Digital Mobile Radio
A Brief Look
Under The Hood

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How do we get from……

Analog

Digital

10011100101101011010

And Back Again……

Analog

Digital

10011100101101011010

The Magic Device

Analog

VOCODER

Voice Encoder

Digital

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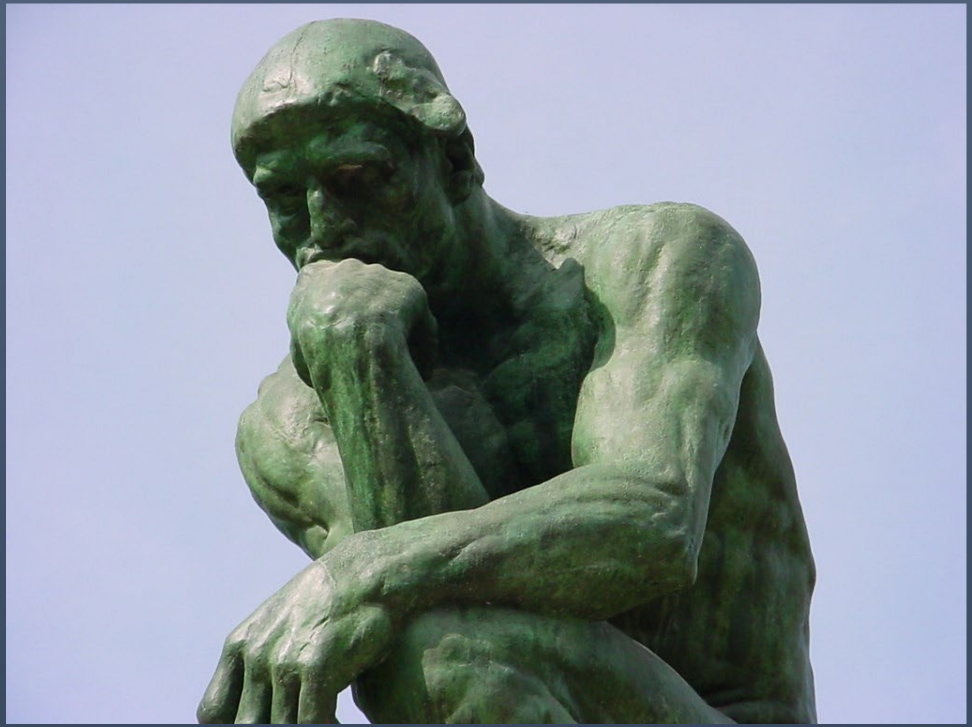
First a Bit of History



The Carrier Nature of Speech
Bell Labs Homer Dudley 1928

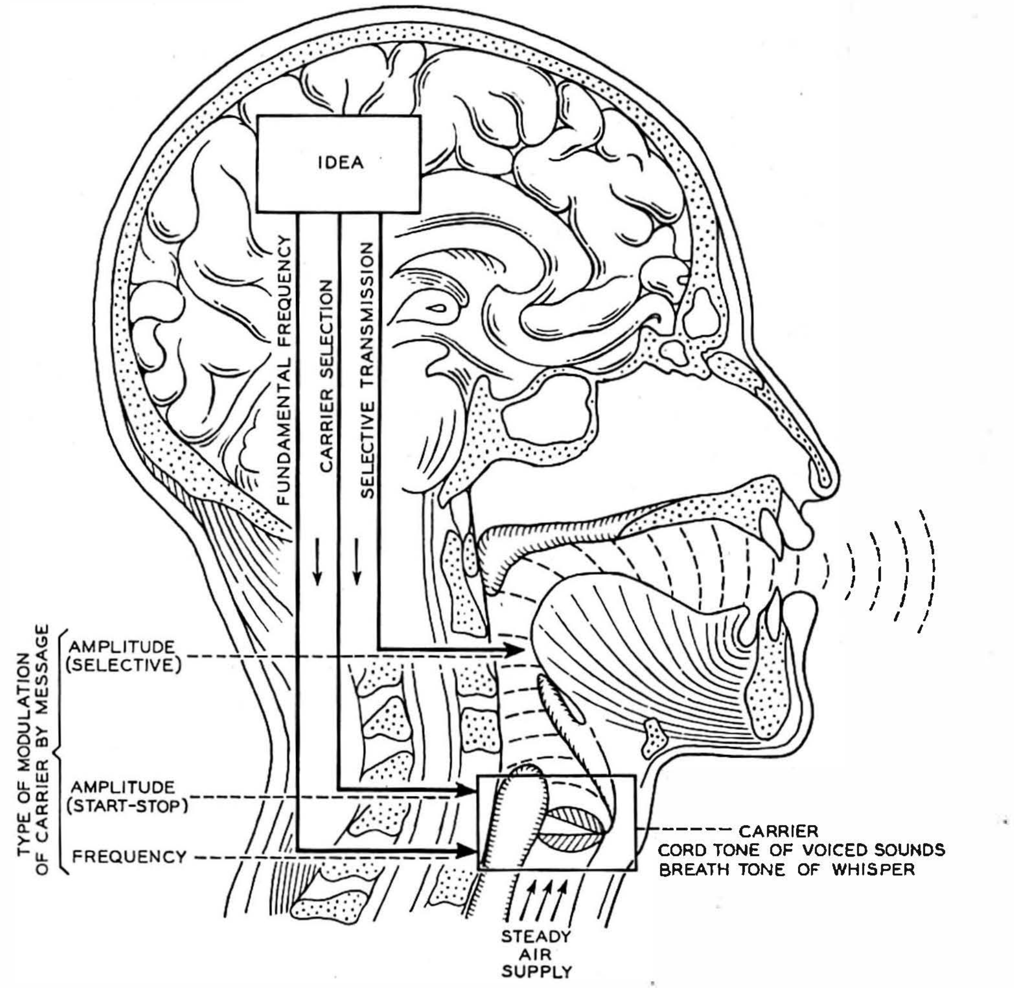


Fig. 1—The vocal system as a carrier circuit.

Bell Labs Homer Dudley Demonstrated 1939-40 at NY Worlds Fair

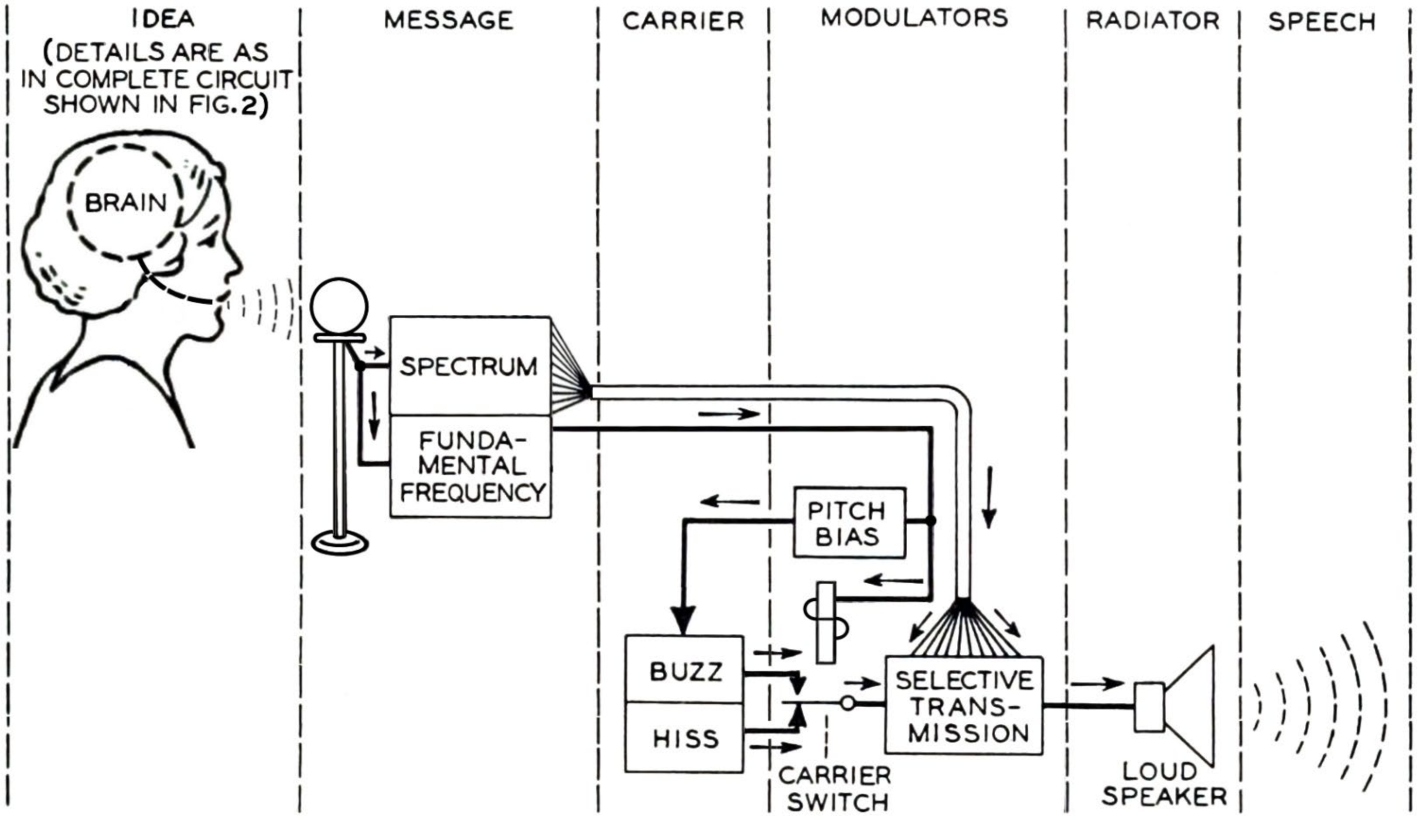


Fig. 7—Schematic circuit of the vocoder.

