

STATISTICAL ANALYSIS OF MESSAGES AND
THEIR CODING OF BENGALI LANGUAGE

BY
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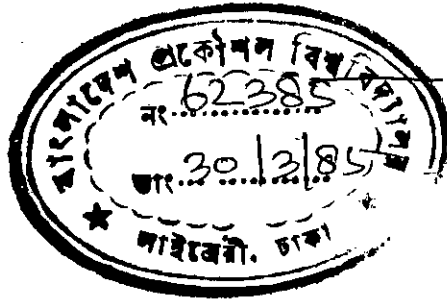
A THESIS
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CERTIFICATE.

This is to certify that this work has been done by me and it has not been submitted elsewhere for the award of any degree or diploma.



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ABSTRACT

A statistical analysis has been performed for determining the electrical characteristics of Bengali Voice Signals. For this purpose the amplitude and duration pattern of the letters of Bengali alphabet uttered in isolation and in different words has been studied from speech samples recorded from twenty Bengali speaking persons. Then the bandwidth of the letters were also determined both individually and occurring in syllables of different words. The letters in male and female voices were treated separately. On the basis of the bandwidth analysis it can be suggested that the bandwidth of a telephone channel adaptive to Bengali Voice Signals should be 3.5 KHz for uninterrupted transmission. Also the sampling rate for an analog to digital converter has been calculated from this band limit. Based on these statistical data some prospective coding schemes for digital processing of Bengali voice signals have been suggested. The number of bits required for an algebraic coding has been found to be 10 including 6 message bits and 4 redundant bits. For a convolution coding a code tree has been designed for 6-bit messages in Bengali.

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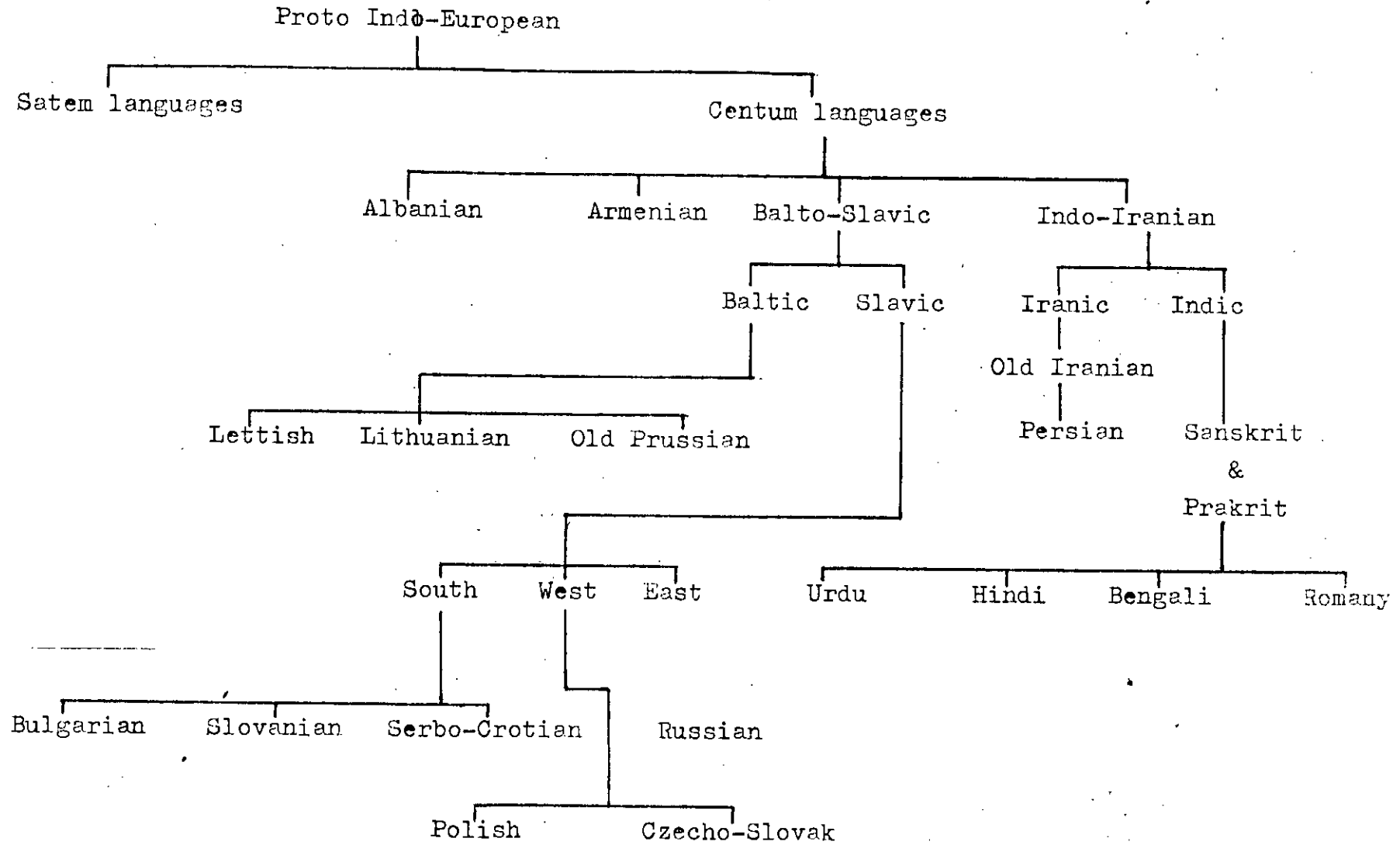
CHAPTER - 1

GENERAL INTRODUCTION

1.1. A Brief History of Bengali Language :

Bengali is the language of over 150 million people. Among them one third live in the West Bengal and Tripura States of India, a few millions in the various districts of Assam, Orisha and Bihar States of India, a few million in Britain and about 100 million in Bangladesh. The history of Bengali begins in the early centuries of the present millennium. Before that there was only a family of dialects commonly known as Prakrit. The gradual development and the location of Bengali in the Indo-European family of languages is shown in page-2 in tabular form [1-2]. In linguistic relationship, Bengali is closer to Assamese, then to Oriya and then to Hindi. About sixty percent of the word types in formal Bengali are classical Sanskrit. The rest contains British English, Persian, Portuguese and other south Asian Languages. The script is historically derived from ancient Indian Brahmin, itself a modification of ancient southern Arabic. It goes from left to right and unlike roman hangs from a line and there are no capitals. Modern Bengali is an Indoaryan language. It has been written in a script called Bongolipi. Modernisation of Bengali started from late eighteenth century. This was the time of advent of modern prose and standard colloquial Bengali. However, Bengali language like any other language has several directal variations.

The gradual development of Bengali language.



Bengali is structurally known as a SOV (Subject object verb) language. But it has noticeable flexibility in the order of the words depending on the intentional contextualisation of the speaker.

There are about 4000 languages in the world. The position of Bengali is eighth in view of the number of speakers. Its position is after Chinese, English, Hindustani, Spanish, Russian, German and Japanese. From the consideration of literary achievement its position is unique in South Asia. About 1600 newspapers and journals are published in Bengali.

The Language movement of 1952 and the subsequent establishment of Bangladesh in 1971 have greatly influenced the modern trend of the language. It is now being extensively used in academic institutions, government offices, autonomous bodies and in almost all public affairs. In brief it is the major medium of mass communication in Bangladesh. Because of this changing status the domains of uses of the languages has been extended substantially. So Bengali as a language has to cope with the new situations. Bengali as a language has not been extensively analyzed for an electrical communication channel. The most relevant work on the acoustical study of the vowel structure of Bengali language was carried out ^{by} Pramanik [2]. Das [3] studied the information contents of messages in Bengali language. The purpose of this thesis is to study statistically the time- amplitude pattern and the frequency bandwidth of Bengali alphabets in voice signals which are the constituents of the language and to extend this

study to digital processing of Bengali messages by appropriate coding.

1.2. Object and Method of Study:

The object of the study is to find the electrical characteristics of Bengali Voice Signals and the possibility of digital processing of Bengali messages- by statistically measuring their time- amplitude and frequency bandwidth pattern. For this purpose the following steps have been carried out.

1. The time-amplitude signal patterns of Bengali alphabets uttered in isolation and occurring in different words were recorded from both male and female voices and statistical averages were established for their respective amplitude and duration.
2. For assessment of the bandwidth of a voice channel adaptive to Bengali, the bandwidth of the Bengali alphabets uttered in isolation and occurring in words from male and female voices were determined by the method of Gaussian frequency analysis.
3. Based on the data obtained in steps 1 and 2 appropriate coding schemes for efficient digital processing of Bengali messages have been suggested.

In Chapter-2 the time-amplitude pattern of Bengali Vowels recorded from the voices of ten males and ten females of different ages and professions were studied. A similar study on Bengali Consonants uttered in isolation is given in Chapter-3.

Since in normal speech the alphabets occur in different words a study has been given to their time-amplitude pattern occurring in different words. The results of this study are given in chapter-4. In chapter-5 a frequency analysis has been performed over the penrecorded data of the time-amplitude pattern. The method is based on Gaussian Spectrum analysis. The statistical data for amplitude and duration pattern as well as the frequency bandwidths of the alphabets enabled us to think over the design considerations for digital processing of Bengali messages. For this purpose some coding schemes have been developed for Bengali Voice Signals and illustrated in chapter-6. The thesis has been concluded with a general discussion in chapter-7.



Chapter 2

MEASUREMENT OF THE AMPLITUDE VERSUS TIME PATTERN OF BENGALI VOWELS IN VOICE SIGNALS:

2.1 Introduction

Bengali Vowels have been recorded from the voices of twenty Bengali persons. Ten of them are males and ten are females. The persons are of different profession and hailing from different districts of the country. Their ages range from 20 to 40 years. The speech samples were tape recorded and then pen recorded as amplitude versus time. Each vowels has been pronounced thrice by each person and an average amplitude and duration of each alphabet have been calculated for each person. Again an average amplitude and duration for each alphabet pronounced by different persons have been calculated and bargraphs of the average amplitude versus duration have been drawn. The data for male and female voices have been processed seperately.

2.2 Experimental Set-up

A photograph of the experimental set up is given in Fig.1. A tape recorder type 7003 of Bruel & Kjaer is connected to a level recorder type 2307 (of Bruel & Kjaer). The voice signal is first recorded from the microphone and then replayed to the level recorder giving the pen recorded data. The electrical and mechanical characteristics of the instruments are described below.

Tape Recorder [4]

This is a portable multichannel instrumentation tape recorder type 7003 of Bruel & Kjaer designed to give optimum performance and

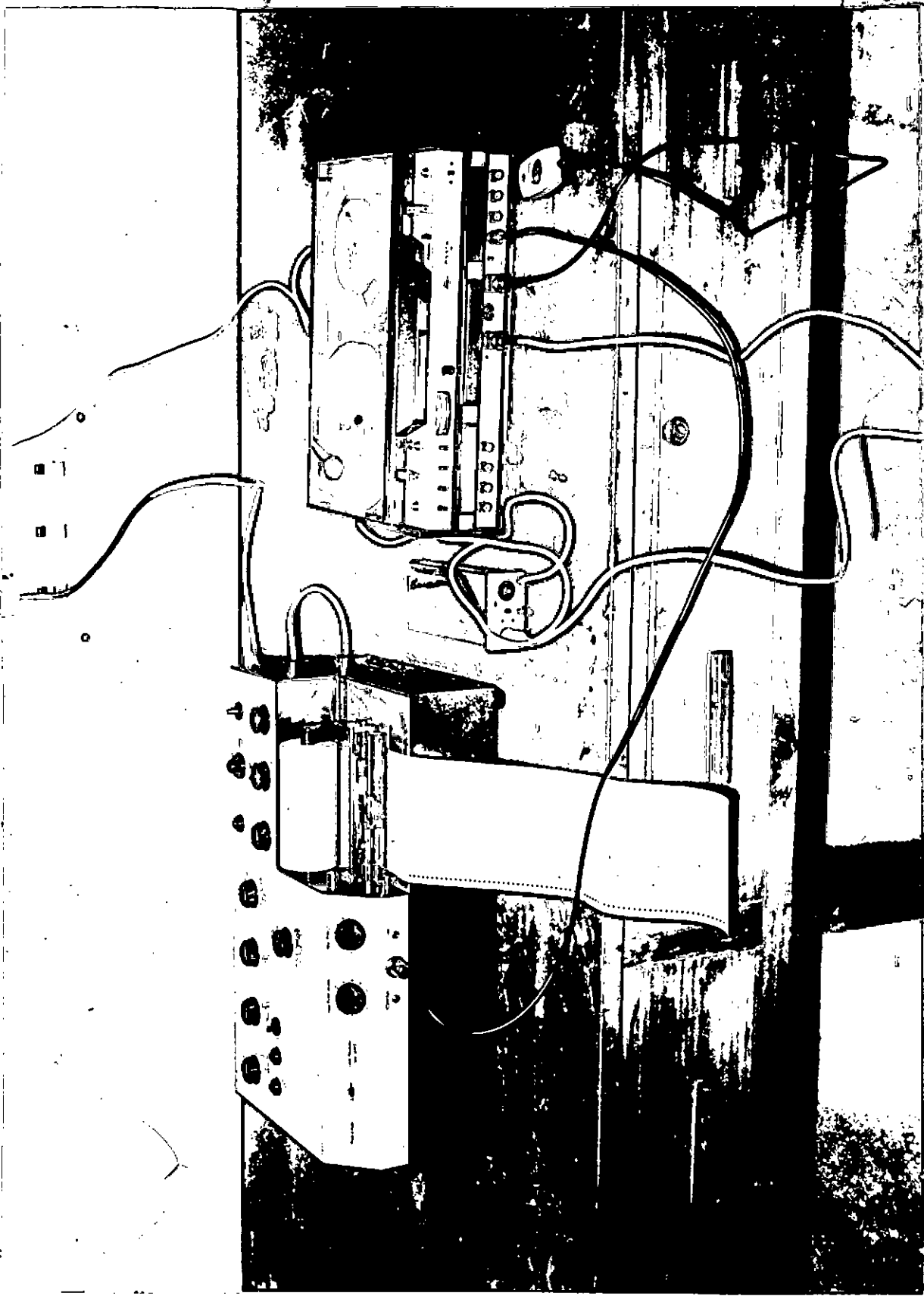


Fig. 1. A Photography of the Experimental Setup.

reliability. It is especially designed for recording of Vibration and acoustic data. It employs all solid state Circuitry giving accuracy and repeatability of performance. It uses $\frac{1}{4}$ " professional tape on 7" reels.

The tape recorder 7003 has four tracks and is intended mainly for vibration measurement. It uses FM recording techniques giving a frequency range down to DC. Two tape speeds are available, 15 ips and 1.5 ips which allow a frequency transformation ratio of 1 : 10.

The recording technique is FM and each of the four identical measurement channels consists of a 'record', section and a 'reproduce' section mounted on exchangeable plug-in cards. A block diagram of one measurement channel is shown in Fig. 2.

The channels feature very low distortion, high linearity and low noise. The wide band dynamic ranges are 39 dB and 44 dB at 1.5 ips and 15 ips respectively. For the available direct channels the dynamic ranges are 35 dB and 39 dB. If the recorded signal is to be frequency analyzed, the dynamic range will be considerably greater over most of the frequency range depending upon the analysis bandwidth.

A circuit for recording voice signals on channel 1 is also included. It consists of a dynamic microphone, an amplifier and a relay, which is controlled from the microphone. When recording voice signals the output of the amplifier is switched via the relay

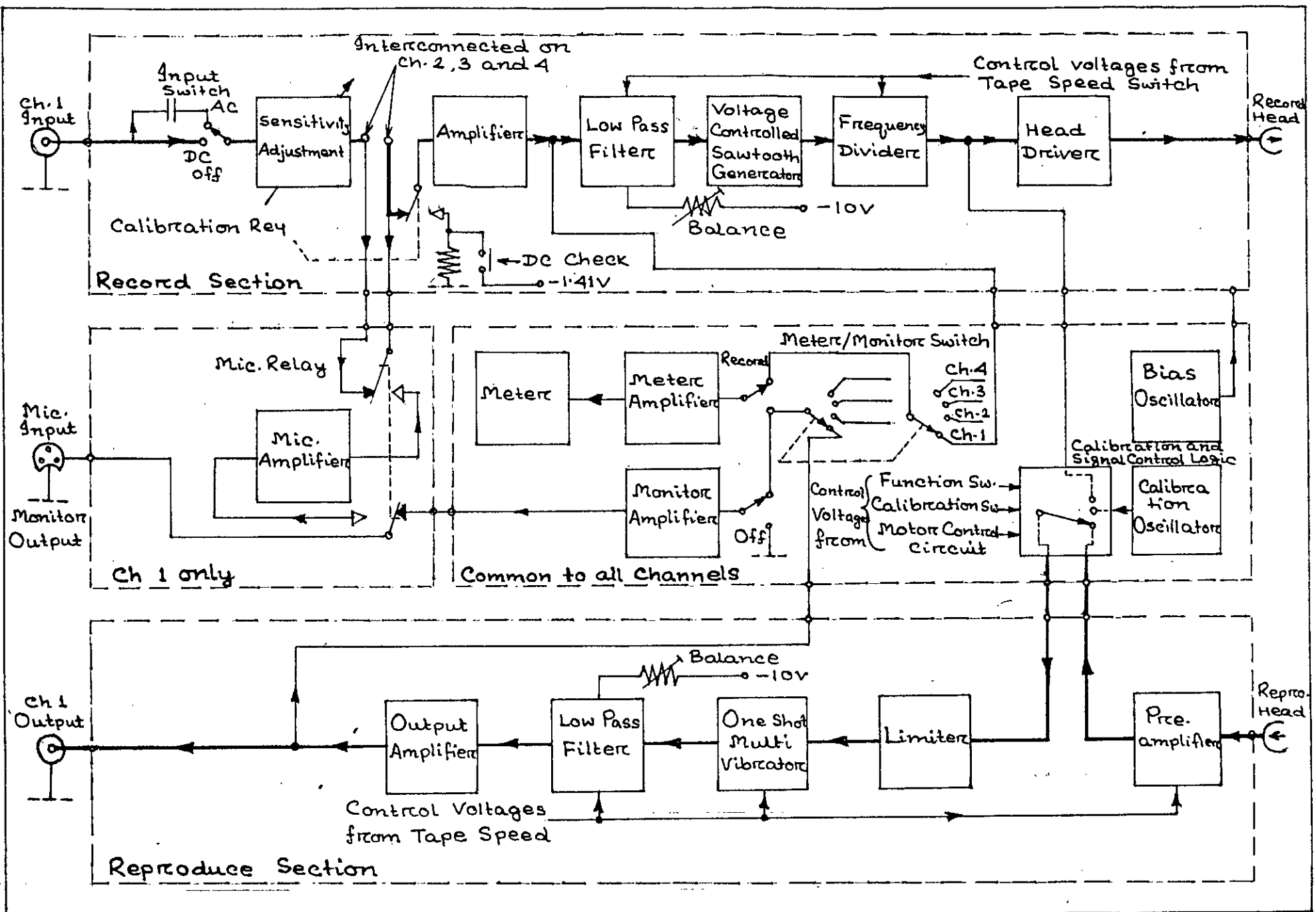


Fig. 2. Block diagram of measurement channel (ch. 1) of Tape Recorder Type 7003

to the input of channel 1, which then serves as voice channel. At playback the microphone acts as a loudspeaker and reproduces the track selected by the meter/monitor switch.

Graphic Level Recorder [5]

The Level Recorder is an instrument type 2307 of Bruel & Kjaer. It is basically a recording voltmeter designed to accurately record the RMS, average or peak level of an AC signal from 2 Hz to 200 KHz as well as dc signals. Recording as a function of time or frequency can be made on preprinted lined or frequency calibrated strip-chart paper, 50 or 100 mm wide.

Electrical description of the Level Recorder:

A block diagram of the level recorder is shown in fig. 3. The level recorder operates as an automatic null balancing bridge. The input signal is applied to the interchangeable Range Potentiometer via a continuously variable input Potentiometer and a calibrated input attenuator. The wiper at the Range Potentiometer is linked with the pen drive.

