber Loop:** The twisted-pair connection from the subscriber to the CO.
3. **Central Office (CO) / Exchange:** The local switching centre.
4. **Off-hook / On-hook:** The active (circuit closed) and idle (circuit open) states of a telephone.

5. **Voiceband:** The 300 Hz - 3.4 kHz frequency range for speech.
6. **Hybrid Coil:** A transformer that converts between 2-wire and 4-wire circuits.
7. **Sidetone:** The sound of your own voice in your receiver.
8. **DTMF (Dual-Tone Multi-Frequency):** The touch-tone dialling system.
9. **Circuit Switching:** A method where a dedicated path is established for the entire call.
10. **FDM (Frequency-Division Multiplexing):** Sharing a medium by allocating different frequency bands to different signals.
11. **TDM (Time-Division Multiplexing):** Sharing a medium by allocating repeating time slots to different signals.
12. **PCM (Pulse Code Modulation):** The standard method for digitizing an analogue signal, specifically voice.

6. STUDY QUESTIONS & PROBLEMS

1. **Conceptual:** Why is the voiceband limited to 300 Hz - 3.4 kHz? What aspects of speech are lost with this limitation?
2. **Analysis:** Draw a simple circuit diagram of the local loop, showing the DC voltage source from the CO, the off-hook switch, and the AC voice signal as a source. How does a blocking capacitor work in this circuit?
3. **Comparison:** Compare and contrast FDM and TDM. What are the advantages of TDM that led to it superseding FDM for core network trunks?
4. **Signalling:** Describe the sequence of electrical events on the local loop from the moment you pick up the handset to the moment the called party's phone starts ringing.
5. **Historical Context:** Research the basic operation of a Step-by-Step (Strowger) switch. How did it use pulse dialling to physically connect circuits?