Worlds Fair Demonstrations

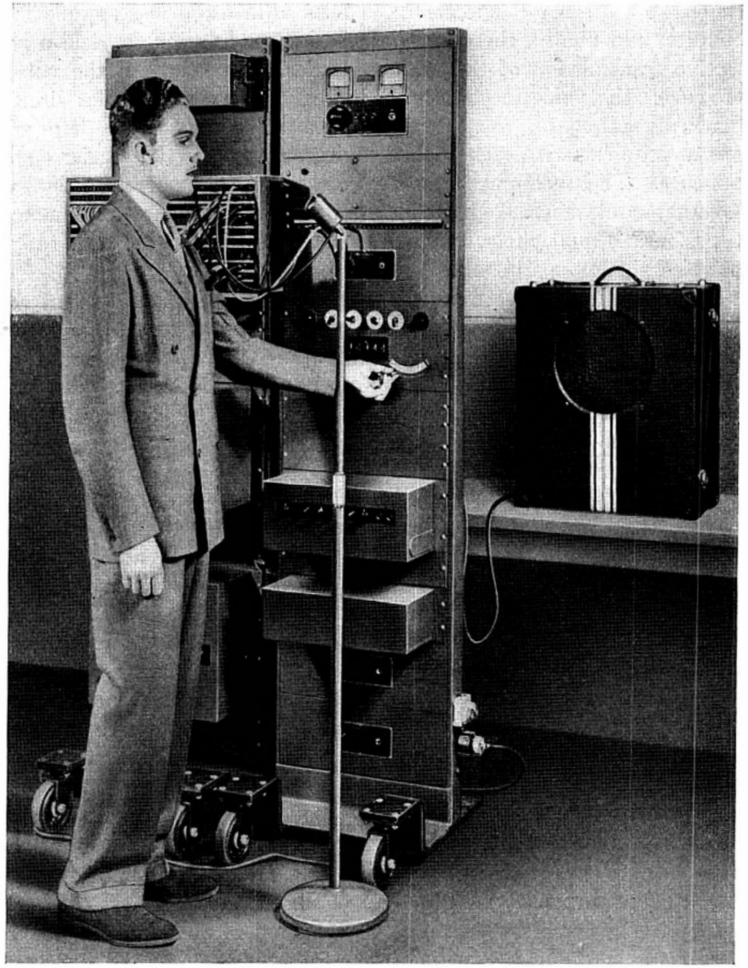


Fig. 4—The vocoder as demonstrated.

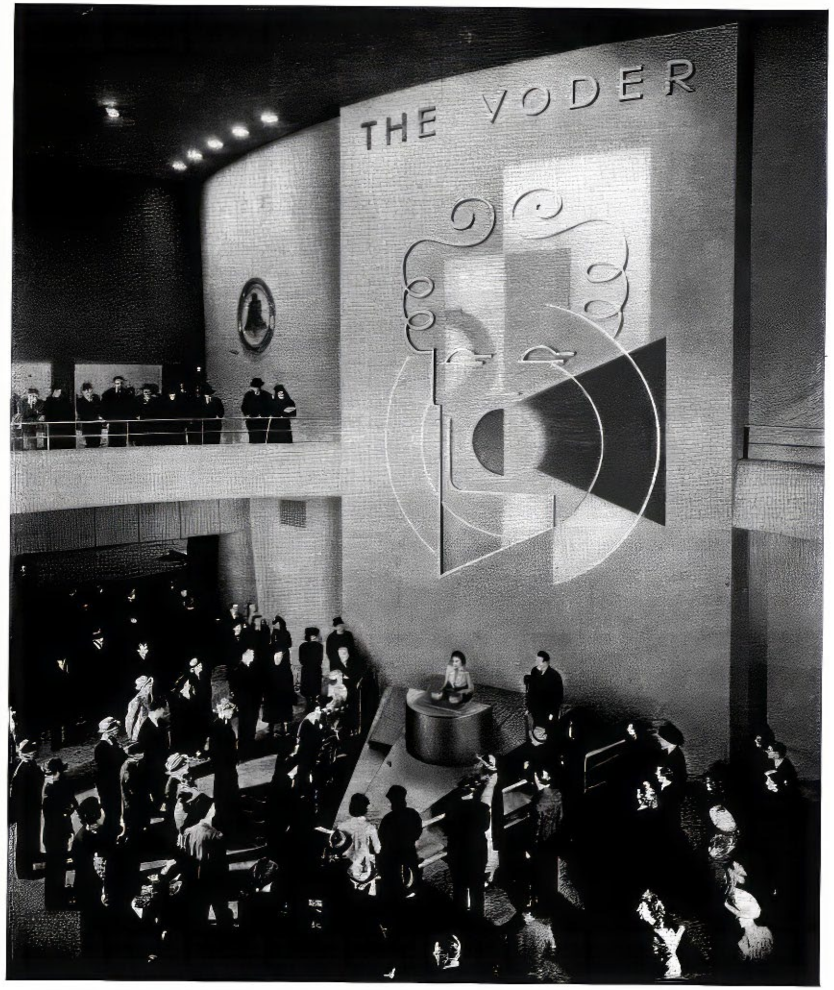


Fig. 5—The voder being demonstrated at the New York World's Fair.

The “Receive” side

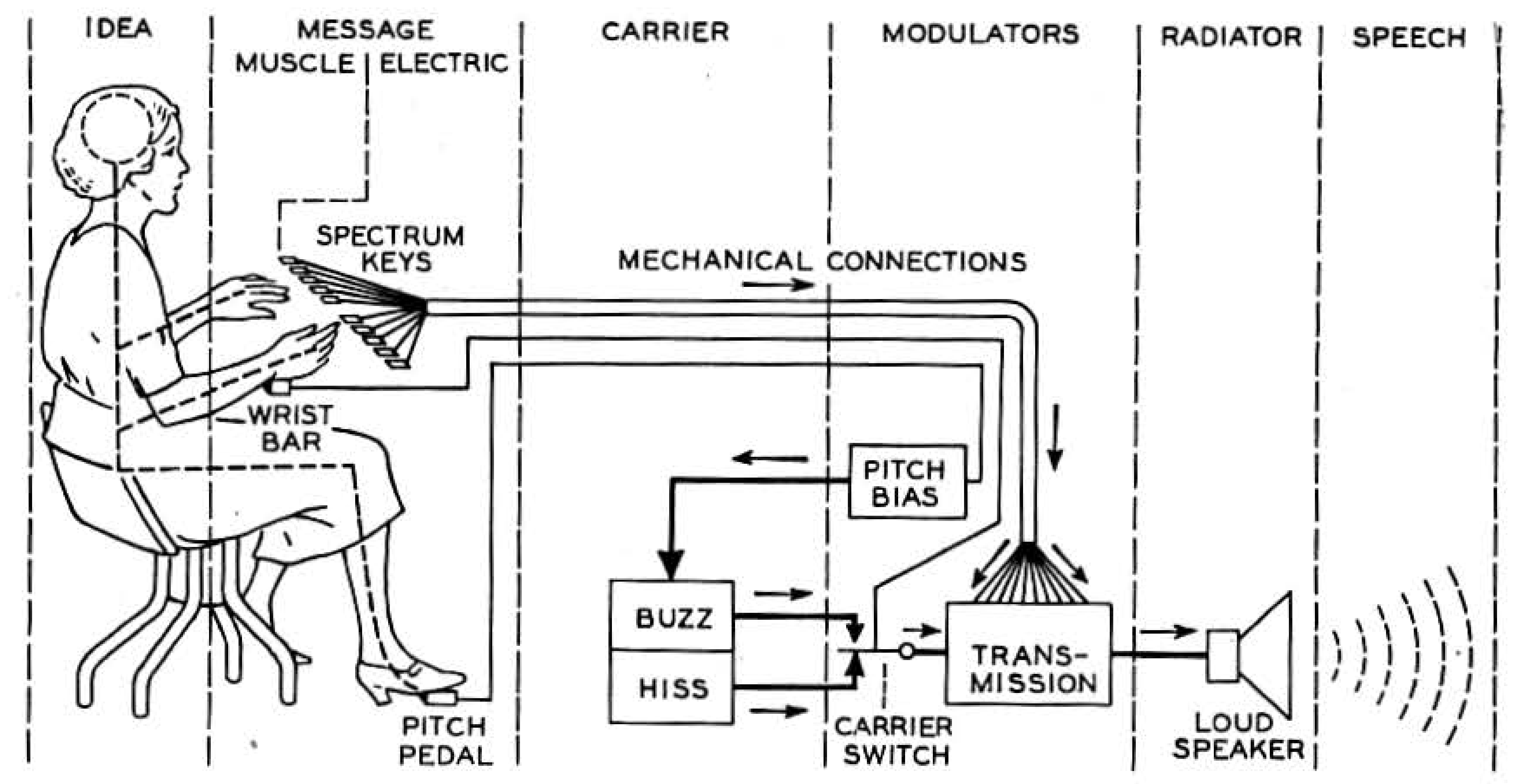


Fig. 8—Schematic circuit of the voder.