Input to the recorder is performed via a 14 mm coaxial socket for standard B and K plugs. A ground socket is also provided enabling banana plugs to be used. The input signal can be attenuated continuously over a range of approximately 12 dB by Input Potentiometer. The Input Attenuator attenuates the signals in accurate 10 dB steps. With these two controls the pen position can be adjusted to obtain the desired base-line calibration. A push button

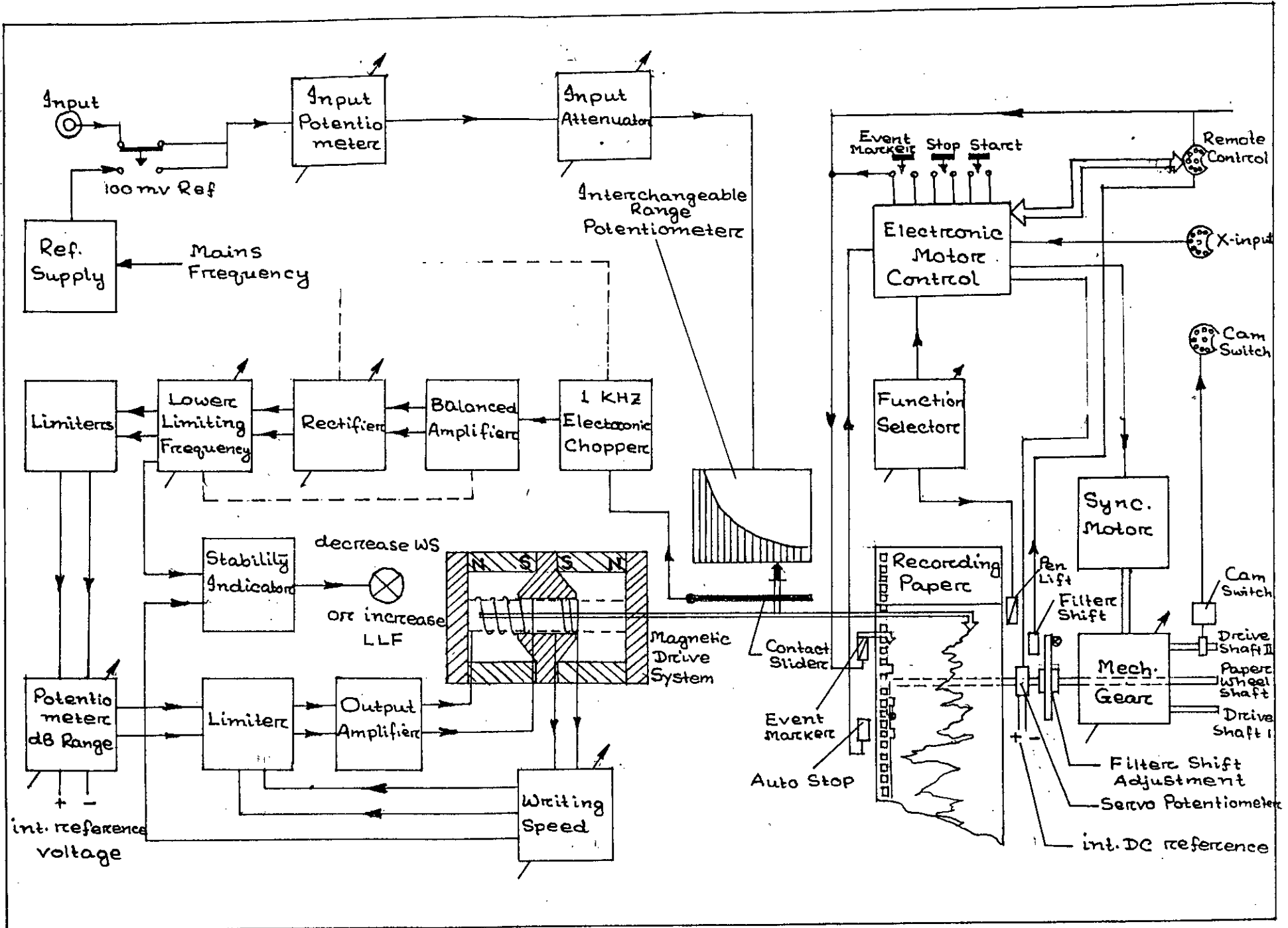


Fig. 3. Block Diagram of the Level Recorder Type 2307

operated 100 mv reference voltage is provided for easy calibration.

The dynamic range of the recorder is determined by the interchangeable range potentiometer. There are six different potentiometers, two linear and four logarithmic with dynamic ranges of 10, 25, 50 and 75 dB. The resolving power is adjustable by the Potentiometer Range attenuator.

Time averaging is required for the measurement of varying signals. The averaging time of the level Recorder is determined by the setting of the writing speed control.

The Lower Limiting Frequency Control determines the lowest frequency to which the recorder responds correctly. The lower limiting frequency limit may be adjusted to be 2, 10, 20, 50, or 200 Hz. Writing Speeds can be selected from 2 to 200 mm/s giving effective averaging times from the order of seconds down to approximately 10 ms.

The level Recorder records the absolute arithmetic average, the root mean square or the instantaneous half peak-to-peak value of any waveform from 2 Hz to 200 KHz. The recorded RMS value is accurate to within ± 0.5 dB for signals with crest factor upto 10. Phase distortion will not affect the RMS accuracy.

In the DC recording mode a 1 KHz electric chopper is introduced before the average rectifier.

Mechanical Description :

The mechanical section of the Level Recorder consists of a pen drive system, an event marker facility and a paper drive mechanism.

As well as driving the paper, the paper drive mechanism also incorporates an automatic stop device for single chart recording, synchronization of external instruments with the paper movement, and control of a multiplexing switch is used e.g., for two channel recording.

There are two drive shafts for driving external equipment. One of them can also be used as an input for external mechanical control of the paper movement.

The Level Recorder is capable of writing on 50mm and 100 mm widths of strip chart recording paper and on 200 mm dia Polar paper. For 50 mm writing width the moving arm is coupled directly to the Pen holder. For 100 mm writing width a very accurate wire driven mechanical gear transforms the movement of the drive coil into the required pen movement. When recording on Polar paper a small pin supplied is inserted through the hole in the centre of the paper and into a hole in the writing platform.

A Pen Lift mechanism enables the pen to be lifted from the paper when-ever desired.

The Level Recorder is also equipped with an Event Marker facility whose markings at the chart border can represent frequency, time or other quantities as required. The event marking can be controlled manually or remotely.

The writing system uses either pens loaded with ink cartridge or disposable fibre pens for writing on white paper or sapphire style for writing on white-wax-coated paper.

The paper drive of the level recorder uses a special motor with very short start and stop times. With 50 Hz power supply the starting and stopping times are as short as 15ms and time for reversal of paper direction is 70ms.

2.3 Measured Data

The wave shapes of the measured data recorded from various persons are shown for a typical voice in fig. 4 . It can be observed that although the waves have some similarities their distinctive features are their amplitudes and durations which are found to be the major characteristics of the alphabet . Comparative study of the amplitudes and durations of the vowels have been carried out in the following sections.

2.4 Amplitude and Duration of Bengali Vowels in Male Voice:

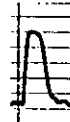
Traditionally there are 13 vowel characters in Bengali Language. They are shown below with the phonetic transcription of their normal pronunciation. [6].



অ



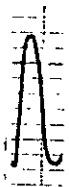
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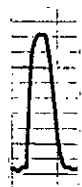
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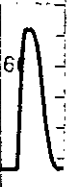
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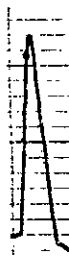
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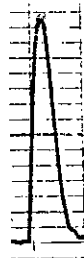
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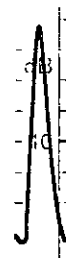
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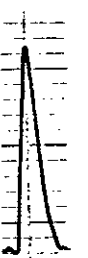
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ঔ



অঃ



অঃ

Fig. 4 Wave Shapes of Bengali Vowels in Voice Signal for a typical Voice.



অ	আ	ই	ঈ	উ	ঊ	ঋ
o	a	i	i:	u	u:	ɹi
এ	ঐ	ও	ঔ	অং	অঃ	
e	oi	o	ou	ong	oh	

Among them অ, আ, ই, উ, এ and ও are original vowels and are known as Phonemes or Phonological units. ঐ and ঊ are variations of ই and উ. ই and উ are short vowels and ঐ and ঊ are long vowels and are not mutually contrastive. So ই and ঐ are considered as members of the same phoneme. Similar is the case with উ and ঊ. ঋ, অং and অঃ are semivowels and ঐ and ঔ are called compound vowels or Diphthongs. Each of them are actually sum of two vowels,

e.g.,

$$\text{ঐ} = \text{ও} + \text{ই}$$

$$\text{ঔ} = \text{ও} + \text{উ}$$

Amplitude and duration of Bengali Vowels in different male voices are shown in table 1 and their average is shown in table 2. The average values are shown in bar graphs in figure - 5. From the data it is seen that অং has the highest amplitude level (129.10mv). ই has the lowest amplitude (43.60 mv) and minimum duration (0.41 Sec.). The duration of উ is maximum (0.51 Sec.). The amplitude and duration of ঐ is greater than ই and those of ঊ are greater than উ. The reason of these higher amplitude and duration is probably psychological. ঐ and ঊ are known as long vowel. This notion might have influenced the speakers in realizing the sounds in longer duration and higher amplitude. 'অ' is known as back vowel and both 'its' amplitude and duration are higher than

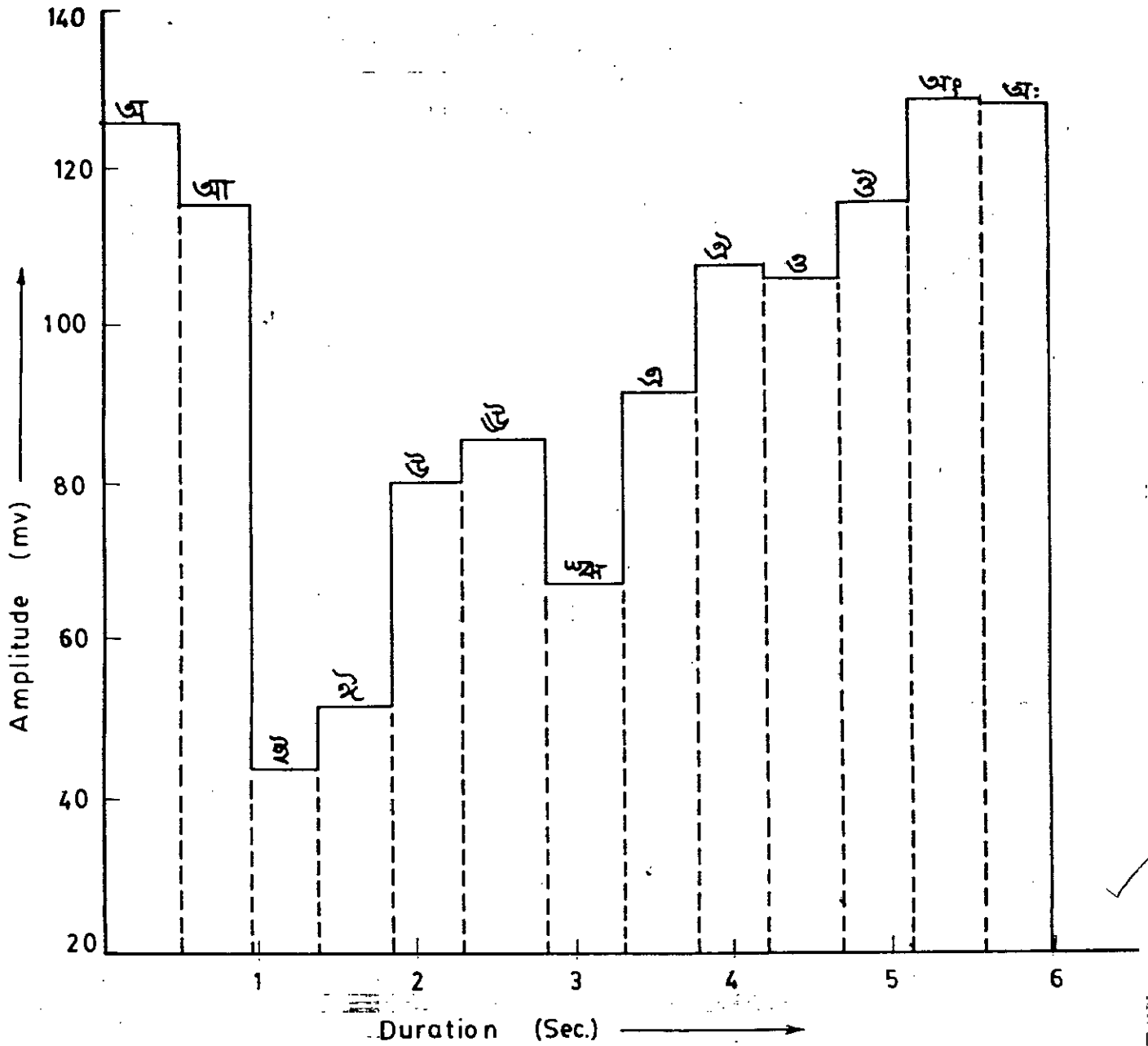


Fig. 5. Bar Graph showing the Average Amplitude and Duration of Bengali Vowels in Male Voice.

'আ' which is known as low vowel. This is because during pronunciation of 'আ' the aperture of our month is more open than অ and as a result the air thrust is lower.

2.5 Amplitude and Duration of Bengali Vowels in Female Voice:

Amplitude and duration of Bengali Vowels in 10 different female voices are shown in table 3 and their average values are shown in table 4. These data are also shown in bargraphs in fig- Fig.6. There is resemblance of amplitude pattern of female voice with that of male voice. However the difference occurs in their relative amplitudes and duration. In female voice 'আ' has the highest amplitude in contrast to অ which has the highest amplitude in male voice. Other characteristics are systematically similar with lower amplitude and duration.

2.6. Discussion:

From the data we find that অ has the highest amplitude in male voice and আ has the highest amplitude in female voice. The lowest amplitude occurs in ই in both male and female voices. The duration is maximum for অ and minimum for ই, and ঐ in both the cases. The average amplitude variation ranges from 43.60 mv- 129.10 mv for male voice and 39.90 mv- 118.80 mv for female voice. The ranges of variation of the duration is 0.41 sec-0.51 sec. for male voice and 0.40 sec-0.49 sec. for female voice. The results of the analysis of the average amplitude and duration pattern of the vowels are illustrated in figures 3 and 4 for comparative study.

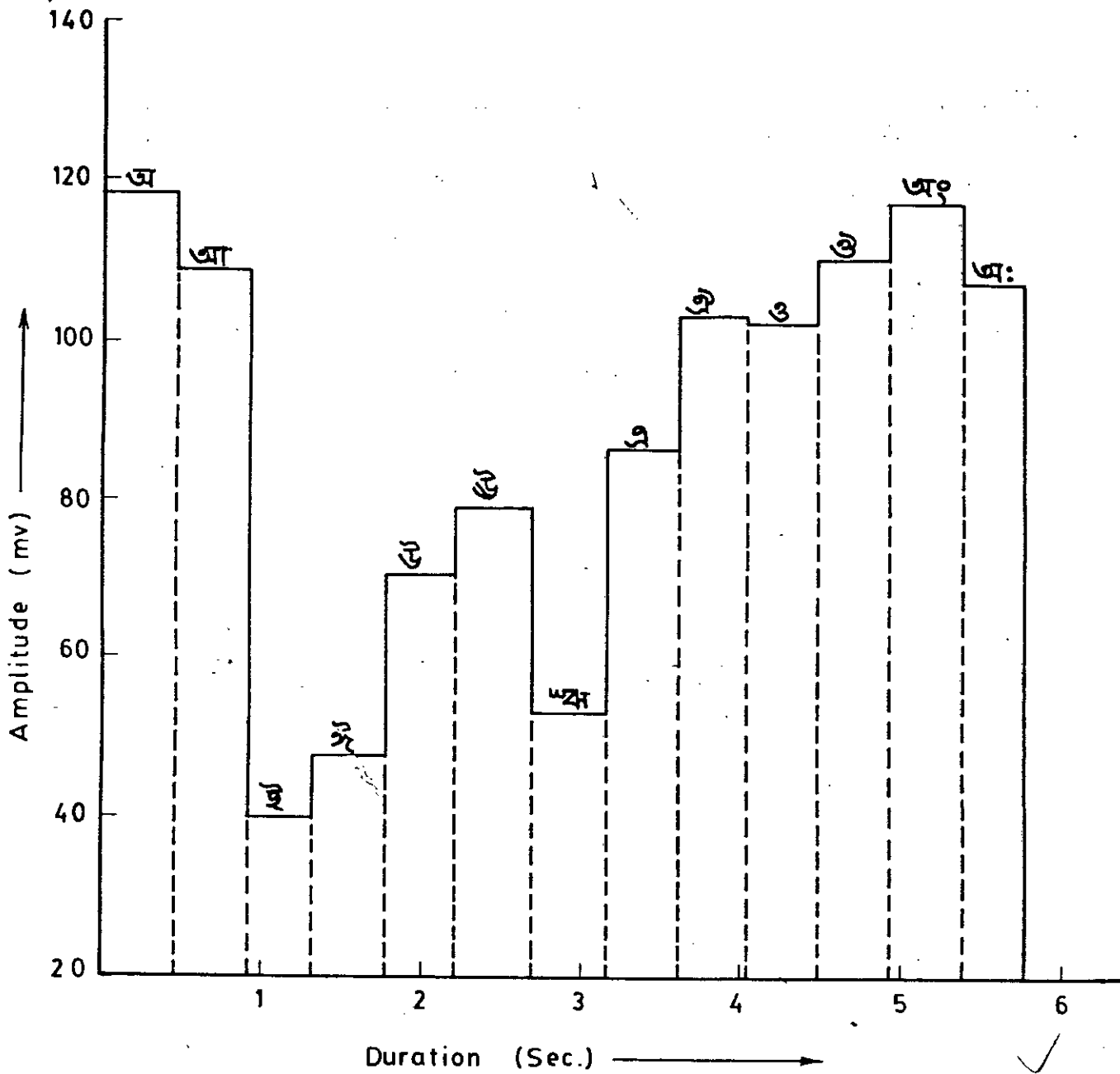


Fig. 6. Bar Graph showing the Average Amplitude and Duration of Bengali Vowels in Female Voice.

Amplitude and Duration of Bengali Vowels
Pronounced by different Persons (Male Voice)

Person	অ		আ		ই	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	143.30	0.53	140.00	0.47	44.20	0.37
2	130.00	0.60	128.30	0.60	32.50	0.53
3	125.00	0.43	105.00	0.37	41.70	0.37
4	102.50	0.35	95.00	0.30	36.70	0.37
5	116.70	0.40	105.80	0.37	32.50	0.30
6	116.70	0.38	102.50	0.35	59.60	0.38
7	121.70	0.60	116.70	0.60	34.20	0.40
8	143.30	0.60	122.50	0.47	50.00	0.43
9	140.30	0.53	130.00	0.52	57.80	0.45
10	123.50	0.63	113.60	0.55	47.00	0.40

TABLE 1.

Amplitude and Duration of Bengali Vowels
Pronounced by different Persons(Male Voice)

Person	ঐ		ঔ		ঊ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	52.50	0.43	90.00	0.53	85.00	0.53
2	50.80	0.60	85.00	0.60	85.80	0.60
3	45.00	0.37	83.30	0.40	83.30	0.40
4	38.30	0.42	70.00	0.37	70.00	0.47
5	45.00	0.35	65.00	0.38	671.70	0.35
6	60.00	0.50	70.00	0.37	80.00	0.50
7	45.00	0.50	72.50	0.55	89.20	0.60
8	60.00	0.45	90.00	0.43	100.00	0.50
9	69.00	0.58	95.00	0.53	105.00	0.60
10	51.50	0.45	78.80	0.48	84.10	0.50

TABLE 1.