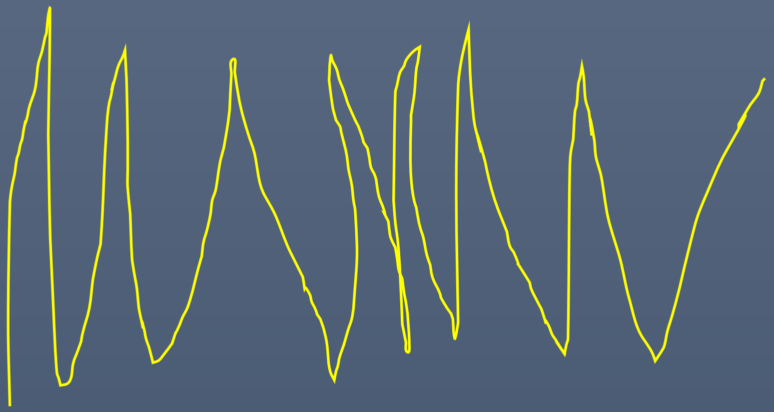
https://www.youtube.com/watch?v=TsdOej_nC1M

Bell Labs SIGSALY 1943
Used for encrypted Voice in WW2

The SIGSALY terminal was massive. Consisting of 40 racks of equipment, it weighed over 50 tons, and featured two turntables which were synchronized on both the sending and the receiving end by an agreed upon timing signal from the U.S. Naval Observatory. SIGSALY used 30kW of power and required air conditioning.

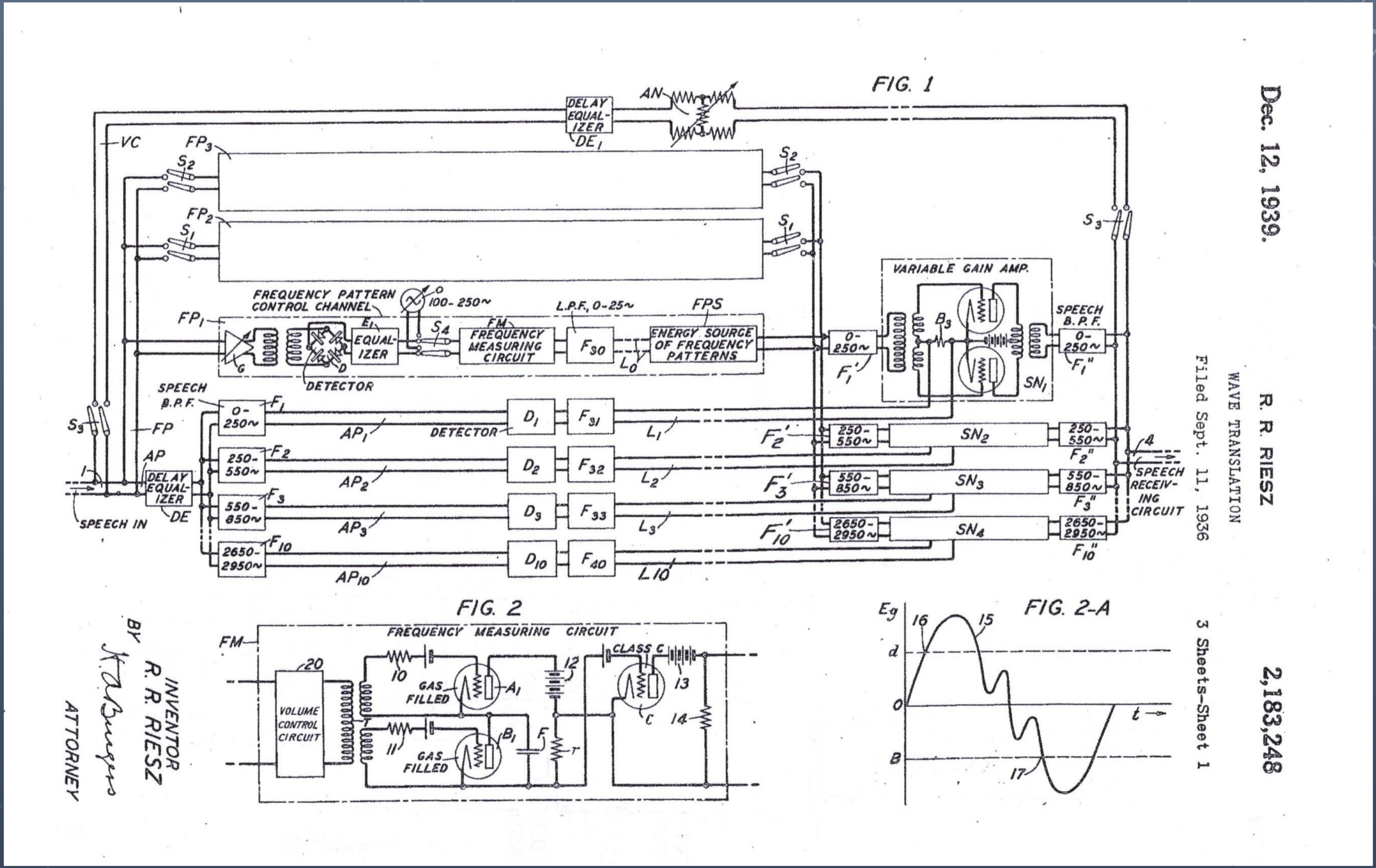
This was the first use of Pulse Code Modulation and was transmitted using a form of Frequency Shift Keying.

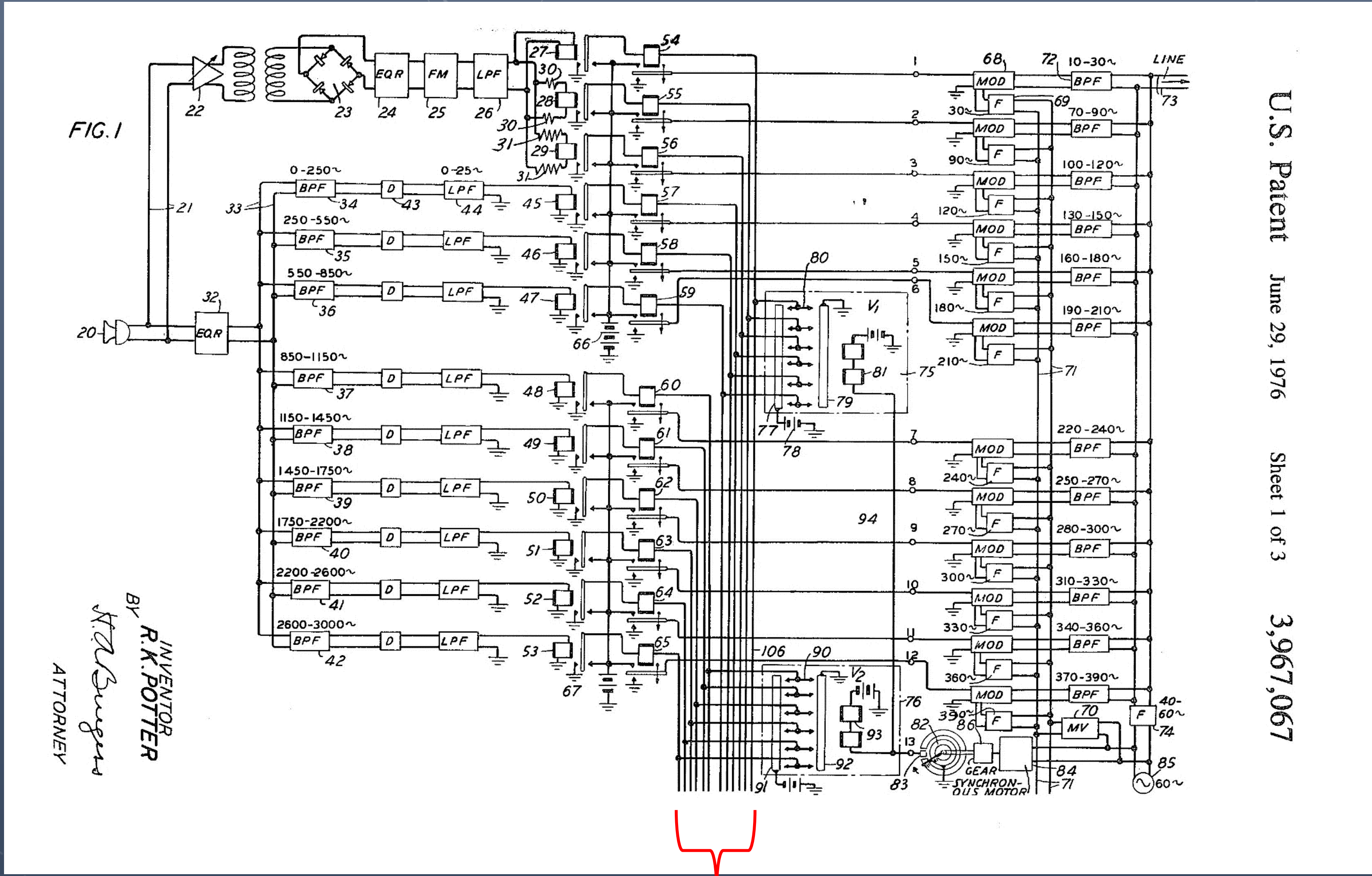
Sampling the Analog Signal?



- Different Voices
    1. Chanting Monotone
    2. Whisper
    3. Ventriloquistic
    4. Nasal
    5. Southern Drawl
    6. Squeak-Drunken man's hiccup effect
    7. Voice Breaking in an adolescent
    8. Talker Chewing Gum
    9. Crying Child
    10. Reversed Inflection –Swedish Voice
    11. Tremulousness of Old Man
    12. Music-Singing

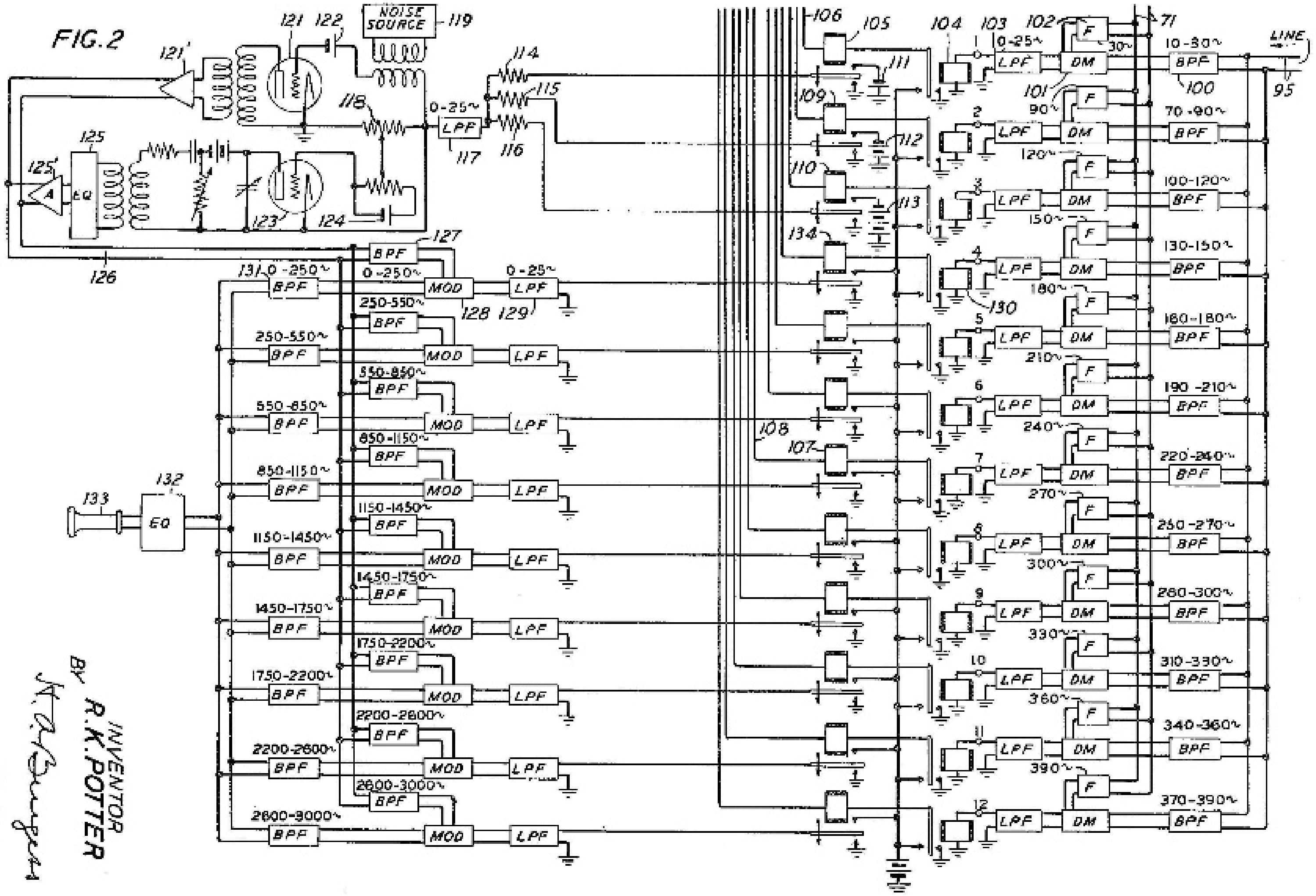
- How often?
- What levels?
- Fundamental Characteristics
    - Pitch
    - Resonant Frequency regions
    - Loudness
- How accurate does the reproduction need to be?


Dec. 12, 1939.
R. R. RIESZ
WAVE TRANSLATION
Filed Sept. 11, 1936
2,183,248
3 Sheets-Sheet 1
FIG. 1
DELAY EQUALIZER
DE1
AN
VC
FP3
FP2
S2
S1
S3
FP1
FREQUENCY PATTERN CONTROL CHANNEL
100-250~
E1
EQUALIZER
DETECTOR
S4
FM
FREQUENCY MEASURING CIRCUIT
L.P.F. 0-25~
F30
L0
FPS
ENERGY SOURCE OF FREQUENCY PATTERNS
VARIABLE GAIN AMP.
B3
SN1
SPEECH B.P.F.
0-250~
F1'
F1"
SPEECH B.P.F.
F1
FP
AP
DELAY EQUALIZER
DE
SPEECH IN
250-550~
F2
550-850~
F3
2650-2950~
F10
AP1
AP2
AP3
AP10
DETECTOR
D1
D2
D3
D10
F31
F32
F33
F40
L1
L2
L3
L10
F2'
F3'
F10'
SN2
SN3
SN4
F2"
F3"
F10"
SPEECH RECEIVING CIRCUIT
FIG. 2
FREQUENCY MEASURING CIRCUIT
FM
VOLUME CONTROL CIRCUIT
20
10
11
GAS FILLED
A1
B1
12
CLASS C
13
14
FIG. 2-A
Eg
d
O
B
t
15
16
17
INVENTOR
R. R. RIESZ
BY
ATTORNEY



Note: 12 output signals! Each was sent over a different radio frequency.
This is the first application of Direct Sequence Spread Spectrum Radio.