Amplitude and Duration of Bengali Vowels
Pronounced by Different Persons(Male Voice)

Person	ঐ		এ		ঔ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	81.70	0.55	101.70	0.50	125.50	0.43
2	58.30	0.53	93.30	0.60	105.80	0.48
3	65.00	0.45	74.20	0.40	96.70	0.40
4	56.70	0.42	88.30	0.42	111.70	0.40
5	60.00	0.35	78.30	0.40	83.30	0.38
6	50.00	0.47	70.00	0.40	80.00	0.40
7	64.20	0.52	80.80	0.50	90.80	0.47
8	80.00	0.47	115.80	0.43	118.30	0.43
9	85.50	0.58	119.00	0.55	132.40	0.50
10	66.70	0.47	89.40	0.50	132.40	0.50

TABLE 1

Amplitude and Duration of Bengali Vowels
pronounced by different Persons (Male Voice)

Person	ৗ		ঔ		৑		৑:	
	Amplitude V_m (mv)	Duration T (Sec)	Amplitude V_m (mv)	Duration T (Sec)	Amplitude V_m (mv)	Duration T (Sec)	Amplitude V_m (mv)	Duration T (Sec)
1	120.00	0.53	140.00	0.50	148.80	0.53	148.30	0.50
2	119.20	0.60	129.20	0.53	137.50	0.53	135.00	0.53
3	84.20	0.37	91.70	0.33	100.00	0.33	108.30	0.30
4	100.00	0.47	108.30	0.45	123.30	0.47	111.70	0.43
5	88.30	0.32	93.30	0.30	111.70	0.37	115.00	0.30
6	80.00	0.43	90.00	0.38	108.30	0.33	103.30	0.30
7	94.20	0.53	99.20	0.50	122.50	0.40	136.00	0.37
8	115.00	0.50	125.80	0.48	141.70	0.47	137.50	0.40
9	133.20	0.55 ^{8/5}	139.30	0.53	150.00	0.52	156.00	0.43
10	125.00	0.65	140.00	0.55	146.00	0.50	133.40	0.50

TABLE 1.

Average Amplitude and Duration of Bengali Vowels
in Male Voice.

Vowels	Amplitude V_m (mv)	Duration T(Sec)
অ	126.30	0.50
আ	115.90	0.47
ই	43.60	0.41
ঈ	51.70	0.46
উ	79.80	0.46
ঊ	85.20	0.51
ঋ	66.80	0.48
ৠ	91.10	0.45
এ	107.70	0.44
ঐ	105.90	0.49
ঔ	115.70	0.45
ঘ	129.10	0.44
ঙ	128.40	0.41

TABLE 2.

Amplitid Amplitude and Duration of Bengali Vowels
Pronounced by different Persons(Female Voice)

Person	ঐ		এ		ঔ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	135.00	0.50	130.00	0.47	45.300	0.37
2	130.80	0.50	125.00	0.50	42.50	0.40
3	112.50	0.38	101.70	0.37	43.30	0.37
4	120.00	0.50	115.00	0.44	41.70	0.30
5	123.30	0.38	103.30	0.35	37.50	0.35
6	121.70	0.50	115.80	0.40	47.50	0.32
7	105.00	0.50	91.70	0.48	30.00	0.40
8	100.00	0.60	85.00	0.55	33.30	0.53
9	111.70	0.40	96.70	0.47	35.00	0.40
10	128.30	0.55	125.00	0.50	42.50	0.53

TABLE 3

Amplitude and Duration of Bengali Vowels
pronounced by different Persons(Female Voice)

Person	ঐ		ঔ		ঊ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	60.00	0.44	80.00	0.47	85.00	0.50
2	43.30	0.47	73.30	0.40	80.30	0.50
3	46.70	0.37	71.70	0.42	78.30	0.48
4	50.00	0.37	66.70	0.48	75.80	0.48
5	40.80	0.38	70.00	0.40	78.30	0.45
6	60.00	0.40	75.00	0.45	82.50	0.48
7	45.00	0.50	80.00	0.50	83.30	0.50
8	41.70	0.53	57.50	0.53	70.00	0.60
9	40.00	0.45	51.70	0.40	63.30	0.42
10	48.30	0.53	75.80	0.50	88.30	0.53

TABLE 3

Amplitude and Duration of Bengali Vowels
pronounced by different Persons (Female Voice)

Person	ঈ		এ		ঐ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(sec)	Amplitude V_m (mv)	Duration T(Sec)
1	67.70	0.47	86.70	0.45	121.70	0.47
2	51.70	0.50	82.50	0.40	98.30	0.38
3	51.70	0.40	100.00	0.37	113.30	0.37
4	63.30	0.40	78.30	0.40	93.30	0.45
5	56.70	0.50	95.00	0.42	113.30	0.40
6	52.50	0.47	79.20	0.45	95.00	0.40
7	38.30	0.50	88.30	0.48	93.30	0.50
8	40.00	0.50	68.30	0.53	95.00	0.50
9	51.70	0.40	81.70	0.43	98.30	0.50
10	57.50	0.50	96.70	0.50	110.00	0.50

TABLE 3

Amplitude and Duration of Bengali Vowels
pronounced by different Persons (Male Voice)

Person	ও		ওঁ		ৗ		ৗঃ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	115.00	0.47	116.70	0.45	126.70	0.43	131.70	0.37
2	103.30	0.40	115.00	0.40	128.30	0.40	120.00	0.40
3	75.00	0.37	110.00	0.43	120.00	0.43	116.70	0.30
4	100.00	0.48	105.00	0.42	120.00	0.43	113.30	0.42
5	110.00	0.45	118.30	0.47	115.00	0.40	128.30	0.30
6	101.70	0.50	103.30	0.40	115.00	0.40	119.20	0.45
7	110.00	0.48	113.30	0.45	110.00	0.43	95.00	0.37
8	103.30	0.53	103.30	0.50	101.70	0.47	98.30	0.47
9	100.00	0.45	98.30	0.47	119.20	0.40	115.00	0.43
10	105.80	0.50	113.30	0.45	131.70	0.43	134.20	0.47

TABLE 3.

Average Amplitude and Duration of Bengali Vowels in Female Voice.

Vowels	Amplitude V_m (mv)	Duration T(Sec)
অ	118.80	0.48
আ	108.90	0.45
ই	39.90	0.40
ঈ	47.60	0.45
উ	70.20	0.45
ঊ	79.30	0.49
এ	53.10	0.46
ঐ	86.20	0.44
ঔ	103.20	0.45
ও	102.40	0.46
ঔ	110.60	0.44
ঋ	117.80	0.42
ঌ	117.20	0.40

TABLE 4.

CHAPTER 3

MEASUREMENT OF THE AMPLITUDE VERSUS TIME PATTERN OF BENGALI CONSONANTS IN VOICE SIGNALS.

3.1 Introduction

There are 37 consonants in Bengali language. They are listed below with phonetic transcription of their normal pronunciation [6].

ক	খ	গ	ঘ	ঙ	চ	ছ	জ	ঝ	ঞ
kɔ	kʰɔ	gɔ	gʱɔ	ŋɔ	tɔ	tʰɔ	ʒɔ	ʒʱɔ	ɟɔ
ট	ঠ	ড	ঢ	ণ	ত	থ	দ	ধ	ন
tɔ	tʰɔ	dɔ	dʱɔ	ɳɔ	tɔ	tʰɔ	dɔ	dʱɔ	nɔ
প	ফ	ব	ভ	ম	য	র	ল	শ	
pɔ	phɔ	bɔ	bʱɔ	mɔ	jɔ	rɔ	lɔ	ʃɔ	
ষ	স	হ	ক	খ	গ	ঘ	ঙ	চ	ছ
ʃɔ	sɔ	hɔ	kʰɔ	tʰɔ	gɔ	gʱɔ	ŋɔ	tɔ	tʰɔ

The number of consonant phonemes are 31. We have excluded ঙ, ঞ, ঞ, ক and য from recording because they are not pronounced independently. Also ঙ, ঞ, য, ঞ, ক, : do not occur in the initial position of words. However ঙ and ক has been explained with vowel sound as ঞক and ঞঃ (Chapter 2). ঞ is phonetically equivalent to ন phoneme. So it does not deserve any separate treatment. The sounds represented by ঞ and ন are in complementary distribution with dental ন and so the three sounds can be assumed to be allophones or members of the same phoneme. They can be represented by the same letter, preferably ন. য represents two phonemes of Bengali, y and w. ঞ is known as a diacritic. It has no

cate nasalisation, predominantly vowel nasalisation.

ক and ঞ are also allophones of the same phoneme. Although the pronunciation of ঞ is similar to ক in most places the sound represented by ঞ has a distinctive function. So ঞ is considered as a different phoneme. উ and ঊ are in complementary distribution. উ occurs only in initial positions and ঊ in medial and final positions of words. They are also treated as separate phonemes.

Bengali consonants uttered in isolation by 20 Bengali speakers were recorded. They were the same persons from whom the vowels had been recorded. Each consonant was pronounced once by each person. The average amplitude and duration have been calculated from the data and represented in bar graphs. Male and female voices has been treated separately. Wave shapes of the consonants of a typical voice are shown in fig. 7.

3.2 Amplitude and Duration of Bengali Consonants in Male Voice:

The amplitude and duration of Bengali consonants in 10 different male voices are shown in table 5 and their average is shown in table 6, which are plotted in bar graph in fig. 8.

From the data it is seen that ক shows the highest amplitude (129.70mv) and ঞ the lowest amplitude (110.50mv). According to the place of pronunciation Bengali consonants are divided into 9

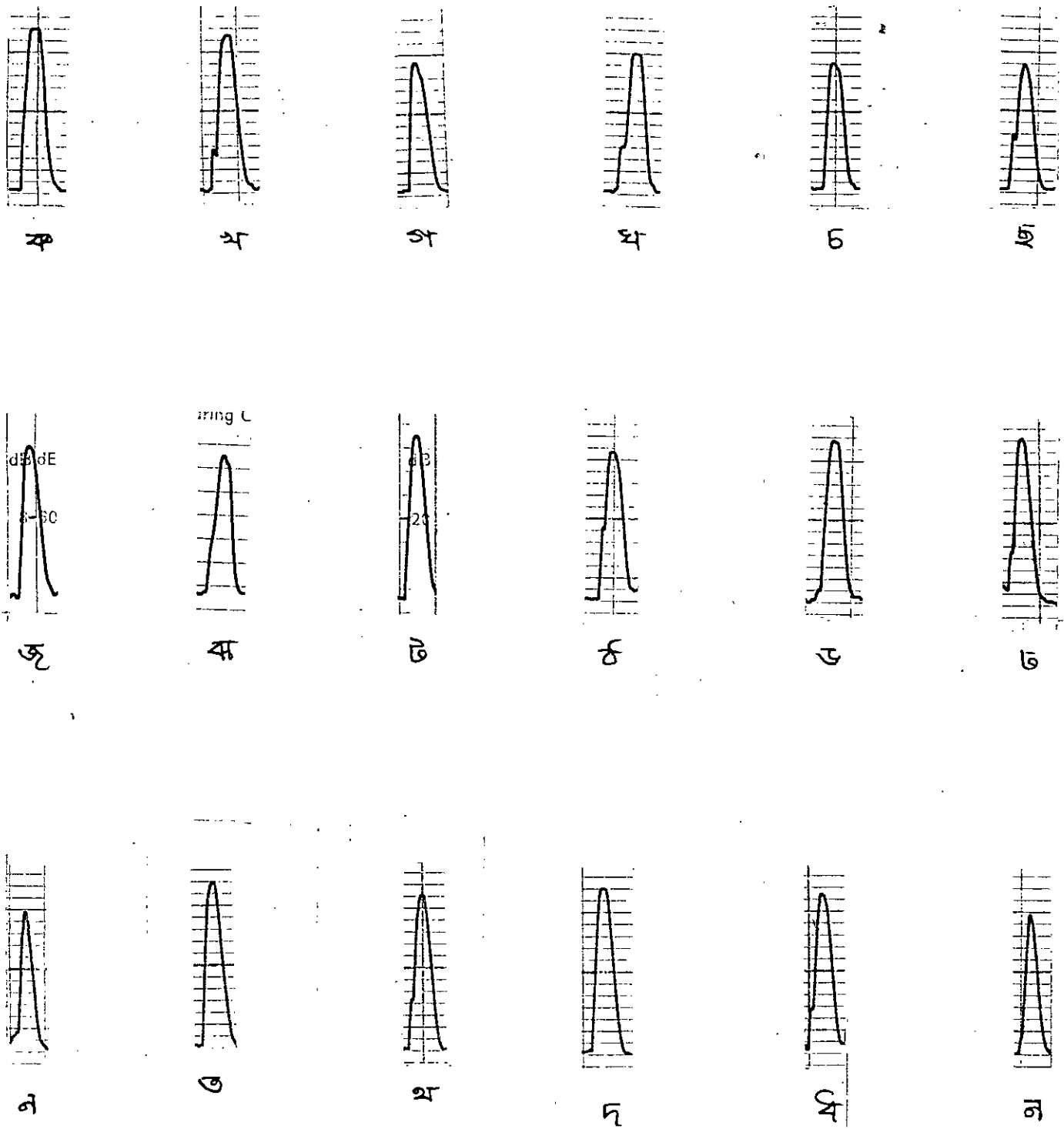


Fig. 7 Wave shapes of Bengali Consonants in voice signal for a typical voice.

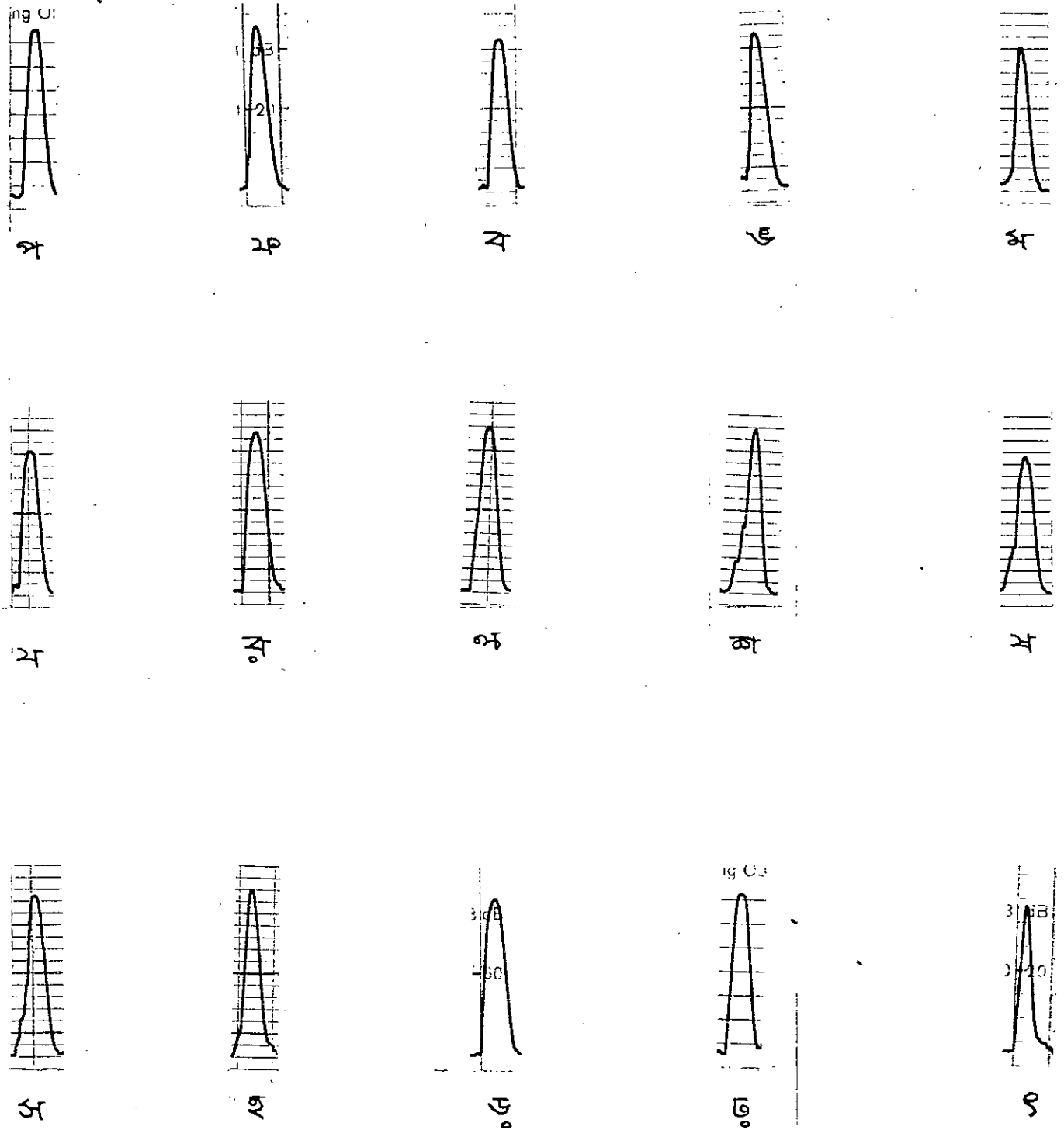


Fig. 7 Wave Shapes of Bengali Consonants in voice signal for a typical voice.

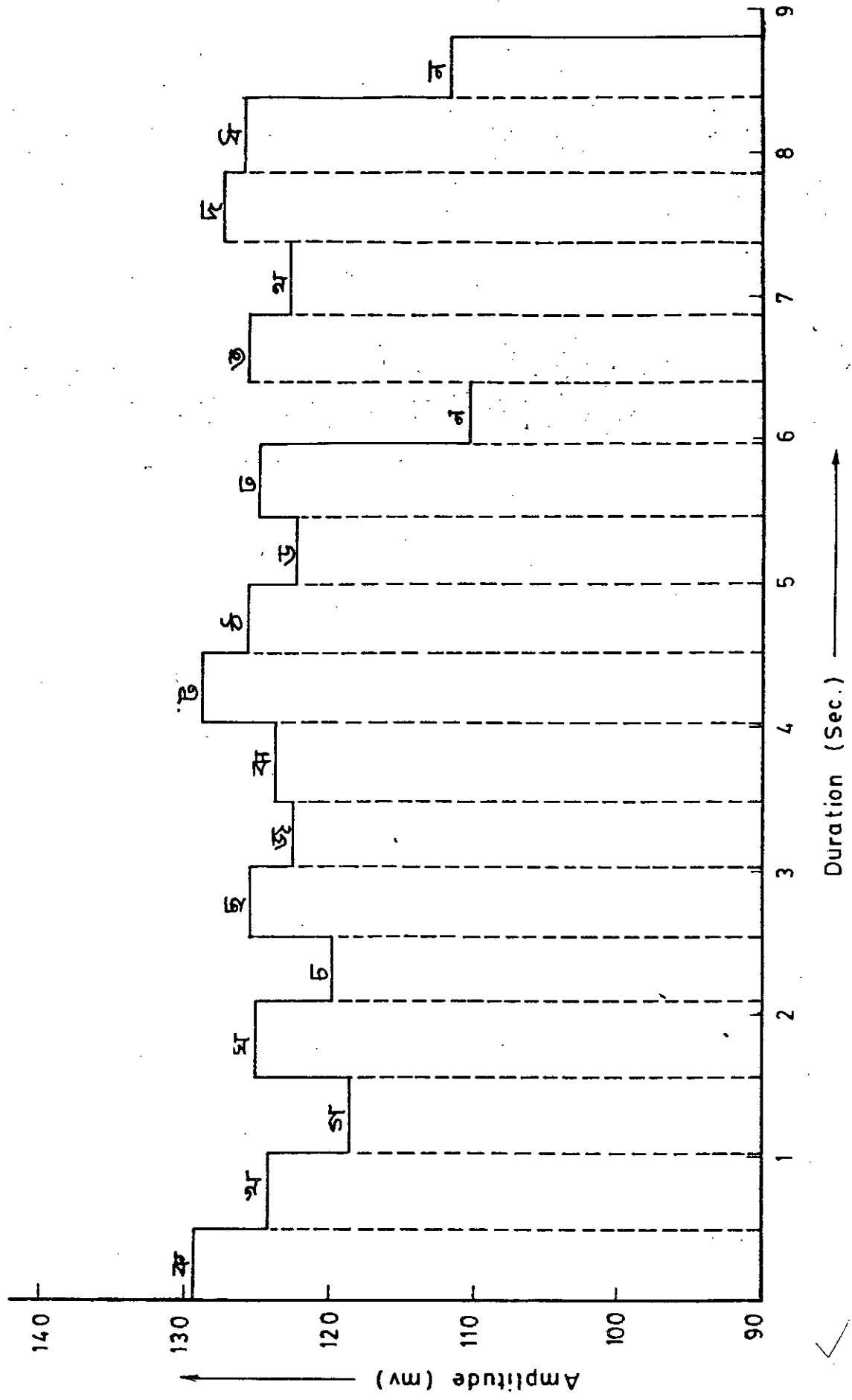


Fig. 8. Bar Graph showing the Average Amplitude and Duration of Bengali Consonants in Male Voice.

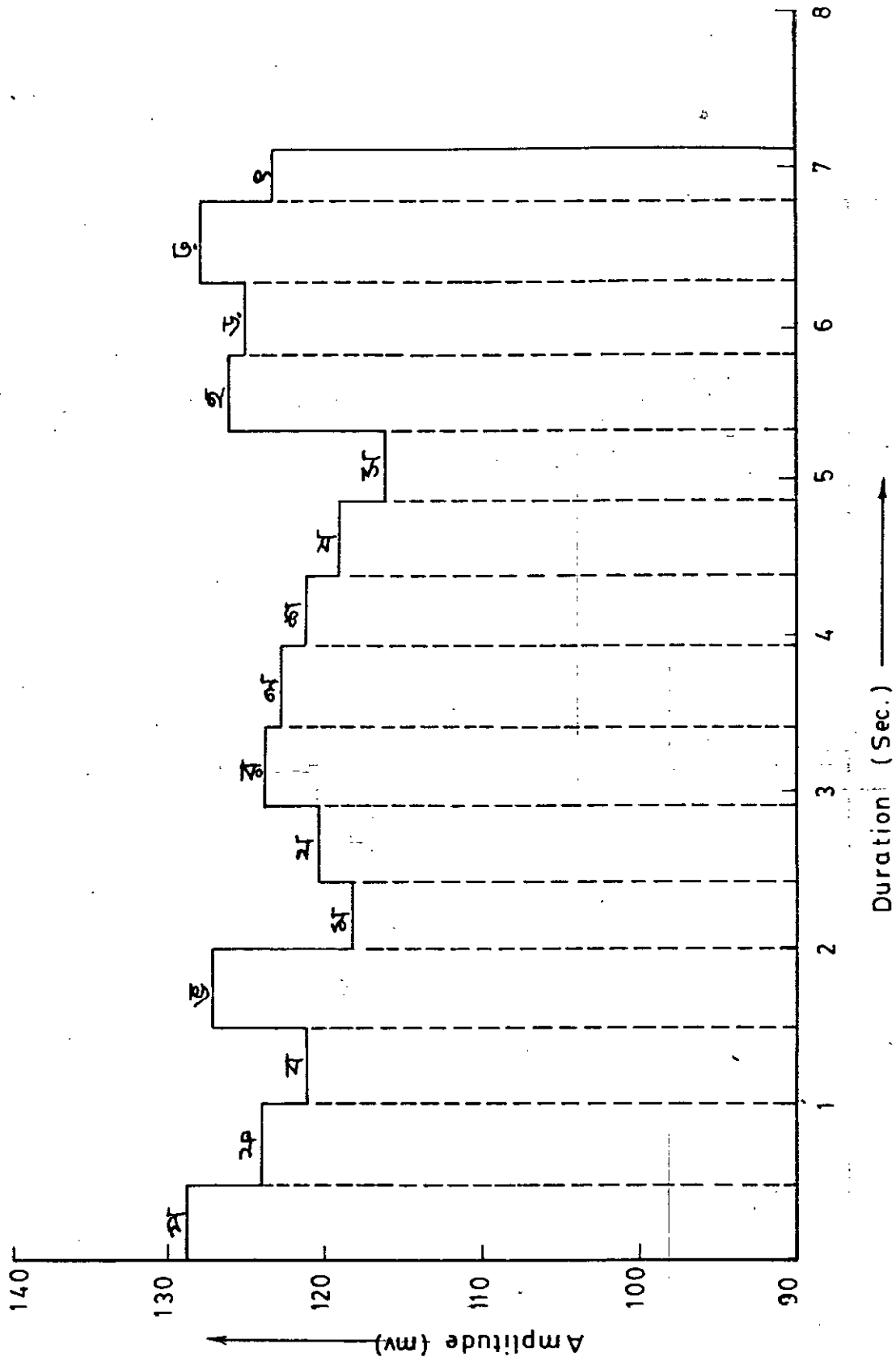


Fig. 8. Bar Graph showing the Average Amplitude and Duration of Bengali Consonants in Male Voice.

classes [7]. They are shown below with their corresponding amplitude/ amplitude ranges :

- 1) Velar :- examples ক, খ, গ, ঘ
Amplitude range: 119.00mv - 129.70mv
- 2) Dorso-Alveolar : examples চ, ছ, জ, ঝ
Amplitude range: 120.00mv-125.50 mv
- 3) Alvelo-retroflex: examples ট, ঠ, ড, ঢ, ঢ, ঢ
Amplitude range : 122.20mv - 129.00mv.
- 4) Dental : examples ত, থ, দ, ধ
Amplitude range : 123.20mv - 128.00mv.
- 5) Labial :- Examples প, ফ, ব, ভ, ম
Amplitude range : 118.70mv - 129.20mv.
- 6) Alveolar:- examples য, র, ল, শ, ন
Amplitude range : 112.00mv - 124.20mv
- 7) Post alveolar : examples ণ
Amplitude : 121.50mv.
- 8) Glottal or Laryngeal : example হ
Amplitude : 126.70mv.

From the data it is seen that the amplitude characteristics of the different alphabets of the ক, ট and প groups are similar in nature. ক, ট and প which are phonetically unvoiced and unaspirated have the highest amplitude levels and গ, ড, and ব which are

voiced and unaspirated sounds have the lowest amplitude levels. The duration of the aspirated consonants are always higher than the corresponding unaspirated consonants.

In the চ group the unvoiced unaspirated চ has the lowest amplitude and duration and the unvoiced and aspirated consonant ছ has the highest amplitude. The duration of voiced and aspirated consonant খ is maximum.

In the dental ত group the voiced unaspirated consonant দ has the highest amplitude and lowest duration while the unvoiced aspirated থ has the lowest amplitude and highest durations.

ণ never stands at the beginning of a word. In fact the pronunciation of unsyllabic ন in any word is alveolar. The amplitude of ন is higher than ণ although their duration is same.

Among sibilants শ , ষ and স , শ has the highest amplitude. Its phonetic name is unvoiced unaspirated post dental fricative sibilant. স has the lowest amplitude. The amplitude of ষ falls between these two. The names শ (Talobba sha), ষ (MurdhornoSha) and স (Danto Sha) have been derived from Sanskrit. However, in modern Bengali they are not pronounced in accordance with their corresponding articulatory positions. So they are misnomer.

The place and mode of pronunciation of ɸ and ɸ̃ are almost similar. The phonetic name of ɸ is voiced unaspirated alveolo flapped sound and that of ɸ̃ is voiced aspirated alveolo flapped sound. Their amplitudes are almost similar.

3.3 Amplitude and Duration of Bengali Consonants in Female Voice:

The amplitude and duration of Bengali consonants in different female voices are shown in table 7. Their average is shown in table 8. They are shown in bar graph in fig. 9. In female voice also 'ক' shows the highest amplitude (124.50mv) and 'গ' the lowest amplitude (106.30mv).

The different types of consonants are shown below with their corresponding amplitude/amplitude ranges:

- 1) Velar : examples ক, খ, গ, ঘ
Amplitude range : 116.20mv - 124.50mv.
- 2) Dorso alveolar : examples চ, ছ, জ, ঝ
Amplitude range : 116.50mv - 119.70mv.
- 3) Alveolo-retroflex: examples ট, ঠ, ড, ঢ, ঢ, ণ
Amplitude range : 117.60mv - 121.90mv.
- 4) Dental : examples ত, থ, দ, ধ
Amplitude range : 117.90 mv - 122.40mv.
- 5) Labial : examples প, ফ, ব, ভ, ম
Amplitude range : 113.90mv - 119.60mv.
- 6) Alveolar : examples য, র, ল, শ, ন
Amplitude range : 107.20mv - 122.20mv.
- 7) Post alveolar : example ঞ

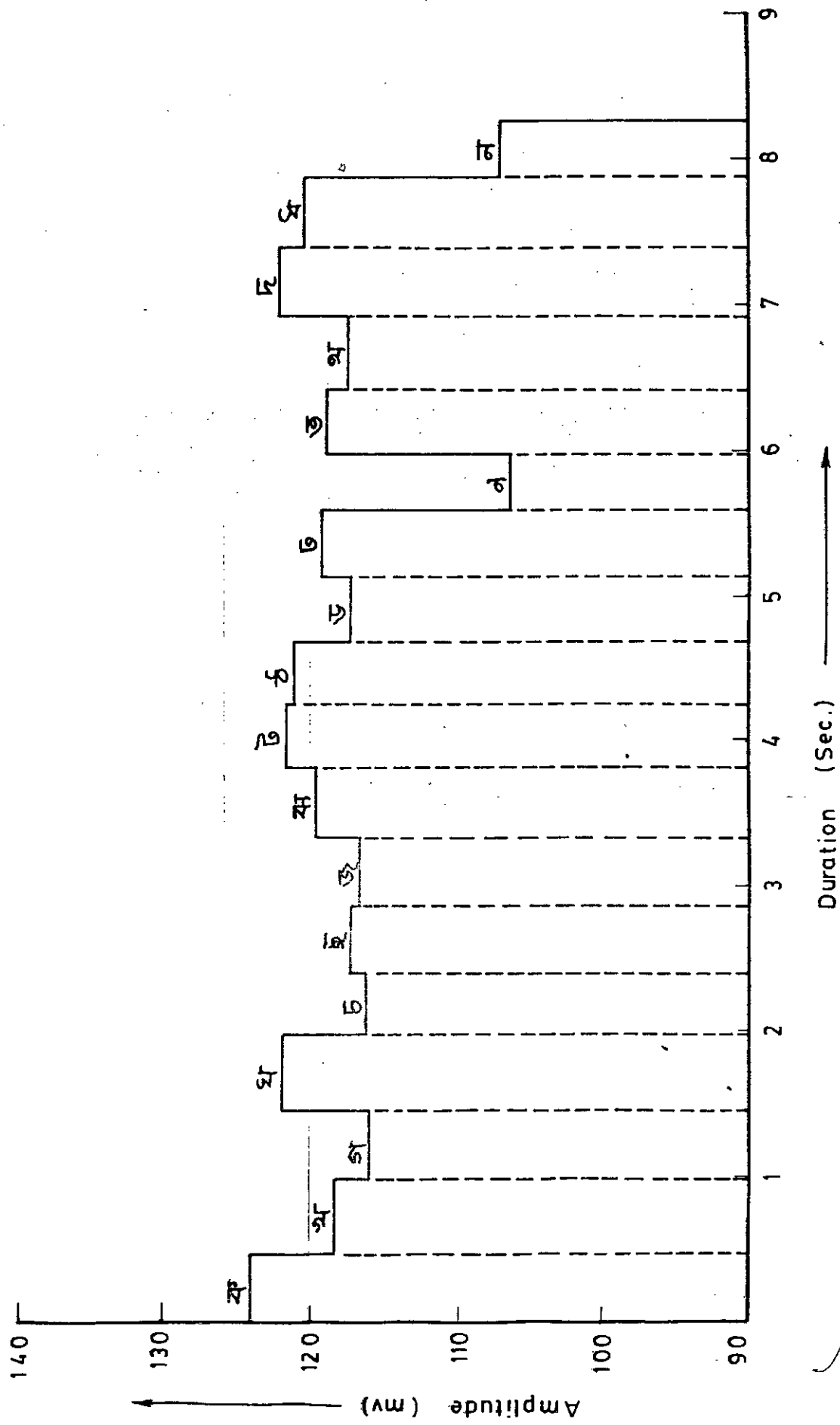


Fig. 9. Bar Graph showing the Average Amplitude and Duration of Bengali Consonants in Female Voice.

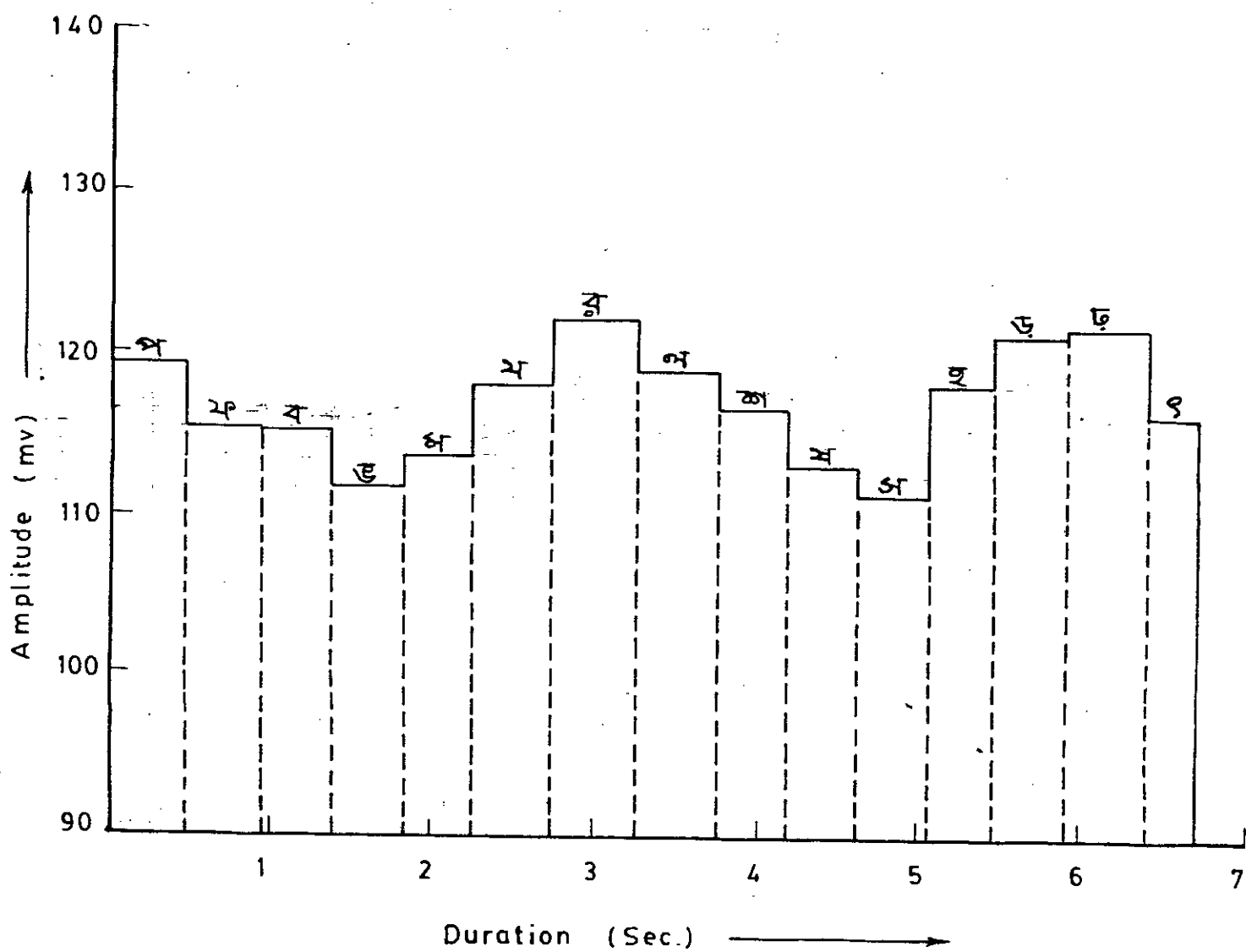


Fig.9. Bar Graph showing the Average Amplitude and Duration of Bengali Consonants in Female Voice.

8) Glottal or Laryngeal : example ष
Amplitude : 118.50mv.

The क, ट and ष groups exhibit identical characteristics as the male voice. That means the unvoiced and unaspirated क, ट and ष have the highest amplitude and the voiced and unaspirated ग, ड and ब have the lowest amplitude levels. In ङ group also the unvoiced unaspirated 'ङ' has the minimum amplitude and duration. The highest and duration is occupied by the voiced aspirated consonant ञ . In ढ group the voiced unaspirated consonant ढ has the highest amplitude and the unvoiced aspirated consonant ण has the lowest amplitude. The duration of ढ and ण are equal. Similarly the duration of ष and ष are also equal.

The amplitude of ष is higher than ग although their durations are same. Like male voices ष has higher amplitude than ष and ण. The amplitude of ण is the lowest and ष is in the intermediate position. The duration, of ष and ष are, however, seen to be similar. Again ङ has somewhat higher amplitude and duration than ङ .

3.4. Discussion:

From the data it is observed that ष has the highest amplitude and ग has the lowest amplitude in both male and female voices. The duration is maximum for ष and minimum for ग in both the cases. The variation of the amplitude ranges from 110.50 mv- 129.70 mv for male voice and 106.30 mv-124.50 mv for female voice. The duration

varies from 0.35 sec-0.54 sec. in male voice and 0.30 sec-0.52 sec. in female voice. The observed data were explained phonetically in sections 3.2 and 3.3. For a comparative study the average amplitude and duration pattern of Bengali consonants are graphically illustrated in figures 6 and 7 respectively for male and female voices.

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons. (Male Voice)

Person	ফ		খ		গ	
	Amplitude V_m (mv)	Duration T (Sec)	Amplitude V_m (mv)	Duration T (Sec)	Amplitude V_m (mv)	Duration T (Sec)
1	150.00	0.60	140.00	0.60	115.00	0.60
2	135.00	0.60	130.00	0.65	117.50	0.60
3	115.00	0.40	105.00	0.50	110.00	0.50
4	110.00	0.45	107.50	0.50	100.00	0.40
5	110.00	0.40	105.00	0.40	105.00	0.40
6	120.00	0.40	110.00	0.40	112.50	0.40
7	110.00	0.50	105.00	0.60	125.00	0.55
8	142.50	0.60	140.00	0.60	140.00	0.60
9	165.00	0.55	165.00	0.60	150.00	0.60
10	140.00	0.60	135.00	0.60	115.00	0.50

TABLE-5

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons.(Male Voice)

Person	ঘ		ঙ		জ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	145.00	0.50	125.00	0.40	150.00	0.50
2	137.50	0.60	125.00	0.50	122.50	0.60
3	112.50	0.50	110.00	0.40	105.00	0.50
4	100.00	0.50	110.00	0.40	97.50	0.50
5	95.00	0.40	95.00	0.35	100.00	0.40
6	107.50	0.40	105.00	0.40	110.00	0.40
7	135.00	0.60	130.00	0.45	125.00	0.50
8	140.00	0.50	135.00	0.40	145.00	0.50
9	160.00	0.60	155.00	0.50	167.50	0.50
10	120.00	0.65	110.00	0.50	132.50	0.60

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons. (Male Voice)

Person	ক		খ		গ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	145.00	0.50	140.00	0.50	130.00	0.50
2	120.00	0.60	125.00	0.60	125.00	0.60
3	110.00	0.40	120.00	0.40	125.00	0.50
4	100.00	0.40	107.50	0.50	115.00	0.40
5	105.00	0.40	100.00	0.40	110.00	0.40
6	102.50	0.40	102.50	0.40	110.00	0.40
7	120.00	0.50	115.00	0.60	135.00	0.50
8	135.00	0.50	145.00	0.60	140.00	0.50
9	160.00	0.60	162.50	0.65	160.00	0.60
10	130.00	0.55	120.00	0.55	140.00	0.50

TABLE 5.