FIG. 2

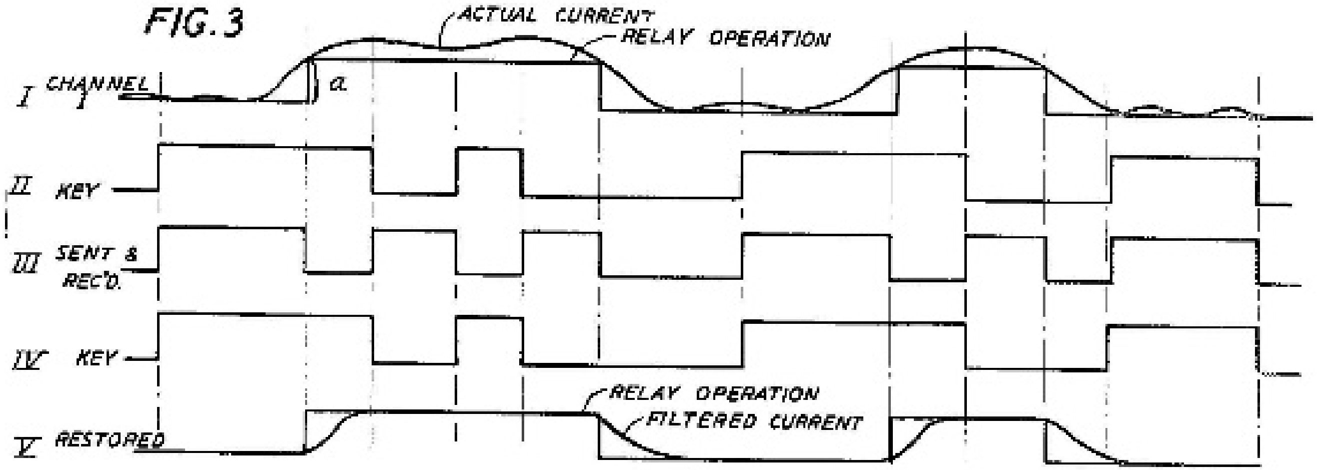


INVENTOR
BY R. K. POTTER

ATTORNEY

U.S. Patent June 29, 1976 Sheet 3 of 3 3,967,067

FIG. 3

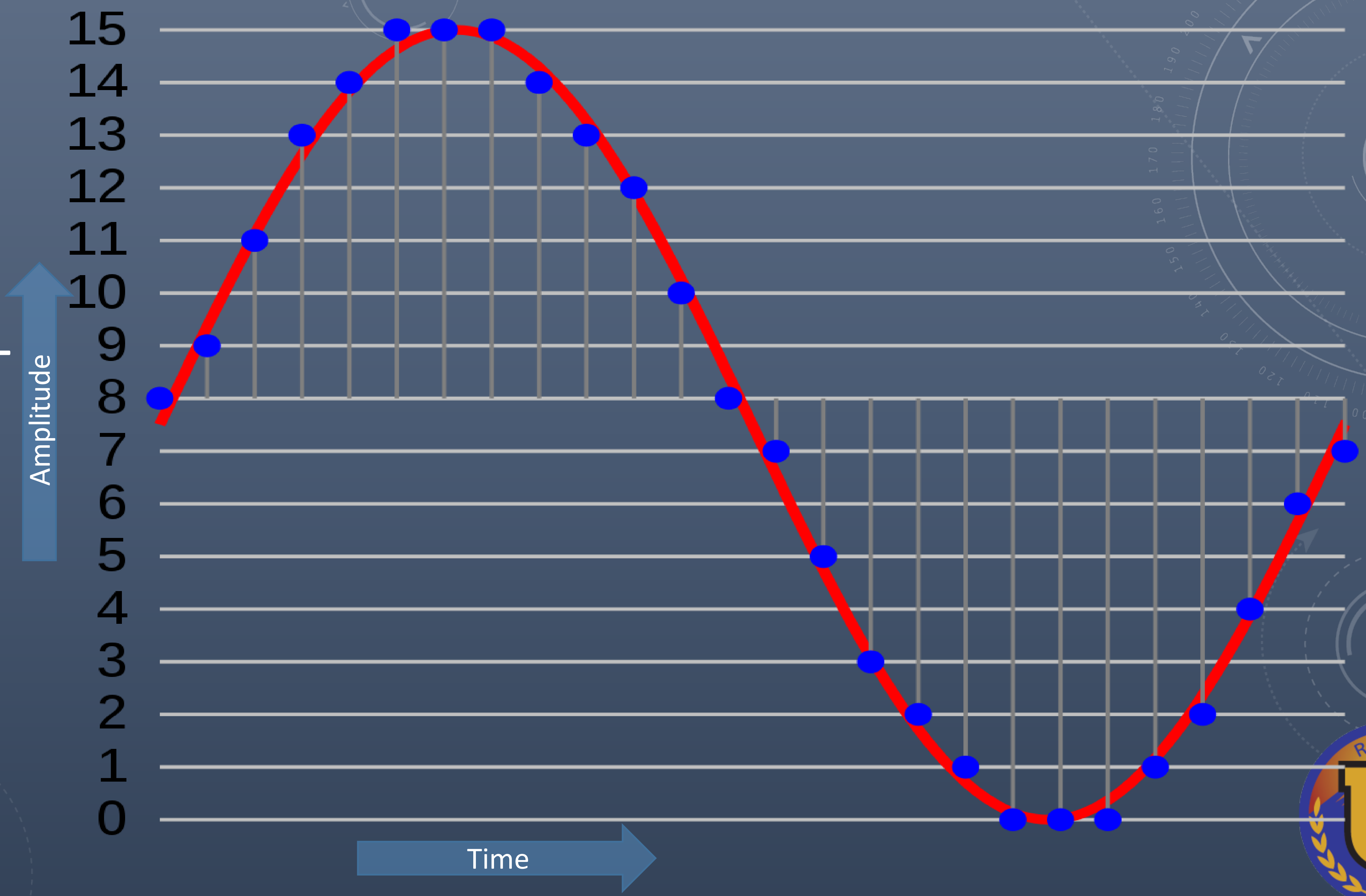


How Often to Sample?

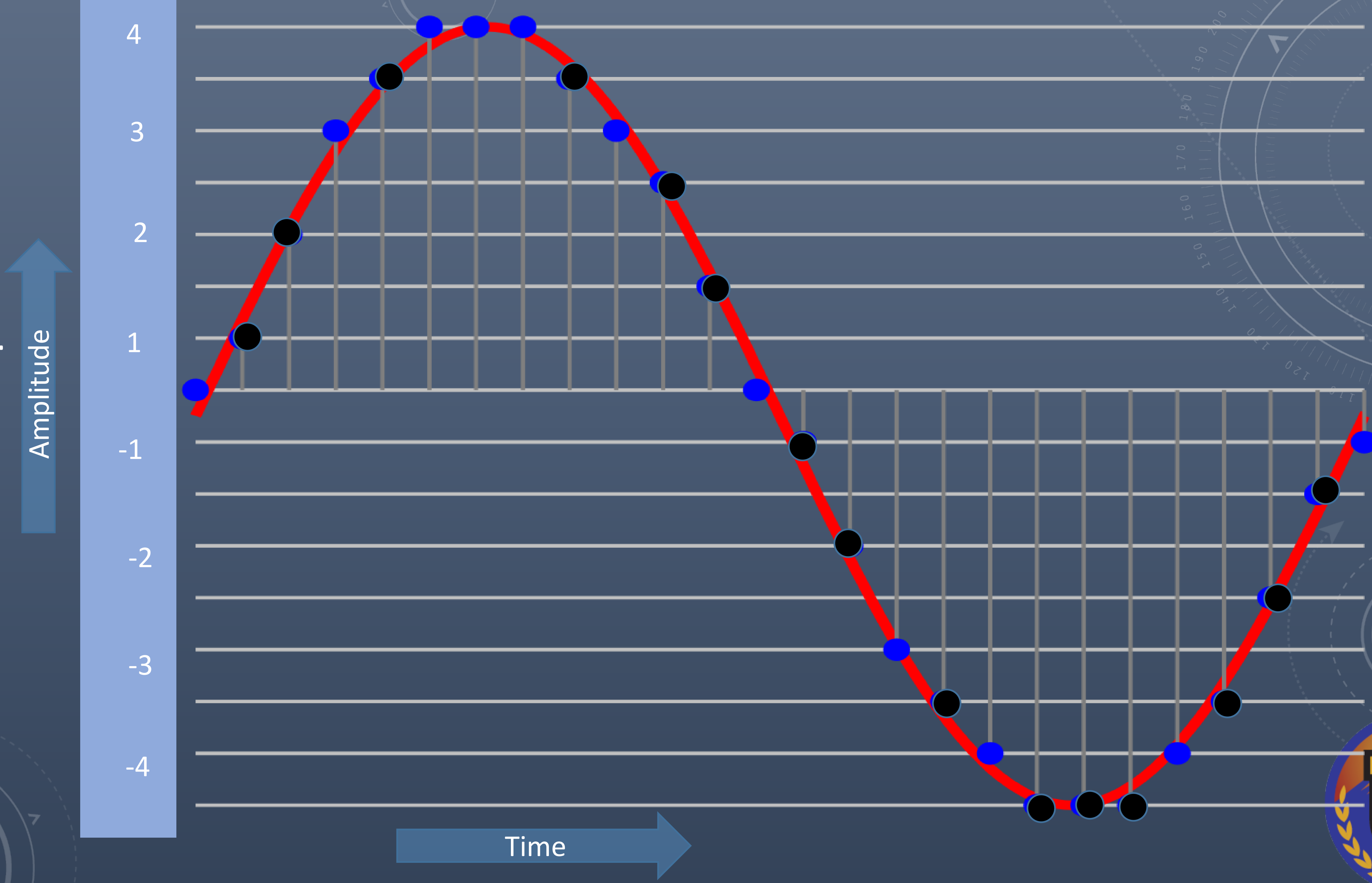
- Nyquist-Shannon Sampling Theorem
  - Establishes a method to change a continuous-time signal to a discrete-time signal.
  - It establishes a sample rate that permits a discrete sequence of samples to capture all the information from a continuous-time signal of finite bandwidth.

- **Theorem** – If a function *x(t)* contains no frequencies higher than *B* hertz, then it can be completely determined from its ordinates at a sequence of points spaced less than *1/(2B)* seconds apart.

Example



Example



A bit of math

- Human voice bandwidth is about 4000 Hz
- The original PCM had 8 sample points

- Applying Nyquest - 1/2B seconds apart. Therefore sampling would be done every 1/8000 seconds or 8000 samples per second.
- Then with 8 sample points would result in a data stream of
  8X8000 or 64,000 data points per second

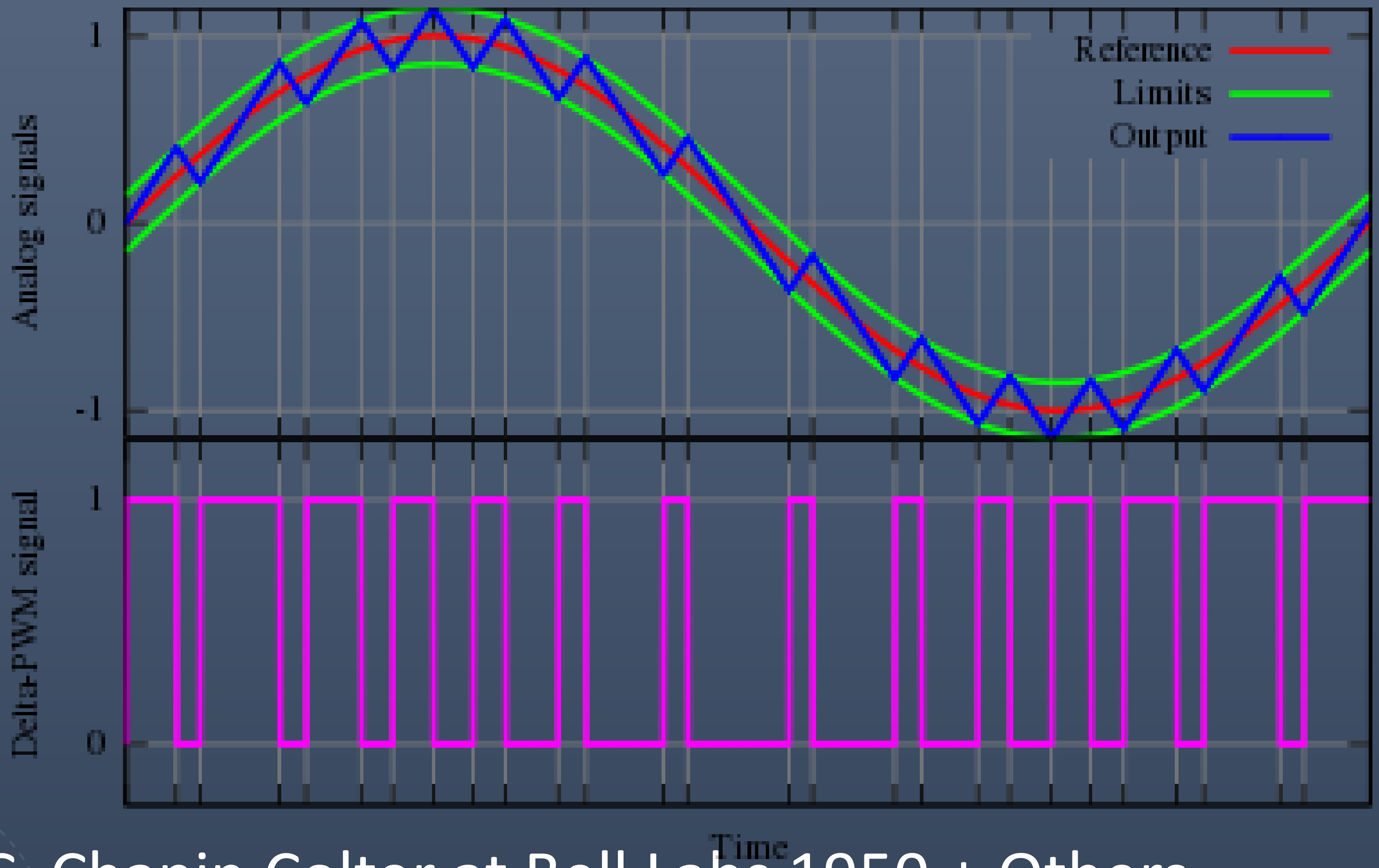
This is what the phone company standardized on.
64Kbps per voice channel