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons.(Male Voice)

Person	ð		ʈ		ʑ	
	Amplitude V _m (mv)	Duration T(Sec)	Amplitude V _m (mv)	Duration T(Sec)	Amplitude V _m (mv)	Duration T(Sec)
1	125.00	0.50	130.00	0.40	125.00	0.45
2	130.00	0.60	120.00	0.60	130.00	0.60
3	125.00	0.40	125.00	0.40	120.00	0.50
4	95.00	0.50	95.00	0.60	112.50	60.00
5	110.00	0.40	100.00	0.40	105.00	0.40
6	115.00	0.45	115.00	0.40	110.00	0.40
7	125.00	0.55	110.00	0.55	120.00	0.60
8	140.00	0.50	140.00	0.50	137.50	0.50
9	165.00	0.60	155.00	0.60	160.00	0.60
10	127.50	0.55	137.50	0.55	140.00	0.60

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons. (Male Voice)

Person	গ		ঙ		খ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	132.50	0.40	137.50	0.50	130.00	0.50
2	105.00	0.55	117.50	0.60	125.00	0.65
3	105.00	0.30	115.00	0.50	120.00	0.50
4	85.00	0.30	115.00	0.40	105.00	0.45
5	105.00	0.40	110.00	0.40	105.00	0.45
6	85.00	0.40	120.00	0.40	110.00	0.40
7	115.00	0.50	120.00	0.50	130.00	0.55
8	125.00	0.40	142.50	0.60	140.00	0.60
9	140.00	0.55	145.00	0.60	150.00	0.65
10	117.50	0.40	140.00	0.55	117.50	0.55

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Male Voice)

Person	ক		খ		গ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	140.00	0.55	130.00	0.45	125.00	0.35
2	120.00	0.60	130.00	0.60	125.00	0.45
3	130.00	0.50	125.00	0.50	100.00	0.30
4	110.00	0.50	110.00	0.45	92.50	0.45
5	105.00	0.40	105.00	0.50	90.00	0.30
6	115.00	0.40	100.00	0.40	85.00	0.40
7	127.50	0.50	135.00	0.60	125.00	0.50
8	140.00	0.50	145.00	0.60	130.00	0.50
9	150.00	0.55	150.00	0.60	137.50	0.50
10	142.50	0.50	135.00	0.50	110.00	0.40

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons. (Male voice)

Person	ক		ফ		ব	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	140.00	0.50	120.00	0.50	150.00	0.40
2	135.00	0.60	130.00	0.60	125.00	0.60
3	115.00	0.50	100.00	0.40	95.00	0.45
4	105.00	0.40	105.00	0.50	102.50	0.50
5	112.50	0.40	110.00	0.40	105.00	0.40
6	120.00	0.40	110.00	0.40	115.00	0.40
7	130.00	0.50	140.00	0.50	120.00	0.50
8	145.00	0.50	137.50	0.50	127.50	0.50
9	150.00	0.60	152.50	0.65	147.50	0.60
10	140.00	0.55	140.00	0.55	125.00	0.50

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Male Voice)

Person	ত		ন		ষ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	135.00	0.60	120.00	0.50	130.00	0.50
2	132.50	0.60	135.00	0.50	135.00	0.60
3	115.00	0.50	102.50	0.35	100.00	0.50
4	120.00	0.50	90.00	0.40	112.50	0.60
5	110.00	0.35	105.00	0.30	95.00	0.40
6	112.50	0.40	110.00	0.40	115.00	0.40
7	130.00	0.50	125.00	0.45	120.00	0.50
8	140.00	0.50	135.00	0.50	130.00	0.45
9	150.00	0.60	145.00	0.50	150.00	0.60
10	130.00	0.60	120.00	0.50	120.00	0.50

TABLE 5

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Male Voice)

Person	ক		ন		ক	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	145.00	0.50	140.00	0.60	137.50	0.50
2	135.00	0.60	130.00	0.60	120.00	0.60
3	100.00	0.50	100.00	0.50	125.00	0.30
4	105.00	0.55	95.00	0.50	85.00	0.30
5	95.00	0.50	100.00	0.40	85.00	0.30
6	152.00	0.50	120.00	0.50	112.50	0.40
7	125.00	0.50	130.00	0.55	130.00	0.50
8	132.50	0.55	130.00	0.50	132.50	0.50
9	145.00	0.60	150.00	0.60	150.00	0.55
10	135.00	0.55	137.50	0.60	137.50	0.60

TABLE 5.

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Male Voice)

Person	ষ		স		শ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	135.00	0.50	120.00	0.50	140.00	0.50
2	125.00	0.60	115.00	0.60	137.50	0.60
3	105.00	0.35	100.00	0.40	110.00	0.40
4	105.00	0.40	102.50	0.40	110.00	0.40
5	105.00	0.40	95.00	0.30	105.00	0.40
6	105.00	0.50	112.50	0.50	120.00	0.50
7	110.00	0.40	110.00	0.40	120.00	0.55
8	140.00	0.50	137.50	0.50	137.00	0.45
9	150.00	0.45	140.00	0.50	150.00	0.60
10	115.00	0.60	135.00	0.70	140.00	0.60

TABLE 5.

Amplitude and Duration of Bengali Consonants
Pronounced by different Persons.(Male Voice)

Person	ফ		ফ		স	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	135.00	0.50	145.00	0.50	135.00	0.40
2	122.50	0.50	135.00	0.60	127.50	0.40
3	100.00	0.50	107.50	0.50	105.00	0.35
4	120.00	0.50	132.50	0.60	115.00	0.40
5	100.00	0.40	95.00	0.40	105.00	0.30
6	115.00	0.50	110.00	0.50	125.00	0.35
7	145.00	0.50	140.00	0.50	135.00	0.30
8	140.00	0.50	135.00	0.50	125.00	0.30
9	150.00	0.60	155.00	0.60	147.0	0.30
10	130.00	0.55	130.00	0.55	120.00	0.40

TABLE 5.

Average Amplitude and Duration of Bengali
Consonants in Male Voice.

Consonants	Amplitude V_m (mv)	Duration T(Sec)
ক	129.70	0.50
খ	124.20	0.54
গ	119.00	0.51
ঘ	125.20	0.52
চ	120.00	0.43
ছ	125.50	0.50
জ	122.70	0.48
ঝ	123.70	0.52
ট	129.00	0.49
ঠ	125.70	0.50
ড	122.20	0.48
ঢ	126.00	0.50
ণ	110.50	0.42
ত	126.20	0.50
থ	123.20	0.53
দ	128.00	0.49
ধ	126.50	0.52
ন	112.00	0.42

TABLE 6.

Average Amplitude and Duration of Bengali Consonants in Male Voice.

Consonant	Amplitude V_m (mv)	Duration T(Sec)
ক	129.20	0.48
খ	124.50	0.50
গ	121.20	0.48
ঘ	127.50	0.51
ঙ	118.70	0.45
চ	120.70	0.49
ছ	124.20	0.53
জ	123.20	0.52
ট	121.50	0.45
ঠ	119.50	0.47
ড	116.70	0.46
ঢ	126.70	0.49
ণ	125.70	0.50
ত	128.50	0.52
থ	124.00	0.35

TABLE 6.

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Female Voice)

Person	ক		খ		গ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	140.90	0.45	140.90	0.50	140.90	0.50
2	115.00	0.45	110.00	0.50	107.50	0.45
3	135.00	0.50	130.00	0.55	113.60	0.45
4	107.50	0.45	105.00	0.45	102.50	0.40
5	131.80	0.40	120.00	0.50	125.00	0.45
6	105.00	0.50	100.00	0.50	100.00	0.50
7	105.00	0.40	102.50	0.40	105.00	0.50
8	135.00	0.60	130.00	0.60	125.00	0.55
9	130.00	0.50	120.00	0.50	112.50	0.50
10	140.00	0.60	130.00	0.60	120.00	0.60

TABLE 7.

Amplitude and Duration of Bengali Consonants
pronounced by different person(Female Voice)

Person	ঋ		ঌ		৐	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	131.80	0.50	125.00	0.40	129.50	0.40
2	110.00	0.50	105.00	0.40	110.00	0.50
3	145.00	0.50	135.00	0.45	135.00	0.45
4	105.00	0.50	100.00	0.45	105.00	0.50
5	135.00	0.45	137.50	0.40	137.50	0.45
6	100.00	0.55	97.50	0.45	105.00	0.55
7	110.00	0.40	95.00	0.50	85.00	0.40
8	140.00	0.50	140.00	0.60	140.00	0.60
9	110.00	0.50	105.00	0.40	110.00	0.50
10	135.00	0.55	125.00	0.55	120.00	0.50

TABLE 7.

Amplitude and Duration of Bengali Consonants
Pronounced by different persons(Female Voice)

Person	ঔ		ঋ		ঌ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	120.40	0.50	131.80	0.45	136.30	0.50
2	115.00	0.40	120.00	0.55	120.00	0.40
3	140.00	0.40	135.00	0.50	135.00	0.45
4	105.00	0.40	105.00	0.55	110.00	0.40
5	140.00	0.50	140.00	0.45	135.00	0.45
6	102.50	0.50	105.00	0.60	107.50	0.45
7	95.00	0.40	100.00	0.40	95.00	0.50
8	120.00	0.60	145.00	0.45	145.00	0.50
9	105.00	0.45	110.00	0.50	102.50	0.35
10	127.50	0.60	105.00	0.50	132.50	0.60

TABLE 7.

Amplitude and Duration of Bengali Consonants
Pronounced by different Person(Female Voice)

Person	ঔ		ঊ		ঋ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	140.90	0.40	136.30	0.50	131.80	0.45
2	125.00	0.45	112.50	0.40	120.00	0.45
3	135.00	0.45	125.00	0.40	132.50	0.50
4	115.00	0.45	110.00	0.50	115.00	0.60
5	140.00	0.55	130.00	0.40	140.00	0.40
6	110.00	0.50	105.00	0.50	107.50	0.60
7	100.00	0.40	95.00	0.45	115.00	0.40
8	140.00	0.45	130.00	0.50	130.00	0.40
9	90.00	0.40	102.50	0.40	90.00	0.45
10	115.00	0.55	130.00	0.60	115.00	0.55

TABLE 7

Amplitude and Duration of Bengali Consonants p
Pronounced by different person(Female Voice)

Person	ণ		ণ		খ	
	Amplitude V_m (mv)	Duration V_m (mv)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	113.60	0.35	140.90	0.40	136.30	0.45
2	100.00	0.40	117.50	0.50	115.00	0.55
3	125.00	0.40	135.00	0.45	137.50	0.45
4	110.00	0.40	115.00	0.50	115.00	0.60
5	120.00	0.30	130.00	0.50	132.50	0.50
6	100.00	0.40	110.00	0.40	107.50	0.45
7	80.00	0.40	105.00	0.50	100.00	0.55
8	105.00	0.45	120.00	0.50	125.00	0.50
9	95.00	0.40	90.00	0.40	95.00	0.40
10	115.00	0.50	130.00	0.55	115.00	0.55

TABLE 7.

Amplitude and Duration of Bengali Consonants
pronounced by different person (Female voice)

Person	ক		খ		গ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	131.80	0.50	127.30	0.50	127.30	0.30
2	120.00	0.40	110.00	0.55	120.00	0.40
3	122.50	0.40	140.00	0.45	120.00	0.40
4	120.00	0.45	117.50	0.50	110.00	0.40
5	140.00	0.50	140.00	0.50	130.00	0.35
6	115.00	0.50	110.00	0.50	105.00	0.40
7	105.00	0.40	110.00	0.40	75.00	0.35
8	130.00	0.55	132.50	0.55	105.00	0.40
9	100.00	0.45	105.00	0.50	85.00	0.40
10	140.00	0.60	115.00	0.60	95.00	0.50

TABLE 7.

Amplitude and Duration of Bengali Consonants
Pronounced by different person (Female voice):

Person	ক		ফ		ব	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	140.90	0.40	131.80	0.40	127.30	0.45
2	112.50	0.45	110.00	0.45	107.50	0.45
3	132.50	0.40	130.00	0.40	130.00	0.40
4	112.50	0.45	105.00	0.45	107.50	0.40
5	135.00	0.45	140.00	0.55	135.00	0.50
6	105.00	0.50	100.00	0.50	105.00	0.50
7	95.00	0.50	95.00	0.50	100.00	0.40
8	137.50	0.45	140.00	0.50	125.00	0.50
9	100.00	0.40	90.00	0.45	97.50	0.40
10	125.00	0.60	115.00	0.60	120.00	0.60

TABLE 7.

Amplitude and Duration of Bengali Consonants
pronounced by different person (Female voice)

Person	গ		ন		ব	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	122.70	0.40	113.60	0.40	122.70	0.45
2	120.00	0.50	120.00	0.40	120.00	0.40
3	140.00	0.40	130.00	0.40	135.00	0.40
4	115.00	0.45	115.00	0.40	107.50	0.50
5	135.00	0.50	130.00	0.35	135.000	0.45
6	110.00	0.40	110.00	0.50	120.50	0.50
7	90.00	0.40	95.00	0.35	97.50	0.45
8	140.00	0.45	135.00	0.50	125.00	0.45
9	90.00	0.40	90.00	0.40	100.00	0.40
10	107.50	0.50	100.00	0.50	120.00	0.60

TABLE 7.

Amplitude and Duration of Bengali Consonants
Pronounced by different person(Female Voice)

Person	ক		খ		গ	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	131.80	0.50	131.80	0.50	125.00	0.45
2	125.00	0.50	117.50	0.50	115.00	0.45
3	150.00	0.60	140.00	0.55	135.00	0.30
4	110.00	0.50	105.00	0.50	100.00	0.45
5	140.00	0.50	140.00	0.50	140.00	0.45
6	105.00	0.50	120.50	0.50	100.00	0.45
7	100.00	0.45	110.00	0.40	100.00	0.30
8	135.00	0.50	135.00	0.55	140.00	0.40
9	110.00	0.50	100.00	0.40	95.00	0.50
10	115.00	0.60	110.00	0.60	120.00	0.60

TABLE 7.

Amplitude and Duration of Bengali Consonants
pronounced by different person (Female voice):

Person	ষ		শ		স	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	118.20	0.45	113.60	0.40	122.70	0.40
2	115.00	0.40	112.50	0.40	120.00	0.40
3	135.00	0.40	135.00	0.35	150.00	0.40
4	105.00	0.45	105.00	0.45	110.00	0.50
5	130.00	0.40	130.00	0.40	140.00	0.45
6	97.50	0.45	95.00	0.40	100.00	0.50
7	95.00	0.35	90.00	0.35	95.00	0.40
8	125.00	0.45	130.00	0.45	135.00	0.40
9	95.00	0.40	97.50	0.40	90.00	0.40
10	117.50	0.60	105.00	0.60	122.50	0.55

TABLE 7.

Amplitude and Duration of Bengali Consonants
pronounced by different person (Female voice)

Person	য		ফ		স	
	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)	Amplitude V_m (mv)	Duration T(Sec)
1	115.90	0.45	122.70	0.45	113.60	0.30
2	110.00	0.45	120.00	0.50	110.00	0.30
3	135.00	0.50	132.50	0.50	130.00	0.20
4	115.00	0.50	120.00	0.50	117.50	0.30
5	145.00	0.50	145.00	0.50	145.00	0.40
6	110.00	0.40	112.50	0.45	110.00	0.30
7	112.50	0.50	110.00	0.50	105.00	0.30
8	140.00	0.40	130.00	0.50	120.00	0.30
9	115.00	0.50	105.00	0.60	100.00	0.30
10	115.00	0.50	120.00	0.50	115.00	0.30

TABLE 7.

Average Amplitude and duration of Bengali Consonants in Female Voice.

Consonant	Amplitude V_m (mv)	Duration T(Sec)
ক	124.50	0.48
খ	118.80	0.52
গ	116.20	0.49
ঘ	122.20	0.50
ঙ	116.50	0.41
চ	117.70	0.48
ছ	117.00	0.47
জ	119.70	0.49
ঝ	121.90	0.46
ঞ	121.10	0.47
ট	117.60	0.45
ঠ	119.70	0.48
ড	106.30	0.40
ঢ	119.30	0.47
ণ	117.90	0.50
ত	122.40	0.47
থ	120.70	0.50
দ	107.20	0.40

TABLE 8.

Average Amplitude and Duration of Bengali Consonants
in Female Voice.

Consonant	Amplitude V_m (mv)	Duration T(Sec)
প	119.60	0.46
ফ	115.70	0.48
ব	115.50	0.46
ভ	117.00	0.46
ম	113.90	0.42
য	118.30	0.46
র	122.20	0.51
ল	119.20	0.50
শ	117.00	0.43
ষ	113.30	0.43
স	111.40	0.42
হ	118.50	0.44
ড়	121.30	0.48
ঢ়	121.80	0.50
ৎ	116.60	0.30

TABLE 8.

CHAPTER 4

MEASUREMENT OF THE AMPLITUDE VERSUS TIME PATTERN OF THE BENGALI ALPHABET IN WORDS IN VOICE SIGNALS.

4.1 Introduction

In normal speech or connected speech the letters are rarely pronounced individually. They occur in syllables and in words. For practical purposes it is therefore necessary to study their amplitude and duration pattern when they appear in words. This has been carried out in this chapter in both male and female voices. The voices for the recorded data are the same as mentioned in the preceding chapter.

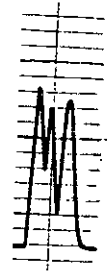
4.2 Amplitude and Duration of Bengali Vowels in Words in Male Voice:

The wave shapes of a typical voice uttering different words initiated by vowels are shown in Fig.10. Average amplitude and duration of Bengali vowels in those words in male voice are shown in table 9. Three words have been uttered corresponding to each alphabet-by each of the 10 persons.

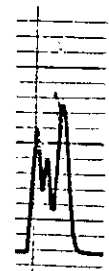
From the data it is observed that both the amplitude and duration of vowels are less when they are used in different words than when pronounced individually. The amplitude and duration of the same alphabet vary from word to word. This is because the mode of pronunciation of an alphabet vary in different words. Again in some cases the mode of pronunciation of a vowel is completely different from the original mode. For example, the pronunciation of



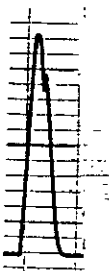
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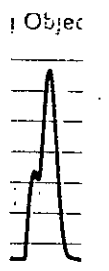
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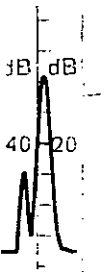
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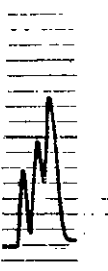
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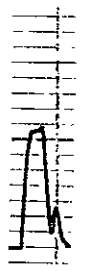
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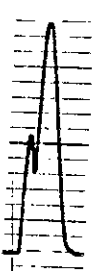
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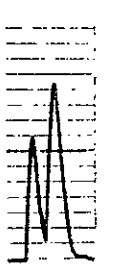
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ঐদ



ঐগন



ঐদগাহ

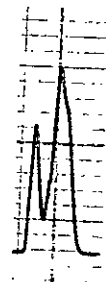
Fig. 10 Wave shapes of some words in Voice Signal for a typical voice.



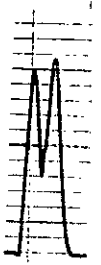
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উচিত্ত



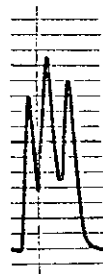
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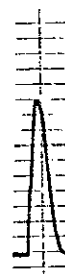
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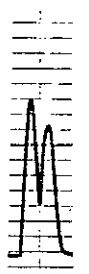
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উৎসাহ্বা



অন



অন্ত



অনন্ত

এই

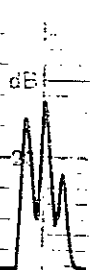


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একটু



একটু

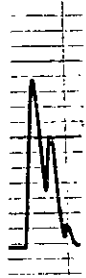


একতাজ

Fig. 10 Wave shapes of some words in Voice Signal for a typical voice.



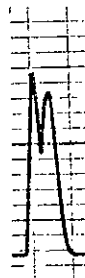
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একাক



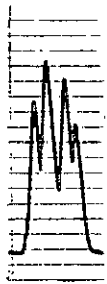
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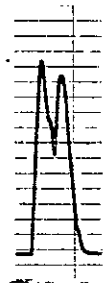
ওজু



ওজন



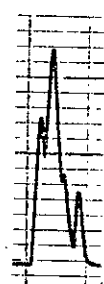
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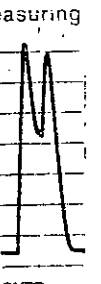
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ওজুপ্য



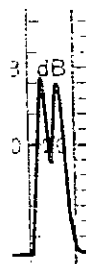
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অপ্ৰকা



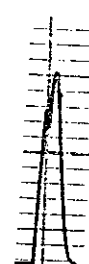
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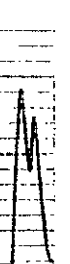
অপ্ৰগাবু



ওপস



পুনঃ



অষি

Fig. 10 Wave shapes of some words in Voice Signal for a typical voice.

অ in the words অতি and অধিকার is like 3 and not like অ. Similarly the pronunciation of এ in the word একমাত্র is like এা rather than এ.

The average amplitude of অ in male voice is 126.30 mv. But the average amplitude of অ in the word অধিকার is as low as 76.90 mv. From the data it is seen that when the word consists of only two alphabets, the average amplitude of the vowel is very near to the average amplitude of the vowel when uttered independently. This is true for all the vowels except অ. It is also very difficult to measure the duration of অ from the word আম as ম appears insignificantly. This is due to closed monosyllabic structure of the word. The mode of pronunciation of অ in different words are almost similar. Its amplitudes in different words are also nearly similar. Again there is no word in Bengali which begins with :. Therefore, we have taken three words ending in :

4.3. Amplitude and Duration of Bengali Vowels in words in Female Voice:

Average amplitude and duration of Bengali vowels in some words uttered in different female voices are shown in table 10. Comparing with the male voices, the amplitudes and duration are, as expected, relatively lower for each vowel. Within the scope of our observation the amplitude variation ranges from 33.60 mv (ই) - 106.20 mv (অ) compared to 34.9 mv (ই) - 112.60 mv (অ) in male voice. The duration ranges from 0.12 sec (ই) - 0.32 sec (অ) compared to 0.14 sec (ই) - 0.35 sec. (অ) in male voice. Again like male voices the amplitude and duration of each vowel occurring in words vary from word to word.