This is a big bandwidth HOG!!!!

- Nyquist- Shannon has saddled us with a more or less fixed sampling frequency (8000 samples/second).

- That leaves only one parameter we can alter.
- Do we really need 8 amplitude sample points?
- What can we do to reduce the number of sample points?

Differential Pulse-Code Modulation



- C. Chapin Colter at Bell Labs 1950 + Others

Key tenants of DPCM

- The analog Signal is approximated with a series of segments
- Each segment of the approximated signal is compared to the previous bits and the successive bits are determined by this comparison
- Only the change of information is sent, either an increase or decrease in value
- However, it requires a higher sampling rate.

Adaptive Delta Modulation (1968)

- Also called Continuously Variable Slope Delta Modulation.
- The step size is not fixed.

- Selected by NASA for mission control communications.

Vocoder Exists Here

7	Application	Application
6	Presentation	Presentation
5	Session	Session
4	Transport	Transport
3	Network	Network
2	Data Link	Data Link
1	Physical	Physical

Radio Frequency
Coding/Modulation
Error Correction

Rules Define a Layer

Before we get into the individual layers we need to present a definition of how they function and relate to one another.

- A layer should be defined for every distinct level of functionality.
- The function of each should be well defined and limited in its scope.
- International standardized protocols layer should be used wherever possible.
- The interface between the layers should minimize the interaction between them
- The interface between layers is well defined.

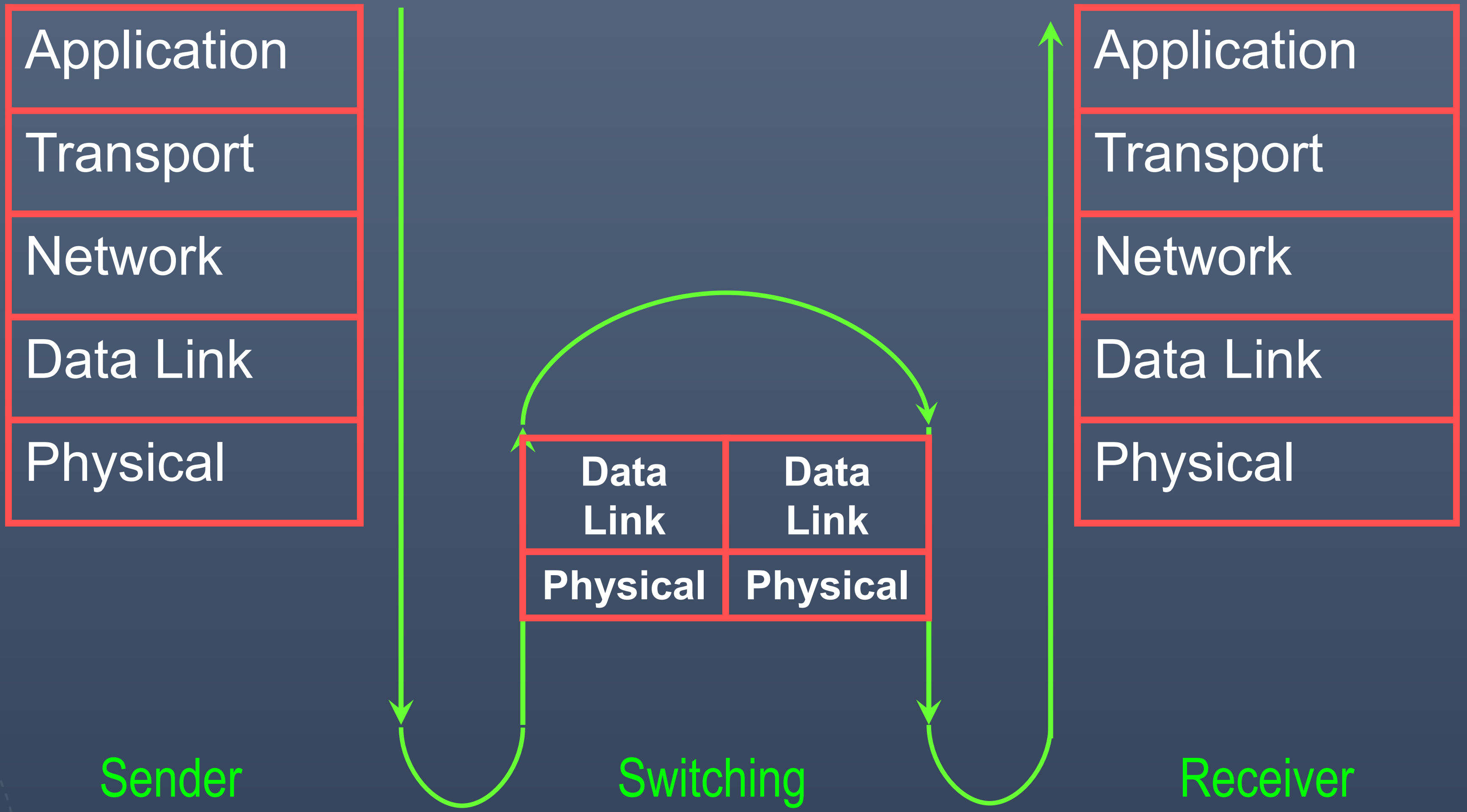
Padlipsky's Rule

If you know what you're doing, three layers is enough.

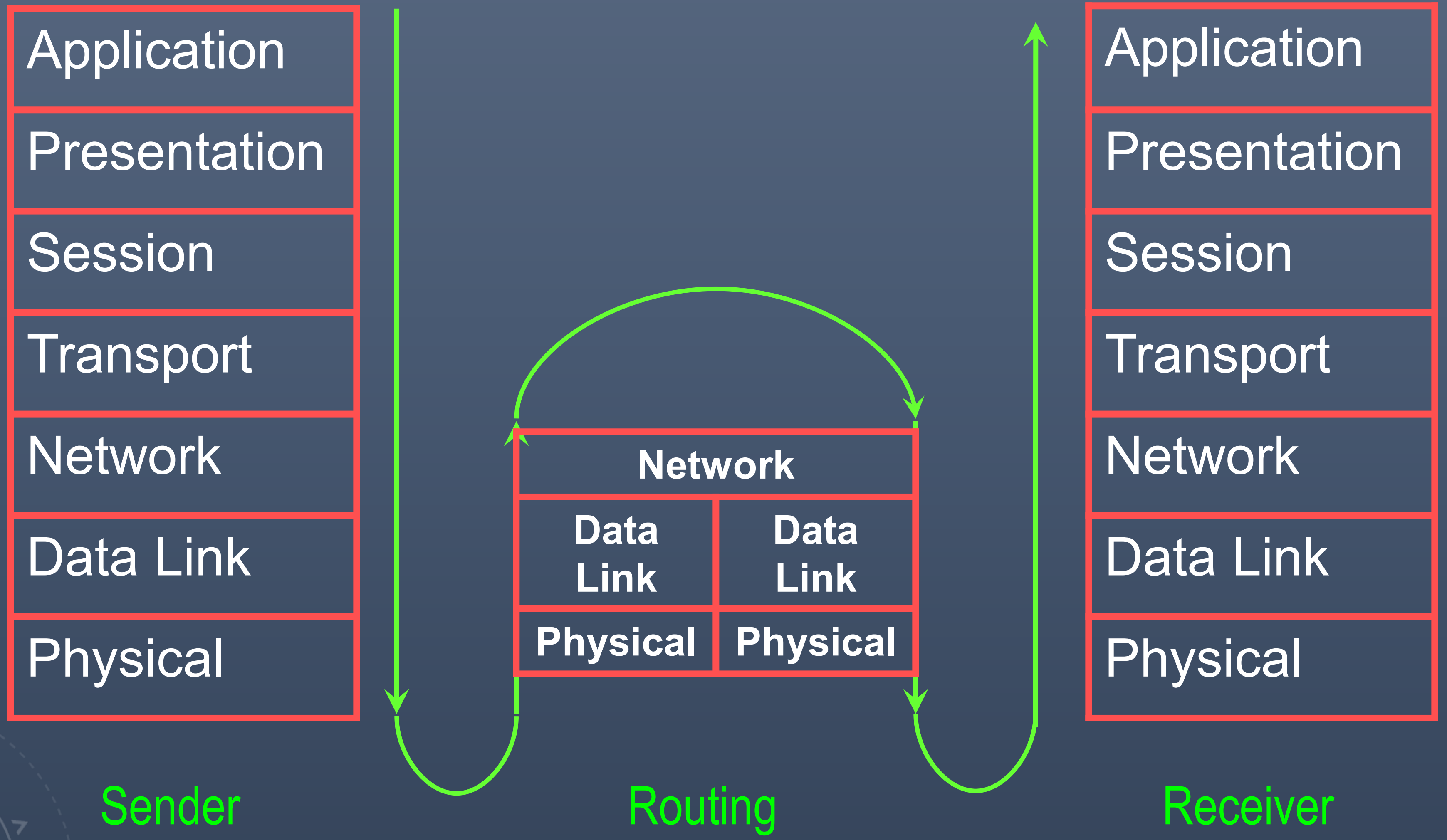
If you don't, even seventeen won't help.