4.4 Amplitude and Duration of Bengali Consonants in Words in Male Voice:

Typical wave shapes of Bengali consonants occurring in different words are shown in Fig. 11. Average amplitude and duration of Bengali consonants in those words in male voice have been calculated from the voices of 10 persons which is shown in table 11. In all 94 words have been recorded from each person.

It is noted that when the word consists of two letters and of closed monosyllabic structure the amplitude of the first consonant is very near to its amplitude uttered in isolation. This characteristic has been observed in the following words.

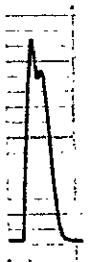
ঘড়, ঘর, চক, জন, ঝড়, টক, ডর,
ঢক, ঢল, দল, বল, ভর, মঠ, সব, হক :

From the measured wave shape it can be observed that in such monosyllabic structures the first alphabet dominates over the entire word.

For other types of words both the amplitude and duration of a consonant are found to vary over a wide range. The amplitude and duration of ক in final position of different words are found to be almost similar.

4.5 Amplitude and Duration of Bengali Consonants in Words in Female Voice.

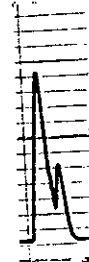
Average amplitude and duration of Bengali consonants in some words in female voice are shown in table 12. Both the amplitude and the duration of a consonant vary from word to word. For example the amplitude of ঘ is 70.00 mv in the



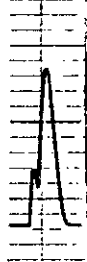
ফলা



ফলাস



ফথা



খড়



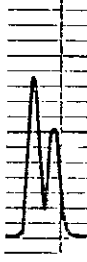
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খবুস



গবু



গবুজ



গতি



ধবু

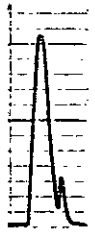


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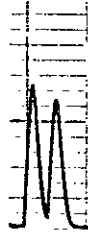


ধনিষ্ঠ

Fig. 11 Wave shapes of some words in Voice Signal for a typical voice .



চক



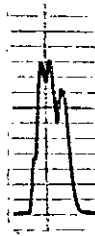
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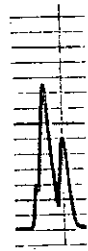
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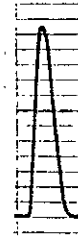
ছবি



ছলনা



ছন্দ



জল



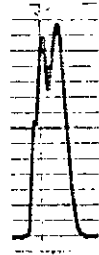
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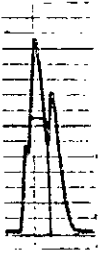
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কড়

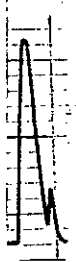


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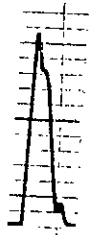


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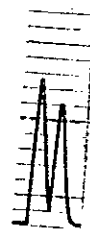
Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.



টক



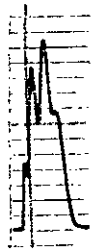
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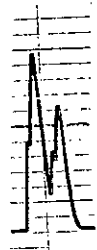
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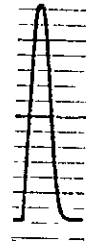
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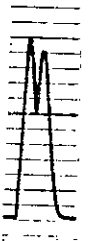
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চনচন



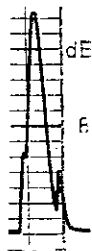
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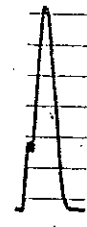
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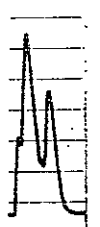
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Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.



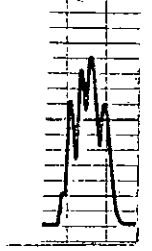
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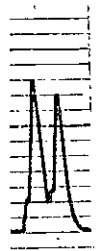
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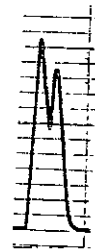
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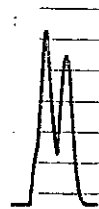
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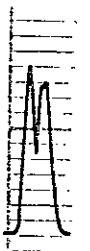
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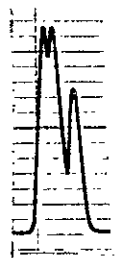


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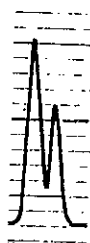


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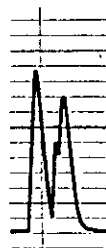
Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.



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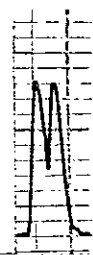
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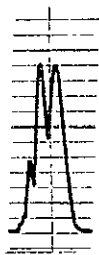
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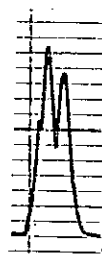
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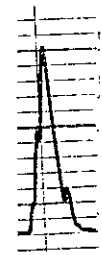
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ফজর



ফাটক



ফানি



বন



বড়কী

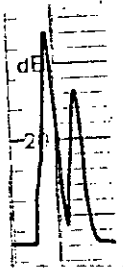


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Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.



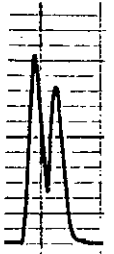
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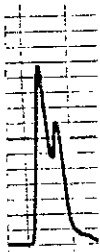
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মঠ



মঞ্জুর



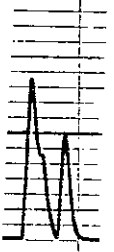
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যদি



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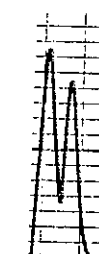
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বৃক্ষা



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মতা

Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.

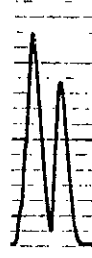
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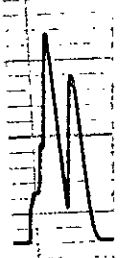
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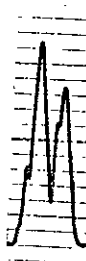
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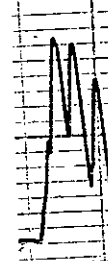
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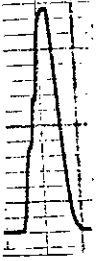
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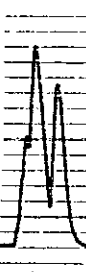
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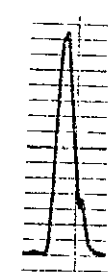
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ଅଧ୍ୟାୟ



ଅଜ୍ଞାନ

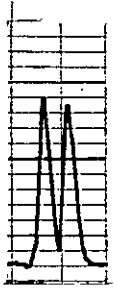


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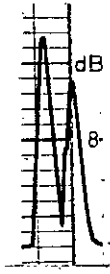


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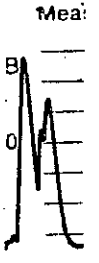
Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.



इत्था

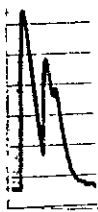


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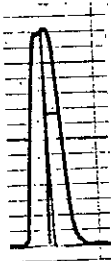


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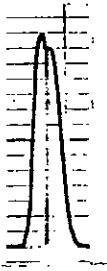
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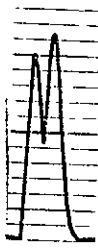
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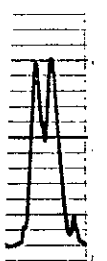
पत्था



आत्था



जत्था



इत्था

Fig. 11 Wave shapes of some words in Voice Signal for a typical voice.

word ঘনিষ্ঠ, 96.50 mv in the word ঘটক and 114.20 mv in the word ঘর The durations of ঘ in the above words are 0.16 sec., 0.20 sec., and 0.25 sec. respectively.

4.6 Discussion:

Amplitude and duration of Bengali Vowels and Consonants occurring in different words uttered by male and female voices were studied from recorded data. We can observe from the relevant data that both the amplitude and the duration of an alphabet vary from word to word. This variation is entirely dependant on the structure of the word and its mode of pronunciation. The distribution of amplitude and duration of an alphabet occurring in different words depends on the length of the word. It is also noted that for a closed monosyllabic word the amplitude of the first alphabet is very near to its amplitude uttered in isolation.

Average Amplitude and Duration of Bengali Vowels
in some words in (Male Voice)

Vowel	Words	Amplitude V_m (mv)	Duration T(Sec)
অ	অতি	92.70	0.21
	অথচ	82.90	0.17
	অধিকার	76.90	0.16
আ	আম	110.00	0.35
	আগুন	105.90	0.21
	আচরন	92.30	0.20
ই	ইহা	43.80	0.17
	ইডর	34.90	0.16
	ইতিহাস	39.70	0.14
ঐ	ঐদ	50.40	0.24
	ঐগল	42.40	0.19
	ঐদগাহ	48.80	0.18
উ	উহা	76.10	0.19
	উচিৎ	57.90	0.19
	উৎসাহ	52.70	0.19

TABLE 9.

Average Amplitude and Duration of Bengali Vowels
& in some Words in (Male Voice)

Vowels	Words	Amplitude V_m (mv)	Duration T(Sec)
উ	উর্ধ্ব	83.00	0.22
	উর্ধ্বর	81.20	0.23
	উর্ধ্বশ্বাস	71.30	0.21
ঋ	ঋন	64.30	0.31
	ঋতু	64.30	0.25
	ঋনগ্রন্থ	63.80	0.26
এ	এই	90.00	0.31
	একটু	77.90	0.21
	একঘাত	80.20	0.21
ঐ	ঐক্য	88.70	0.21
	ঐশিক	93.20	0.25
	ঐশ্বরিক	82.90	0.22
ও	ওঁ	103.20	0.21
	ওজন	99.30	0.21
	ওতপ্রোত	79.20	0.17

TABLE 9.

Average Amplitude and Duration of Bengali Vowels
in some Words in (Male Voice)

Vowels	Words	Amplitude V_m (mv)	Duration T(Sec)
ও	ঔষধ	103.40	0.25
	উজ্জ্বল্য	96.80	0.23
	উদাসীন্য	96.80	0.19
অং	অংশ	112.30	0.25
	অংগ	112.10	0.26
	অংগার	110.00	0.25
অঃ	তপঃ	112.60	0.27
	পুনঃ	112.30	0.28
	অধঃ	110.00	0.25

TABLE 9.

Average Amplitude and Duration of Bengali Vowels
in Some Words in Female Voice.

Vowels	Words	Amplitude V_m (mv)	Duration T(Sec)
অ	অতি	85.60	0.19
	অথচ	74.80	0.16
	অধিকার	68.20	0.15
আ	আমা	102.50	0.32
	আগুন	98.80	0.19
	আচরন	86.10	0.18
ই	ইহা	38.40	0.15
	ইতর	33.60	0.15
	ইতিহাস	36.80	0.12
ঐ	ঐদ	45.00	0.12
	ঐগল	37.50	0.21
	ঐদগাহ	42.50	0.17
উ	উহা	68.80	0.16
	উচিৎ	50.00	0.17
	উৎসাহ	46.40	0.17

TABLE 10.

Average Amplitude and Duration of Bengali
Vowels in Some Words in Female Voice.

Vowels	Words	Amplitude V_m (mv)	Duration T(Sec)
উ	উর্ধ্ব	76.80	0.20
	উর্ধ্বর	74.40	0.20
	উর্ধ্বশ্বাস	65.20	0.19
ঋ	ঋন	52.20	0.27
	ঋতু	51.80	0.23
	ঋনগ্রসু	48.70	0.23
এ	এই	85.40	0.28
	একটু	72.50	0.19
	একমাত্র	74.80	0.18
ঐ	ঐক্য	80.80	0.20
	ঐদিক	85.60	0.22
	ঐশ্বরিক	74.60	0.21
ও	ওছু	100.00	0.19
	ওজন	96.40	0.19
	ওতপ্রোত	75.20	0.18

TABLE 10.

Average Amplitude and Duration of Bengali
Vowels in Some Words in Female Voice.

Vowels	Words	Amplitude V_m (mv)	Duration T(Sec)
ও	ঔষধ	97.50	0.22
	ঔজ্জ্বল্য	91.40	0.20
	ঔদাসীন্য	90.70	0.19
অং	অংশ	106.20	0.22
	অংগ	105.80	0.22
	অংগার	102.20	0.22
অঃ	তপঃ	104.50	0.25
	পুনঃ	102.60	0.26
	অধঃ	101.40	0.25

TABLE 10.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ক	কলা	125.00	0.20
	কলম	117.40	0.18
	কথা	108.70	0.20
খ	খড়	114.20	0.24
	খরচ	110.80	0.22
	খবর	98.90	0.20
গ	গরু	109.30	0.22
	গজর্ন	115.60	0.20
	গতি	105.20	0.20
ঘ	ঘর	118.40	0.27
	ঘটক	101.00	0.21
	ঘণ্টা	72.80	0.17
চ	চক	119.50	0.28
	চক্র	99.30	0.23
	চতুর	87.70	0.18

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ছ	ছবি	104.50	0.23
	ছননা	103.40	0.22
	ছন্দ	88.40	0.23
জ	জল	123.70	0.32
	জগৎ	113.10	0.20
	জটিল	97.40	0.19
ঝ	ঝড়	123.00	0.31
	ঝগড়া	112.10	0.22
	ঝলমল	113.60	0.24
ট	টক	127.40	0.28
	টাক	109.40	0.18
	টাকর	98.40	0.21
ঠ	ঠক	126.30	0.32
	ঠকানো	85.80	1.18
	ঠনঠন	90.60	0.23

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ড	ডল	120.50	0.29
	ডলন	116.10	0.20
	ডবল	114.60	0.19
ঢ	ঢক	125.20	0.32
	ঢল	124.70	0.33
	ঢনঢন	101.80	0.26
ত	তখা	104.70	0.21
	তটিনী	86.80	0.17
থ	থলি	95.60	0.19
	থতমত	80.50	0.18
	থমথম	92.30	0.23
দ	দল	122.00	0.30
	দখল	105.40	0.21
	দকিন	85.70	0.20

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ধ	ধন	119.80	0.29
	ধন্য	95.00	0.22
	ধরনী	104.40	0.22
ন	নতুন	91.40	0.23
	নগন্য	102.50	0.19
	নকশা	97.00	0.22
প	পক্ষ	99.70	0.22
	পকেট	96.70	0.19
	পরিবার	85.90	0.19
ফ	ফজর	103.70	0.20
	ফটক	96.40	0.19
	ফন্দি	88.50	0.21
ব	বল	118.20	0.30
	বড়শী	103.90	0.24
	বন্ধ	112.20	0.23

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ড	ডর	124.90	0.34
	ডুগ	112.22	0.26
	ডুত	99.85	0.23
ম	মঠ	116.80	0.31
	মঞ্জুর	86.00	0.26
	মজলিশ	83.70	0.23
য	যদি	103.30	0.20
	যখন	106.50	0.22
	যথেষ্ট	95.50	0.20
র	রকম	118.00	0.23
	রকা	111.70	0.27
	রমজান	104.10	0.26
ল	লতা	116.70	0.26
	লবন	107.70	0.23
	লটারী	122.80	0.23

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
শ	শব্দ	95.50	0.23
	শব্দ	107.40	0.24
	শতক	90.80	0.20
ষ	ষষ্ঠ	100.00	0.24
	ষড়যন্ত্র	106.60	0.23
স	সব	115.40	0.32
	সময়	96.90	0.21
	সন্থান	89.20	0.23
হ	হক	126.00	0.29
	হজম	95.50	0.19
	হজা	80.60	0.21

TABLE 11.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ক	লক	89.30	0.29
	দক	89.80	0.29
	পক	86.20	0.28
ড	বড	108.50	0.27
	পড	104.00	0.26
ঢ	আ ষা ঢ	109.10	0.26
য়	জয়	107.20	0.25
ৎ	ইঠাৎ	99.10	0.22

TABLE 11.

Average Amplitude and Duration of Bengali
Consonants in Some Words in Female Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ক	কলা	114.70	0.18
	কলম	109.70	0.17
	কথা	105.60	0.18
খ	খড়	108.20	0.24
	খরচ	103.60	0.20
	খবর	92.50	0.18
গ	গরম	103.40	0.20
	গর্জন	107.50	0.19
	গতি	98.50	0.18
ঘ	ঘর	114.20	0.25
	ঘটক	96.50	0.20
	ঘনিষ্ঠ	70.00	0.16
চ	চক	115.50	0.27
	চকোল	93.50	0.22
	চতুর	82.50	0.18

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in Some Words in Female Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ছ	ছবি	99.60	0.22
	ছলনা	96.50	0.20
	ছন্দ	83.00	0.22
জ	জন	115.60	0.30
	জগৎ	108.60	0.20
	জটিল	93.40	0.18
ঝ	ঝড়	117.80	0.31
	ঝগড়া	107.20	0.20
	ঝলমল	106.50	0.22
ট	টরু	120.80	0.25
	টনক	106.50	0.17
	টক্কর	95.60	0.20
ঠ	ঠক	120.10	0.30
	ঠকানো	80.60	0.17
	ঠনঠন	85.50	0.20

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in Some words in Female Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ড	ডর	114.40	0.27
	ডজন	110.20	0.18
	ডবল	107.50	0.18
ঢ	ঢক	117.60	0.30
	ঢল	115.80	0.30
	ঢনঢন	96.70	0.25
ড	ডখা	100.20	0.20
	ডটিনী	83.70	0.15
থ	থলি	92.10	0.17
	থতমত	74.60	0.16
	থমথম	84.40	0.20
দ	দল	116.60	0.28
	দখল	99.50	0.20
	দকিন	80.60	0.18

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in Some words in Female Voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ধ	ধন	116.80	0.28
	ধন্য	90.60	0.20
	ধরনী	98.80	0.21
ন	নতুন	85.50	0.22
	নগন্য	98.20	0.18
	নকশা	92.50	0.20
প	পক্ষ	92.60	0.20
	পকেট	90.20	0.18
	পরিবার	78.80	0.18
ফ	ফজর	98.60	0.18
	ফটক	92.50	0.17
	ফন্দি	82.50	0.18
ব	বল	112.60	0.28
	বড়শী	98.70	0.22
	বস	107.30	0.20

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in some words in Female voice.

115 Consonants	Words	Amplitude V_m (mv)	Duration T(Sec)
ভ	ভর	115.50	0.32
	ভণ্ড	107.60	0.25
	ভদ্রতা	93.80	0.22
ষ	ষঠ	111.20	0.31
	ষজ্জর	82.40	0.24
	ষজ্জলিশ	78.60	0.22
য	যদি	99.60	0.18
	যখন	102.40	0.20
	যথেষ্ট	92.50	0.20
র	রকম	112.20	0.22
	রকা	103.80	0.25
	রমজান	99.50	0.25
ল	লতা	110.70	0.24
	লবন	101.60	0.22
	লটারী	115.30	0.21

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in some words in Female voice.

Consonant	Words	Amplitude V_m (mv)	Duration T(Sec)
ক	কল	90.20	0.22
	কক	103.20	0.22
	কতক	84.30	0.18
ষ	ষল	94.60	0.22
	ষড়যন্ত্র	100.30	0.22
স	সব	110.20	0.30
	সমস্তু	92.80	0.21
	সন্থান	82.70	0.22
হ	হক	115.60	0.27
	হজম	94.50	0.18
	হত্যা	80.20	0.20

TABLE 12.

Average Amplitude and Duration of Bengali Consonants
in some words in Female Voice.

Consonants	Words	Amplitude V_m (mv)	Duration T(Sec)
ক	লক	84.40	0.26
	দক	85.50	0.27
	পক	86.20	0.27
ঙ	বড়	103.80	0.25
	পড়	101.60	0.25
ঢ	আষাঢ়	104.10	0.25
ষ	জয়	102.50	0.22
ৎ	হঠাৎ	94.30	0.20

TABLE 12.

CHAPTER 5

ANALYSIS OF THE FREQUENCY BANDWIDTH OF BENGALI ALPHABETS IN VOICE SIGNALS.

5.1 Introduction

In the preceding chapters we discussed the amplitude and duration characteristics of Bengali alphabets uttered in isolation and in words recorded from different persons both male and female. These characterize the signal shapes and signal strength in the time domain. However the design of a transmitting and receiving system of the Bengali voice signals requires knowledge of their frequency characteristics and particularly the optimum signal bandwidth. In this chapter a bandwidth analysis of the Bengali Vowels and consonants uttered in isolation and in words has been carried out. The method is based on the Gaussian frequency spectrum analysis. Both male and female voices have been treated separately.

5.2 Mathematical Analysis

We know that the frequency bandwidth of a pulse of duration τ_p is given by $B = \frac{K}{\tau_p}$ where K is a constant factor determined from the shape of the pulse. For most of the pulses of regular shapes, $K = 1$.

A study of the wave shapes of the Bengali alphabets indicates that they appear as Gaussian type of pulses at least at the bottom portions. Let us assume, the pulses are of truncated Gaussian type

because the peak portion of the pulses are always truncated at a certain amplitude due to the mechanical damping of the stylus of the pen recorder. A truncated Gaussian pulse is represented by $f(t) \approx V_m e^{-t^2/2T^2}$ which is plotted in the following fig.

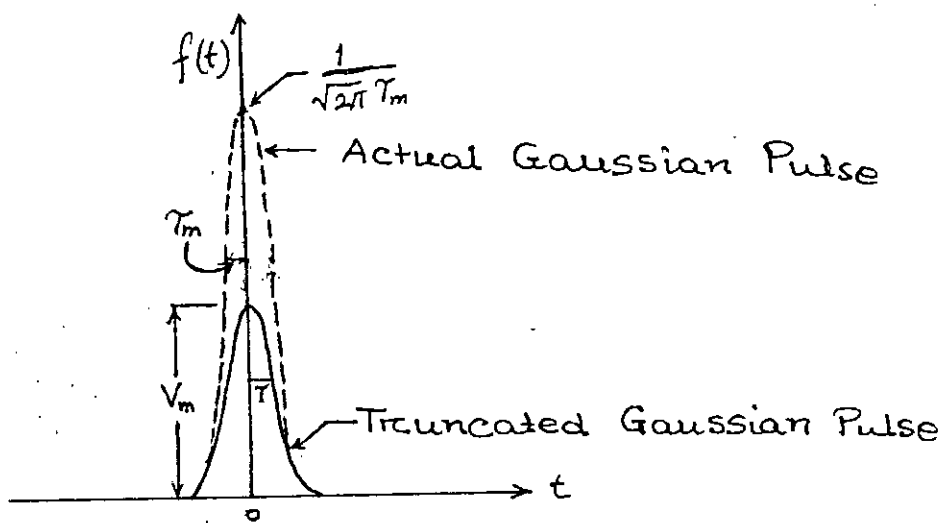


Fig. 12 A Truncated Gaussian Pulse and its Enveloping Gaussian Pulse.

T is measured at a height of $V_m e^{-\frac{1}{2}}$, i.e., $0.606 V_m$.

The actual Gaussian pulse will however become an envelope over the truncated Gaussian. The enveloping pulse shape is given by

$$f(t) = \frac{1}{\sqrt{2\pi} T_m} e^{-t^2/2T_m^2}$$

where T_m is measured at $\frac{0.606}{\sqrt{2\pi} T_m}$. Comparing with the truncated Gaussian the factor K is given by

$$K = \frac{T}{T_m}$$

or $T_m = \frac{T}{K}$

Again by Fourier analysis of the truncated Gaussian pulse [8]

$$F(\omega) = \sqrt{2\pi} T V_m e^{-T^2 \omega^2 / 2}$$

and for the actual Gaussian pulse

$$F(\omega) = e^{-\frac{\omega^2 T_m^2}{2}}$$

From comparison of their amplitudes

$$K = \frac{1}{\sqrt{2\pi} T V_m}$$

Hence the bandwidth of the pulse is given by

$$B = \frac{1}{T_m} = \frac{K}{T}$$

Using the above procedure the bandwidths of Bengali alphabet have been calculated in the later sections.

5.3 Frequency Band of Bengali Vowels in Male Voice

Frequency bandwidth of Bengali Vowels in different male voices are shown in table 13 and their average is shown in table 14. From the data it is seen that the highest bandwidth is required for ই (628 Hz) and the lowest bandwidth is required for ~~আ~~ অ (193 Hz). The bandwidth requirement of the short vowels ই and উ are more than the corresponding long vowels ঐ and ঊ. Comparing the diphthongs the bandwidth requirement of ঐ is much more than ঊ. Among the semivowels ঞ, ঞ্, and ঞ্, ঞ্ requires the highest bandwidth (405 Hz).

5.4. Frequency Band of Bengali Vowels in Female Voice :

Frequency bandwidth of Bengali Vowels in different female voices are shown in table 15 and their average is shown in table 16. Like male voice the bandwidth for ই is maximum (565 Hz) and that for ঐ is minimum (153 Hz). The short vowels require more bandwidths than the long vowels and the bandwidth requirement of ই is greater than ঐ as in male voice.

5.5. Frequency Band of Bengali Consonants in Male Voice:

Frequency bandwidth of Bengali Consonants in different male voices are shown in table 17 and their average is shown in table 18. The maximum bandwidth is shown to occur in ক (398 Hz) and minimum for খ (156 Hz). There is a similarity in ক, চ, ট, ত and খ group in respect of the amplitude of the bandwidth. The last alphabet of these groups, e.g., ঘ, ষ, ঢ, ঢ, ড which are phonetically voiced and aspirated sounds have the highest bandwidth. The consonants ক, চ, ট , which are phonetically unvoiced and unaspirated in the corresponding groups require the minimum bandwidth. In the ত and খ group, the voiced and un-aspirated consonants require minimum bandwidth.

Among ক, ঘ, স the consonant ঘ has the highest bandwidth. The bandwidths for ঙ and ঢ are almost equal.

5.6 Frequency Band of Bengali Consonants in Female Voice:

The Frequency bandwidth of Bengali Consonants in different female voices are shown in table 19 and their average is shown in table 20. In this case also the maximum bandwidth is for ক (288 Hz) and the minimum bandwidth is for স (100 Hz). In the চ and ট groups ব and ড which are voiced and unaspirated consonants have the highest bandwidth. In the ক, খ and গ group ফ, ব and ড which are unvoiced aspirated sounds require ^{the} highest bandwidth. The bandwidth of স is greater than those of ক and গ. Again the bandwidths of ড and ট are almost equal.

5.7 Frequency Band of Bengali Vowels in Words in Male Voice:

Average Frequency bandwidth of Bengali Vowels in some words in male voice has been shown in table-21. We observe from the table that the bandwidth of a vowel increases considerably when used in a word. The highest Bandwidth is seen to occur for ই in the word ইতিহাস (3465 Hz.). There is a great difference between the bandwidths of the same vowel used in different words. The only difference is in the case of অ, অ in different words requires almost similar bandwidths.

5.8. Frequency Band of Bengali Vowels in words in Female Voice.

Average frequency bandwidth of Bengali Vowels in some words in female voice has been shown in table 22. The

bandwidth of the same letter vary over a wide range when used in different words. For example the bandwidth of **আ** is 384 Hz in the word **আম**, 997 Hz in the word **আগুন** and 1385 Hz in the word **আচরণ**. The highest bandwidth is observed for **ই** in the word **ইতিহাস** (2886 Hz). The bandwidth requirement of **:** at the end of any word is dependant to a large extent on the particular letter at the end of which it is used in that word.

5.9. Frequency Band of Bengali Consonants in words in Male Voice

Average frequency bandwidth of Bengali consonants in some words in male voice has been shown in table 23. The highest bandwidth has been observed to be 2497 Hz. for **ঈ** in the word **ঘনিষ্ঠ**.

It has been noted that when the word consists of only two letters and the word is closed monosyllabic type the bandwidth requirement of the consonant is considerably low. For example, the bandwidth of **জ** in the word **জন** is 399 Hz. while its bandwidth in the word **জগৎ** is 1191 Hz and in the word **জটিল** is 1841 Hz. Though the word **কনা** consists of only two letters the bandwidth of **ক** is 1041 Hz which is not considerably low enough. This is because the duration of **ক** in **কনা** is not dominant. The bandwidth requirement of **ক** is almost the same in different words.

5.10 Frequency Band of Bengali Consonants in words in

Female Voice :

Average frequency bandwidth of Bengali consonants in some

words in female voice is shown in table 24. When uttered in isolation the maximum bandwidth requirement was 285 Hz for ' . But when used in words the bandwidth requirement is as high as 1874 Hz for the consonant ' in the word '৳৳৳'.

5.11. Discussion :

An extensive bandwidth analysis has been performed for Bengali alphabet uttered in isolation as well as occurring in different words. The method is based on Gaussian Spectrum analysis over the penrecorded data of their time domain pattern. It has been observed that the average vocal bandwidth required by a letter is more in the case of its occurring in a word rather than that required when it is uttered in isolation. In isolated utterance 'ই' requires the highest bandwidth and 'অ' the lowest bandwidth in both male and female voices. Among the consonants 'ক' has the highest bandwidth in male voice and 'খ' in female voice. The minimum bandwidth is for 'স' in both the cases. While occurring in different words 'ই' requires the highest bandwidth for both male and female voices. For a comparative study of the bandwidths of the alphabet uttered in isolation and in different words the statistical results are illustrated in tables 14-24.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons. (Male Voice)

Person	Vowel ঐ				Vowel ঐ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	143.30	0.157	17.77	113	140.00	0.147	19.44	132
2	130.00	0.167	18.42	110	128.30	0.167	18.67	112
3	125.00	0.118	27.12	230	105.00	0.120	31.75	264
4	102.50	0.108	36.13	335	95.00	0.115	36.61	318
5	116.70	0.100	34.28	343	105.80	0.120	31.50	262
6	116.70	0.125	27.43	219	102.50	0.125	31.22	250
7	121.70	0.150	21.92	146	116.70	0.115	29.81	259
8	143.30	0.130	21.48	165	122.50	0.130	25.12	193
9	140.30	0.160	17.82	111	130.00	0.140	20.51	137
10	123.50	0.142	22.90	161	113.60	0.115	30.61	266

TABLE 13:

Frequency Bandwidth of Bengali Vowels
Pronounced by different persons. (Male Voice):

Person	Person 1				Person 2			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	44.20	0.127	71.26	561	52.50	0.167	45.62	273
2	32.50	0.172	71.56	416	50.80	0.172	45.78	266
3	41.70	0.117	81.98	701	45.00	0.117	75.97	649
4	36.70	0.127	85.82	676	38.30	0.133	78.52	590
5	32.50	0.100	123.10	1231	45.00	0.110	80.81	735
6	59.60	0.112	59.92	535	60.00	0.150	44.44	296
7	34.20	0.130	90.05	693	45.00	0.140	63.49	454
8	50.00	0.133	60.15	452	60.00	0.128	52.08	407
9	57.80	0.137	50.51	369	69.00	0.170	34.10	201
10	47.00	0.135	74.07	644	51.50	0.118	65.81	558

TABLE 13.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Male Voice)

Person	ঔ				ঊ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B (Hz)
1	90.00	0.150	29.63	198	85.00	0.160	29.41	184
2	85.00	0.160	29.41	184	85.80	0.150	31.08	207
3	83.30	0.100	48.00	480	83.30	0.103	46.62	453
4	70.00	0.123	46.46	378	70.00	0.170	33.61	198
5	65.00	0.100	61.54	615	71.70	0.100	55.79	558
6	70.00	0.122	46.84	384	80.00	0.153	32.68	214
7	72.50	0.131	42.12	321	89.20	0.140	32.03	229
8	90.00	0.117	37.99	325	100.00	6.145	27.59	190
9	95.00	0.150	28.07	187	105.00	0.140	27.21	194
10	78.80	0.122	41.62	341	84.10	0.140	33.98	243

TABLE 13.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Male Voice)

Person	ঋ				৐			
	V_m (mv)	τ (Sec)	K	B (Hz)	V_m (mv)	τ (Sec)	K	B (Hz)
1	81.67	0.142	34.49	243	101.70	0.120	32.78	273
2	58.30	0.163	42.10	258	93.30	0.155	27.66	178
3	65.00	0.100	61.54	616	74.20	0.107	50.38	471
4	56.70	0.120	58.79	490	88.30	0.125	36.24	290
5	60.00	0.097	68.73	709	78.30	0.100	51/10	511
6	50.00	0.137	58.39	426	70.00	0.133	50.12	377
7	64.20	0.130	47.98	369	80.83	0.150	50.79	220
8	80.00	0.130	38.46	296	115.80	0.117	29.52	252
9	85.50	0.750	39.19	208	119.00	0.130	25.86	199
10	66.70	0.123	48.78	397	89.40	0.130	34.42	265

TABLE 13.

FREQUENCY BANDWIDTH OF BENGALI VOWELS
PRONOUNCED BY DIFFERENT PERSONS. (MALE VOICE)

Person	Vowel a				Vowel e			
	V_m (mv)	T (Sec)	K	B (Hz)	V_m (mv)	T (Sec)	K	B (Hz)
125	125.50	0.083	38.40	463	120.00	0.110	30.30	275
2	105.80	0.107	35.33	330	119.20	0.120	27.96	233
3	96.70	0.075	55.15	735	84.20	0.110	43.19	393
4	110.70	0.100	35.81	358	100.00	0.120	33.33	278
5	83.30	0.080	60.00	750	88.50	0.100	45.28	453
6	80.00	0.110	45.45	413	80.00	0.120	35.21	248
7	90.80	0.100	44.05	440	94.20	0.120	35.38	295
8	118.30	0.100	33.81	338	115.00	0.120	28.98	242
9	132.40	0.110	27.46	250	133.20	0.120	25.02	209
10	132.40	0.100	30.21	321	125	0.125	25.6	205

TABLE 13.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Male voice)

Person	Vowel ঔ				Vowel ঐ			
	V _m (mv)	T(Sec)	K	B (Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	140.00	0.11	25.97	236	148.85	0.092	29.21	317
2	129.20	0.11	28.14	256	137.50	0.110	26.45	240
3	91.70	0.110	39.65	360	95.00	0.080	52.63	658
4	108.30	0.128	28.85	225	123.30	0.092	35.26	383
5	93.33	0.100	42.86	429	111.67	0.080	44.77	560
6	80.00	0.120	41.67	347	108.33	0.087	42.44	488
7	99.17	0.13	26.25	239	122.50	0.100	32.65	326
8	125.80	0.103	30.87	300	141.70	0.100	28.23	282
9	139.28	0.120	23.93	199	156.05	0.100	25.63	256
10	139.99	0.113	25.29	224	146.05	0.103	26.59	258

TABLE 13.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Male voice).

Person	Vowel %			
	V_m (mv)	T(Sec)	K	B(Hz)
1	148.33	0.100	26.97	270
2	135.00	0.130	22.79	175
3	108.30	0.097	38.07	392
4	111.70	0.108	33.16	307
5	115.00	0.075	46.38	618
6	103.33	0.090	43.01	478
7	136.67	0.120	24.39	203
8	137.50	0.080	36.36	454
9	156.05	0.090	28.48	316
10	133.41	0.100	29.98	300

TABLE 13.

Average Bandwidth of Bengali Vowels in Male Voice.

Vowel	Bandwidth (Hz)
ঐ	193
ঐ	219
ঔ	628
ঊ	443
এ	341
ও	267
ঋ	405
ঌ	313
঍	440
ড	283
ণ	281
ত	377
থ	351

TABLE 14.

Frequency Bandwidth of Bengali Vowels
Pronounced by different persons(Female Voice)

Person	ঐ				ঔ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	145.00	0.135	20.43	151.36	140.00	0.142	20.12	142
2	130.83	0.150	20.38	136.	125.00	0.150	21.33	142
3	112.60	0.127	28.00	220.44	101.67	0.130	30.26	233
4	120.00	0.150	22.22	148	115.00	0.142	24.50	172
5	123.33	0.122	26.58	218	103.33	0.130	29.78	229
6	121.67	0.157	20.94	133	115.83	0.15	23.02	153
7	105.00	0.170	22.41	132	91.67	0.173	25.22	146
8	100.00	0.200	20.00	100	85.00	0.190	24.77	130
9	111.67	0.150	23.88	159	96.67	0.160	25.86	162
10	128.33	0.142	21.95	155	125.00	0.145	22.07	152

TABLE 15.

Frequency Bandwidth of Bengali Vowels
Pronounced by different persons(Female Voice)

Person	Vowel				Vowel			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	48.33	0.117	70.74	605	60.00	0.133	50.12	377
2	42.50	0.117	80.44	688	43.33	0.150	61.54	410
3	43.33	0.127	72.69	572	46.70	0.127	67.44	531
4	41.68	0.125	76.79	614	60.00	0.120	55.55	463
5	37.50	0.150	71.11	474	40.83	0.200	48.98	245
6	47.50	0.140	60.15	430	60.00	0.175	38.10	218
7	30.00	0.183	72.86	398	45.00	0.183	48.57	65
8	33.33	0.183	65.58	358	41.67	0.200	48.00	246
9	27.50	0.190	76.55	403	36.67	0.193	56.5	293
10	42.50	0.120	78.43	654	48.33	0.125	66.21	530

TABLE 15.

Frequency Bandwidth of Bengali vowels
pronounced by different persons(Female voice)

Person	Vowel ঔ				Vowel ঊ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	80.00	0.130	38.46	296	85.00	0.150	31.37	209
2	73.33	0.133	41.00	308	88.33	0.142	31.89	225
3	71.67	0.133	41.96	316	78.33	0.150	34.04	227
4	66.67	0.147	40.81	278	75.83	0.150	35.17	234
5	70.00	0.143	39.96	279	78.33	0.167	30.58	183
6	75.00	0.150	35.55	237	82.50	0.158	30.19	194
7	80.00	0.167	29.94	179	83.33	0.200	24.00	120
8	57.50	0.200	34.78	174	100.00	0.022	18.18	183
9	51.67	0.143	54.13	379	63.33	0.017	37.15	219
10	75.83	0.140	37.68	269	88.33	0.145	31.23	215

TABLE 15.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Female voice)

Person	ঋ				ঌ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	47.67	0.125	67.13	537	86.67	0.150	30.77	205
2	51.67	0.133	58.21	438	82.50	0.158	30.69	194
3	51.67	0.150	51.61	344	105.00	0.130	29.30	225
4	63.35	0.160	39.46	247	78.33	0.142	35.96	253
5	56.67	0.133	53.07	399	95.00	0.133	31.66	238
6	52.50	0.125	60.95	488	79.17	0.150	33.68	225
7	38.33	0.200	52.18	261	88.33	0.133	34.05	256
8	40.00	0.190	52.63	277	68.30	0.200	29.28	196
9	51.67	0.160	48.38	302	81.67	0.160	30.61	191
10	47.50	0.150	56.14	374	96.67	0.160	25.86	162

TABLE 15.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Female voice)

Person	a				o			
	V _m (mv)	τ(Sec)	K	B(Hz)	V _m (mv)	τ(Sec)	K	B(Hz)
1	121.67	0.080	41.10	514	125.00	0.137	23.36	170
2	98.33	0.097	41.94	432	103.33	0.150	25.81	172
3	113.33	0.090	39.22	436	75.00	0.143	37.30	261
4	93.33	0.097	44.18	455	100.00	0.158	25.32	160
5	113.33	0.090	39.22	436	120.00	0.133	25.06	188
6	95.00	0.090	46.78	520	101.67	0.167	23.56	141
7	93.33	0.100	42.86	429	110.00	0.163	22.31	137
8	105.00	0.110	38.28	348	103.33	0.200	19.35	97
9	98.33	0.110	36.98	336	100.00	0.140	28.57	204
10	110.00	0.100	36.36	364	105.83	0.160	23.62	148

TABLE 15.

Frequency Bandwidth of Bengali vowels
pronounced by different person(Female voice)

Person	ঔ				ঐ			
	V_m (mv=)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	116.67	0.150	22.86	152	126.67	0.110	28.71	261
2	115.00	0.150	23.19	155	128.33	0.100	31.17	312
3	120.00	0.014	23.81	171	120.00	0.100	33.33	333
4	105.00	0.140	27.21	194	109.67	0.100	36.47	365
5	118.33	0.013	26.00	200	115.00	0.100	34.78	348
6	103.33	0.125	30.97	248	115.00	0.100	34.78	348
7	113.33	0.137	25.76	188	96.67	0.117	35.36	302
8	103.33	0.150	25.81	172	101.67	0.125	33.10	265
9	98.33	0.142	28.65	202	109.17	0.120	30.53	254
10	113.33	0.150	23.53	157	131.67	0.100	30.38	304

TABLE 15.

Frequency Bandwidth of Bengali Vowels
pronounced by different persons(Female Voice)

Person	Vowel. ঐ			
	V_m (mv)	T (Sec)	K	B(Hz)
1	131.67	0.130	23.37	180
2	120.60	0.110	30.30	275
3	116.67	0.113	30.34	268
4	113.33	0.133	26.54	200
5	128.33	0.093	33.51	360
6	119.17	0.142	23.64	166
7	95.00	0.125	33.68	269
8	98.33	0.15	27.12	181
9	115.00	0.15	23.19	155
10	134.17	0.125	33.85	191

TABLE 15.