Ethernet Switching

(Station to Station)



IP Routing (End to End)



ETSI TR 102 398 V1.4.1 (2018-11)

**Electromagnetic compatibility
and Radio spectrum Matters (ERM);
Digital Mobile Radio (DMR)
General System Design**

ETSI TR 102 398

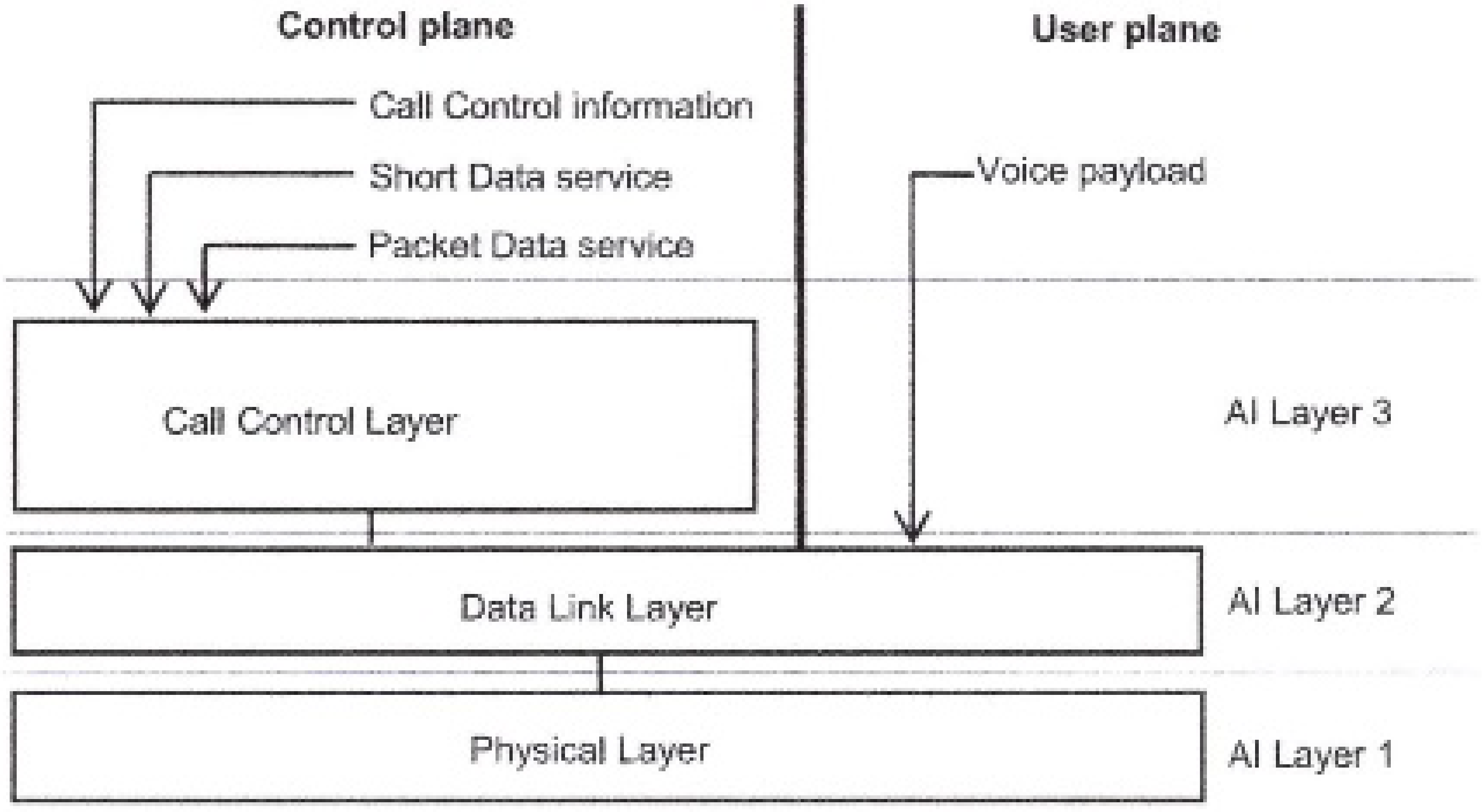


Figure 4.1: DMR protocol stack

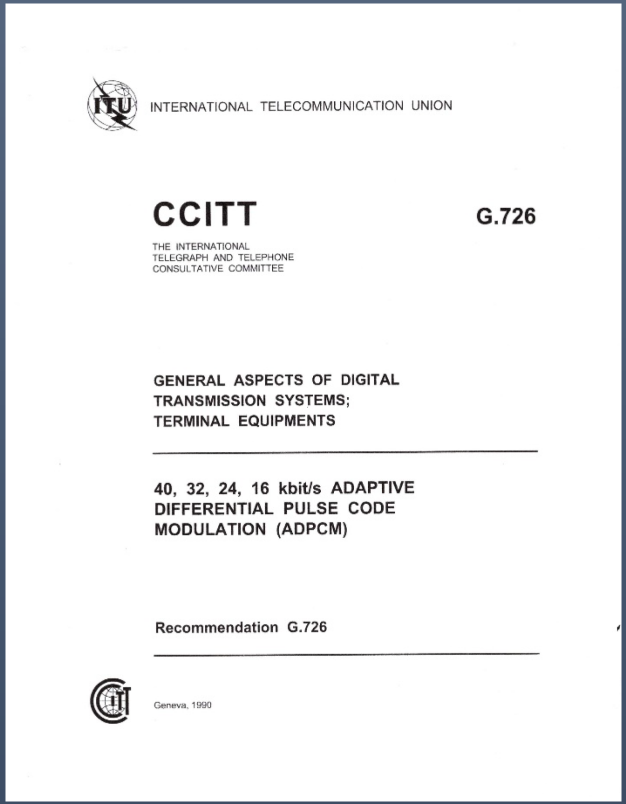
The Vocoder is not included!

- 5.1.3 The vocoder In order to achieve interoperability between units from different suppliers, the same vocoder or a completely compatible vocoder will have to be used. In order to avoid undue restrictions being placed on suppliers and thus limiting the markets that they may choose to address, it has been agreed not to specify any particular vocoder in the standard. There is a vocoder socket specified in the standard and any chosen vocoder should be compatible with the present document.

However:

Each end of the conversation has to employ the same vocoder.

Which one do we use?


INTERNATIONAL TELECOMMUNICATION UNION

CCITT G.726

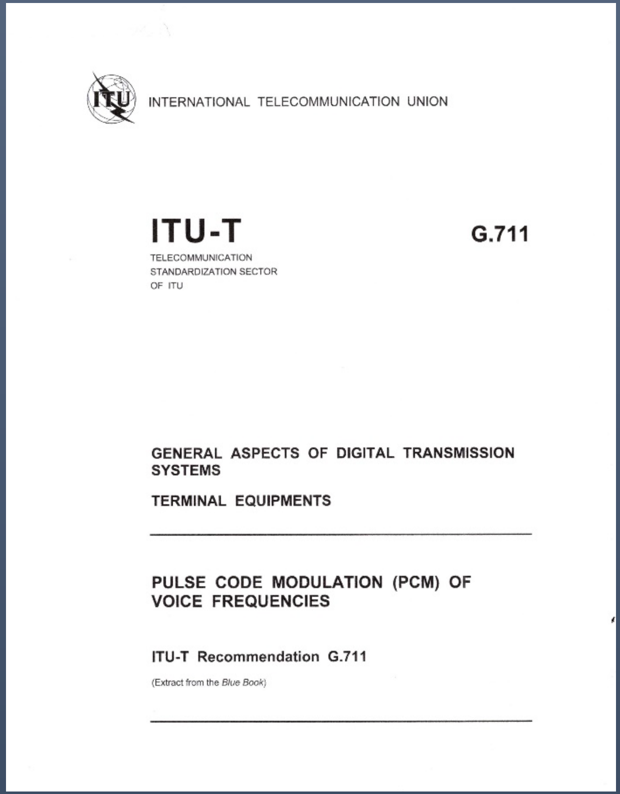
THE INTERNATIONAL TELEGRAPH AND TELEPHONE CONSULTATIVE COMMITTEE

GENERAL ASPECTS OF DIGITAL TRANSMISSION SYSTEMS; TERMINAL EQUIPMENTS

40, 32, 24, 16 kbit/s ADAPTIVE DIFFERENTIAL PULSE CODE MODULATION (ADPCM)

Recommendation G.726

Geneva, 1990


INTERNATIONAL TELECOMMUNICATION UNION

ITU-T G.711

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

GENERAL ASPECTS OF DIGITAL TRANSMISSION SYSTEMS

TERMINAL EQUIPMENTS

PULSE CODE MODULATION (PCM) OF VOICE FREQUENCIES

ITU-T Recommendation G.711

(Extract from the *Blue Book*)


International Telecommunication Union

ITU-T G.722 (09/2012)

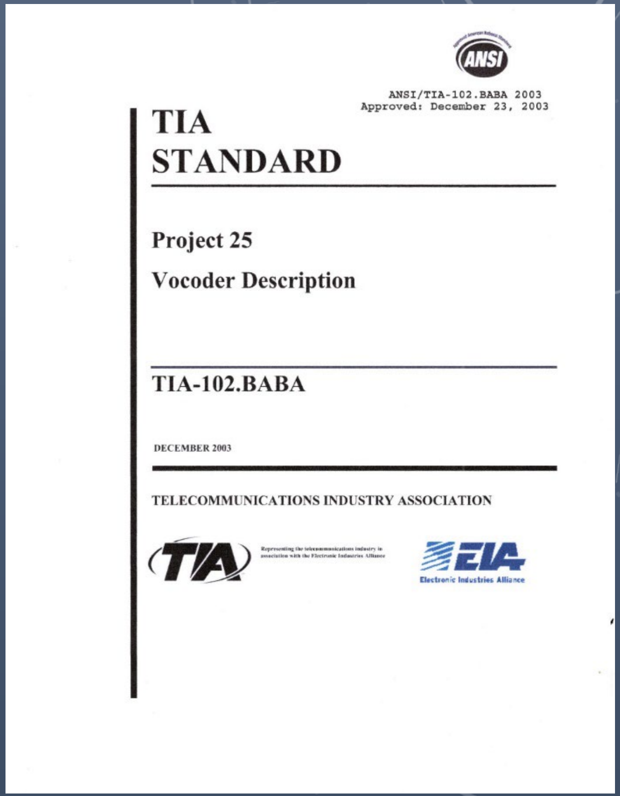
TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital terminal equipments – Coding of voice and audio signals

7 kHz audio-coding within 64 kbit/s

Recommendation ITU-T G.722


ANSI/TIA-102.BABA 2003
Approved: December 23, 2003

TIA STANDARD

Project 25

Vocoder Description

TIA-102.BABA

DECEMBER 2003

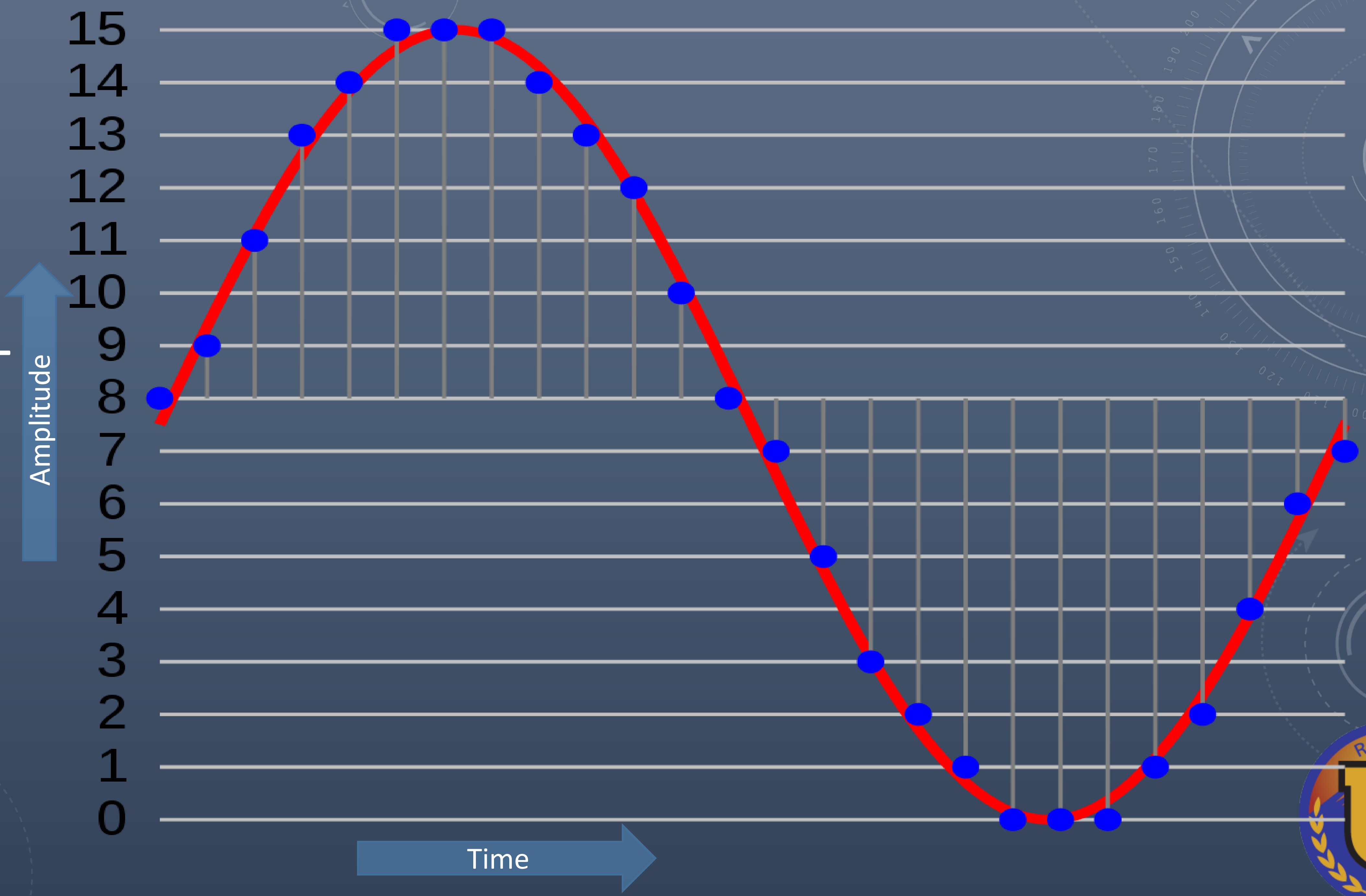
TELECOMMUNICATIONS INDUSTRY ASSOCIATION

What Vocoder is being used?

Mostly Proprietary Chips from
DSP Innovations© with the AMBE2+ Vocoder
(Advanced Multi Band Excitement)

While the Vocoder is not in the ETSI standard!
Project 25 specifies this chip.

Example



Conclusion

We talked About

- The historical beginnings of the Vocoder
- A ground breaking early application of a Vocoder
- Several of the underlying methods of digitizing speech
- The OSI 7 layer model
- Applicable Standards or not!


Any
Questions

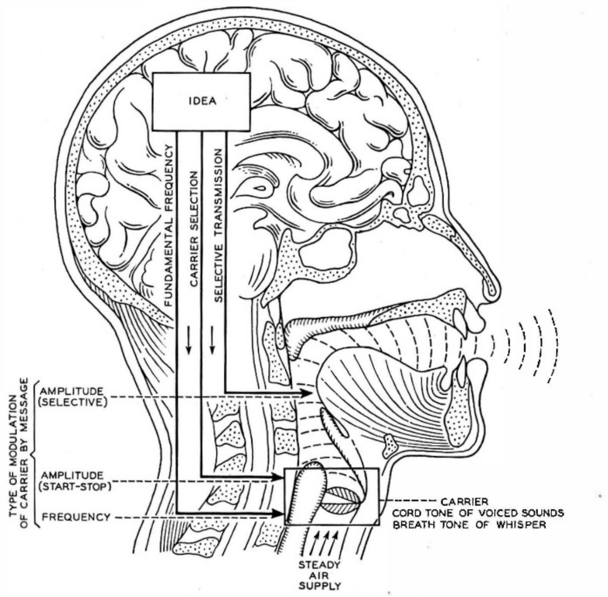


Fig. 1—The vocal system as a carrier circuit.

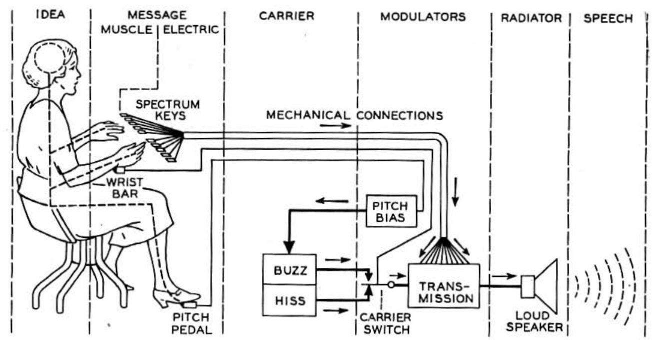


Fig. 8—Schematic circuit of the voder.