Average Bandwidth of Bengali Vowels
in Female Voice.

Vowels	Bandwidth (Hz)
ঐ	153
ঊ	166
আ	520
ই	359
এ	271
উ	191
ঋ	367
ঌ	238
঍	376
ও	188
ঔ	212
ঔ	309
ঔ	282

TABLE 16.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	Consonants				Consonant			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	150.00	0.15	17.78	119	140.00	0.14	20.41	146
2	135.00	0.15	19.75	132	115.00	0.16	21.74	136
3	115.00	0.125	27.83	223	105.00	0.13	29.30	225
4	110.00	0.12	30.30	253	97.50	0.13	31.57	243
5	110.00	0.12	30.30	253	105.00	0.12	31.75	265
6	120.00	0.125	26.67	213	110.00	0.12	30.30	253
7	110.00	0.15	24.24	162	105.00	0.14	27.21	194
8	142.50	0.15	18.71	125	140.00	0.15	19.05	127
9	195.00	0.15	16.16	108	165.00	0.14	17.31	124
10	140.00	0.15	19.05	127	135.00	0.14	21.16	151

TABLE-17.

Frequency Bandwidth of Bengali Consonants
Pronounced by different persons(Male voice)

Person	consonants ঞ				consonant ঞ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	115.00	0.17	20.46	120	145.00	0.150	18.39	123
2	117.50	0.17	20.02	118	137.50	0.16	18.18	114
3	110.00	0.140	25.97	186	92.50	0.125	34.59	277
4	90.00	0.125	33.68	269	100.00	0.125	32.00	256
5	105.00	0.12	31.75	265	95.00	0.12	35.09	292
6	112.50	0.125	28.44	228	107.50	0.12	31.00	258
7	125.00	0.150	21.33	142	135.00	0.11	26.94	245
8	140.00	0.16	17.86	112	140.00	0.16	17.86	112
9	150.00	0.16	16.67	104	160.00	0.15	16.67	111
10	115.00	0.14	24.84	177	120.00	0.14	23.81	170

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	consonant ষ				consonant ঞ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	125.00	0.15	21.33	142	150.00	0.15	17.78	119
2	125.00	0.16	0.20	125	122.50	0.16	20.41	128
3	90.00	0.14	31.75	227	85.00	0.13	36.20	278
4	110.00	0.12	30.30	253	97.50	0.12	34.19	285
5	95.00	0.13	32.39	249	100.00	0.12	33.33	278
6	105.00	0.15	25.40	169	110.00	0.12	30.30	253
7	130.00	0.15	20.51	137	125.00	0.14	22.86	163
8	135.00	0.15	19.75	132	145.00	0.15	18.39	123
9	155.00	0.15	17.20	115	167.50	0.15	15.92	106
10	110.00	0.14	25.97	186	132.50	0.125	24.15	193

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	consonant ঙ				consonant ঞ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	145.00	0.15	18.39	121	140.00	0.125	22.86	183
2	120.00	0.16	30.83	130	125.00	0.14	22.86	163
3	90.00	0.12	37.04	309	100.00	0.12	33.33	278
4	100.00	0.12	33.33	278	107.00	0.125	29.77	238
5	105.00	0.12	31.75	265	100.00	0.125	32.00	250
6	102.50	0.12	32.52	271	102.00	0.12	32.52	271
7	120.00	0.15	22.22	198	115.00	0.14	24.84	177
8	135.00	0.15	19.75	132	145.00	0.15	18.39	123
9	160.00	0.15	16.67	111	162.00	0.15	16.41	109
10	130.00	0.14	21.98	157	120.00	0.14	23.81	170

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Male Voice)

Person	Consonant ঠ				Consonant ঙ			
	V_m (mv)	τ (Sec)	K	B (Hz)	V_m (mv)	τ (Sec)	K	B (Hz)
1	130.00	0.14	21.98	157	125.00	0.14	22.86	163
2	125.00	0.17	18.82	111	130.00	0.16	19.23	120
3	115.00	0.12	28.98	242	95.00	0.12	35.08	292
4	115.00	0.12	28.98	242	95.00	0.125	33.68	269
5	110.00	0.13	27.97	215	110.00	0.12	30.30	258
6	110.00	0.125	29.09	233	115.00	0.12	28.98	242
7	135.00	0.14	21.16	151	125.00	0.13	24.61	189
8	140.00	0.15	19.04	127	140.00	0.14	20.41	146
9	160.00	0.15	16.66	111	165.00	0.15	16.16	108
10	140.00	0.12	23.81	198	127.50	0.14	22.41	160

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different person(Male Voice)

Person	Consonant ক				Consonant গ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	140.00	0.13	21.98	169	125.00	0.125	25.60	205
2	130.00	0.16	19.23	120	130.00	0.16	19.23	120
3	95.00	0.125	33.68	269	85.00	0.125	37.65	301
4	95.00	0.14	30.67	215	112.50	0.125	28.44	228
5	100.00	0.12	33.33	378	105.00	0.11	34.63	315
6	115.00	0.125	27.83	223	110.00	0.11	33.05	300
7	110.00	0.15	24.24	162	130.00	0.14	21.97	157
8	140.00	0.14	20.40	146	137.50	0.15	19.39	129
9	155.00	0.16	16.13	101	160.00	0.15	16.67	111
10	137.50	0.14	20.78	148	140.00	0.14	20.41	146

TABLE-17.

Frequency Bandwidth of Bengali Consonants
Pronounced by different Persons(Male Voice)

Person	Consonant ক				Consonant ঙ			
	V_m (mv)	τ (Sec)	K	B (Hz)	V_m (mv)	τ (Sec)	K	B (Hz)
1	132.50	0.010	30.19	302	137.50	0.14	20.78	148
2	105.00	0.010	38.09	381	117.50	0.16	21.28	138
3	85.00	0.09	52.28	581	105.00	0.13	29.30	225
4	85.00	0.10	47.06	471	115.00	0.14	24.84	177
5	105.00	0.10	38.09	381	110.00	0.12	30.30	252
6	85.00	0.10	47.0.5	471	120.00	0.11	30.30	275
7	115.00	0.10	34.78	348	120.00	0.15	22.22	148
8	125.00	0.09	35.35	395	142.50	0.15	18.71	125
9	150.00	0.09	29.63	329	145.00	0.16	17.24	108
10	117.50	0.10	34.04	340	140.00	0.14	20.41	146

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male Voice)

Person	Consonant ক				Consonant ঙ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	130.00	0.12	25.64	214	140.00	0.15	19.05	127
2	125.00	0.16	15.62	125	120.00	0.17	19.61	115
3	100.00	0.11	36.36	331	150.00	0.14	19.04	136
4	105.00	0.15	25.39	169	95.00	0.15	28.07	187
5	105.00	0.11	34.63	315	95.00	0.12	35.09	292
6	110.00	0.11	33.05	306	115.00	0.11	31.62	287
7	130.00	0.13	23.66	182	127.50	0.125	25.09	201
8	140.00	0.15	19.04	127	140.00	0.15	19.04	127
9	150.00	0.15	17.78	119	150.00	0.16	16.67	104
10	117.50	0.10	34.04	340	142.50	0.14	20.05	143

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	Consonant ক				Consonant ঙ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	130.00	0.12	25.64	214	125.00	0.10	32.00	320
2	130.00	0.16	19.23	120	125.00	0.10	32.00	320
3	125.00	0.10	32.00	320	77.50	0.10	51.61	516
4	110.00	0.11	33.05	300	92.50	0.10	43.24	432
5	95.00	0.11	38.27	398	90.00	0.10	44.44	444
6	100.00	0.11	36.36	330	85.00	0.10	47.05	471
7	135.00	0.125	23.70	190	125.00	0.11	29.09	264
8	145.00	0.14	19.76	141	130.00	0.10	30.76	308
9	150.00	0.16	16.67	104	137.50	0.11	26.45	204
10	135.00	0.13	22.79	175	117.50	0.10	34.05	340

TABLE-17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male Voice)

Person	Consonant ৴				Consonant ঙ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	140.00	0.125	22.86	183	120.00	0.12	27.78	231
2	135.00	0.16	18.52	116	130.00	0.16	19.23	120
3	115.00	0.125	27.82	223	100.00	0.11	36.36	331
4	105.00	0.125	30.47	244	105.00	0.14	27.21	194
5	112.50	0.10	35.55	356	110.00	0.11	33.06	301
6	120.00	0.10	33.33	333	110.00	0.11	33.05	300
7	130.00	0.14	21.97	157	140.00	0.125	22.85	183
8	145.00	0.15	18.39	123	137.50	0.14	20.77	148
9	150.00	0.16	16.67	104	152.50	0.15	17.49	117
10	140.00	0.125	22.86	183	140.00	0.125	22.86	183

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different Persons(Male voice)

Person	Consonant ক				Consonant খ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	150.00	0.10	26.67	267	135.00	0.12	24.69	206
2	125.00	0.16	20.00	125	132.50	0.15	20.12	134
3	95.00	0.14	30.07	215	95.00	0.13	32.38	249
4	102.50	0.14	27.87	199	120.00	0.10	33.33	333
5	105.00	0.12	31.75	265	110.00	0.11	33.06	301
6	115.00	0.12	28.98	242	112.50	0.12	29.62	247
7	120.00	0.14	23.80	170	130.00	0.15	20.51	137
8	127.50	0.15	20.91	139.	140.00	0.15	19.04	127
9	147.50	0.16	16.95	106	150.00	0.15	17.78	119
10	125.00	0.14	22.86	163	130.00	0.125	24.61	197

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Male Voice)

Person	Consonant ণ				Consonant ষ			
	V_m (mv)	τ (Sec)	K	B(Hz)	V_m (mv)	τ (Sec)	K	B(Hz)
1	120.00	0.10	33.33	333	130.00	0.14	21.98	157
2	135.00	0.125	23.70	190	135.00	0.16	18.52	116
3	92.50	0.10	43.24	432	87.50	0.13	35.16	270
4	90.00	0.10	44.44	444	112.50	0.15	23.70	158
5	105.00	0.10	38.09	381	95.00	0.11	38.27	348
6	110.00	0.10	36.36	364	115.00	0.125	27.82	223
7	125.00	0.10	32.00	320	120.00	0.125	26.66	213
8	135.00	0.10	29.62	296	130.00	0.15	20.51	137
9	145.00	0.15	18.39	123	150.00	0.15	17.78	119
10	120.00	0.10	33.33	333	120.00	0.14	23.81	170

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male Voice)

Person	Consonant ঙ				Consonant ঞ			
	V_m (mv) (mv)	τ (Sec)	K	B (Hz)	V_m (mv)	τ (Sec)	K	B (Hz)
1	145.00	0.15	18.39	123	140.00	0.14	20.41	146
2	135.00	0.16	18.52	116	130.00	0.15	20.51	137
3	100.00	0.15	26.66	178	100.00	0.15	22.66	178
4	105.00	0.16	23.30	149	95.00	0.15	28.07	187
5	95.00	0.12	35.08	292	100.00	0.12	33.33	278
6	125.00	0.13	24.61	189	120.00	0.13	25.64	197
7	125.00	0.15	21.33	142	130.00	0.15	20.51	137
8	132.50	0.15	20.12	134	130.00	0.15	20.51	137
9	145.00	0.16	17.24	108	150.00	0.15	17.78	119
10	135.00	0.15	19.75	132	137.50	0.14	20.78	148

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by Different persons(Male Voice):

Person	Consonant				Consonant			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B(Hz)
1	137.50	0.125	23.27	186	135.00	0.13	22.79	175
2	120.00	0.14	23.81	170	125.00	0.15	21.33	142
3	125.00	0.10	32.00	320	85.00	0.10	47.05	471
4	85.00	0.10	47.06	471	105.00	0.125	30.47	244
5	85.00	0.10	47.06	471	95.00	0.10	42.10	421
6	112.50	0.125	28.44	228	105.00	0.125	30.47	244
7	130.00	0.12	25.69	214	110.00	0.11	33.05	300
8	132.50	0.125	24.15	193	140.00	0.13	21.97	169
9	150.00	0.150	17.78	119	150.00	0.15	17.78	119
10	137.50	0.14	20.78	148	135.00	0.15	19.75	132

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	Consonant ক				Consonant খ			
	V _m (mv)	T(Sec)	K	B (Hz)	V _m (mv)	T(Sec)	K	B (Hz)
1	120.00	0.13	25.64	197	140.00	0.10	28.57	268
2	115.00	0.15	23.19	155	137.50	0.15	19.39	129
3	100.00	0.10	40.00	400	110.00	0.10	36.36	364
4	102.50	0.125	31.21	250	110.00	0.10	36.36	364
5	95.00	0.10	42.10	421	105.00	0.10	38.09	381
6	112.50	0.11	32.32	294	120.00	0.10	33.33	333
7	110.00	0.11	33.05	300	120.00	0.14	23.80	170
8	137.50	0.12	24.24	202	135.00	0.14	21.16	151
9	150.00	0.15	17.77	118	150.00	0.15	17.78	119
10	135.00	0.14	21.16	151	140.00	0.11	25.97	236

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male Voice)

Person	Consonants ৷				Consonants ৳			
	$V_m(mv)$	$\tau(\text{Sec})$	K	B(Hz)	$V_m(mv)$	$\tau(\text{Sec})$	K	B(Hz)
1	135.00	0.125	23.70	190	145.00	0.12	22.99	192
2	142.50	0.12	23.39	195	135.00	0.125	23.70	190
3	100.00	0.12	33.33	278	87.50	0.12	38.09	317
4	120.00	0.17	19.61	115	132.50	0.15	20.12	134
5	100.00	0.11	36.36	331	95.00	0.12	38.28	314
6	115.00	0.14	27.82	177	110.00	0.15	24.24	162
7	145.00	0.15	18.39	123	140.00	0.15	19.04	127
8	140.00	0.16	17.85	112	135.00	0.16	18.52	116
9	150.00	0.15	17.78	119	155.00	0.15	17.20	115
10	130.00	0.15	20.51	137	130.00	0.14	21.98	157

TABLE 17.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Male voice)

Person	Consonant ϵ			
	V_m (mv)	τ (Sec)	K	B(Hz)
1	135.00	0.1	29.63	296
2	127.50	0.1	31.37	379
3	95.00	0.10	42.10	421
4	115.00	0.09	38.64	429
5	105.00	0.10	38.09	381
6	125.00	0.12	26.67	222
7	135.00	0.08	37.03	463
8	125.00	0.09	35.55	395
9	147.50	0.09	30.13	335
10	120.00	0.09	37.04	412

TABLE 17.

Average Frequency Bandwidth of Bengali
Consonants in Male Voice.

Consonants	Bandwidth (Hz)
ন	362
ক	202
খ	211
গ	190
ঘ	205
ঙ	322
চ	191
ছ	156
জ	166
ঝ	266
ঞ	272
ট	260
ঠ	253
ড	178
ঢ	182
ণ	369

TABLE 18.

Average Bandwidth of Bengali Consonants
in Male Voice.

Consonants	Bandwidth (Hz)
ক	171
খ	186
গ	172
ঘ	196
চ	173
ছ	193
জ	192
ঝ	200
ট	179
ঠ	194
ড	183
ঢ	201
ণ	400
ত	174
থ	223
দ	172
ধ	224

TABLE 18.

Frequency Bandwidth of Bengali Consonants
pronounced by Different persons. (Female Voice)

Person	Consonant ক				Consonant খ			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B(Hz)
1	140.90	0.15	18.90	126	140.90	0.15	18.90	126
2	115.00	0.14	24.84	177	110.00	0.15	24.24	169
3	135.00	0.15	19.75	132	142.00	0.15	18.71	125
4	107.50	0.16	24.80	165	105.00	0.15	25.39	169
5	131.80	0.15	20.23	135	120.00	0.15	22.22	148
6	105.00	0.15	25.39	169	100.00	0.15	26.66	178
7	105.00	0.15	25.39	169	102.00	0.15	26.02	173
8	135.00	0.20	14.81	74	130.00	0.20	15.38	77
9	130.00	0.14	21.97	157	120.00	0.14	23.81	170
10	140.00	0.19	15.03	79	130.00	0.19	17.54	92

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons.(Female Voice)

Person	Consonant ঙ				Consonant ঞ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Ha)
1	140.90	0.19	14.94	79	131.80	0.15	20.23	135
2	107.50	0.18	20.67	115	110.00	0.14	25.97	186
3	135.00	0.19	15.59	82	145.00	0.17	16.22	95
4	102.55	0.18	21.66	120	105.00	0.16	23.80	149
5	125.00	0.15	21.33	142	135.00	0.17	17.43	103
6	100.00	0.15	26.66	178	100.00	0.15	26.66	178
7	105.00	0.15	25.39	169	110.00	0.15	24.24	162
8	125.00	0.24	13.33	56	140.00	0.20	14.28	71
9	112.50	0.16	22.22	139	110.00	0.16	22.73	142
10	120.00	0.20	16.60	83	135.00	0.20	14.81	74

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female Voice)

Person	Consonant				Consonants			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B(Hz)
1	125.00	0.15	21.33	142	129.50	0.15	20.59	139
2	105.00	0.15	25.39	169	110.00	0.15	24.24	162
3	135.00	0.18	16.64	91	135.00	0.15	19.75	132
4	100.00	0.16	25.00	156	105.00	0.15	25.39	169
5	137.50	0.15	19.39	129	137.50	0.18	16.16	90
6	97.50	0.15	27.35	182	105.00	0.16	23.80	149
7	95.00	0.18	23.39	130	85.00	0.16	29.41	184
8	140.00	0.20	14.28	71	140.00	0.20	14.28	71
9	105.00	0.15	25.40	169	110.00	0.15	24.24	162
10	125.00	0.20	16.00	80	120.00	0.20	16.66	83

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female Voice)

Person	Consonant ঙ				Consonant ঞ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	120.40	0.19	17.48	92	131.80	0.18	16.86	94
2	115.00	0.18	19.32	107	120.00	0.18	18.51	103
3	140.00	0.15	19.04	127	135.00	0.12	24.69	206
4	105.00	0.15	25.39	169	105.00	0.19	27.22	194
5	140.00	0.16	17.86	112	140.00	0.16	17.86	112
6	102.50	0.20	19.31	98	105.00	0.15	25.39	169
7	95.00	0.17	24.77	146	100.00	0.13	30.77	237
8	120.00	0.22	15.15	69	145.00	0.16	17.24	108
9	105.00	0.15	25.40	169	110.00	0.15	24.24	162
10	127.50	0.20	15.69	78	105.00	0.20	19.09	95

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female Voice)

Person	Consonant ষ				Consonant ঙ			
	V _m (mv)	T (Sec)	K	B(Hz)	V _m (mv)	T (Sec)	K	B(Hz)
1	136.30	0.18	16.30	91	140.90	0.17	16.70	98
2	120.00	0.20	16.66	83	125.00	0.15	21.33	142
3	135.00	0.18	16.46	91	135.00	0.15	19.75	132
4	110.00	0.16	22.72	142	115.00	0.15	23.18	155
5	135.00	0.175	16.93	97	140.00	0.18	15.87	88
6	107.50	0.15	24.80	165	110.00	0.18	20.20	112
7	95.00	0.175	24.06	137	100.00	0.15	26.66	178
8	145.00	0.19	14.51	76	140.00	0.16	17.85	112
9	102.50	0.15	26.02	173	90.00	0.15	29.63	198
10	132.50	0.20	15.09	75	115.00	0.20	17.39	87

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female Voice)

Person	Consonant ৗ				Consonant ৗ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	136.30	0.18	16.30	91	131.80	0.17	17.85	105
2	112.50	0.16	22.22	139	120.00	0.16	20.83	130.00
3	125.00	0.18	17.77	99	132.50	0.15	20.12	134
4	110.00	0.16	22.72	142	115.00	0.15	23.18	155
5	130.00	0.16	19.23	120	140.00	0.17	16.81	99
6	105.00	0.15	25.39	169	107.50	0.15	24.80	165
7	95.00	0.15	28.07	187	115.00	0.13	26.75	206
8	130.00	0.18	17.09	95	130.00	0.15	20.51	137
9	102.50	0.13	30.00	231	90.00	0.15	29.63	198
10	130.00	0.21	14.65	70	115.00	0.21	16.56	79

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female voice)

Person	Consonant ৭				Consonant ৪			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	113.60	0.14	25.15	180	140.90	0.15	18.90	126
2	100.00	0.13	30.77	237	117.50	0.14	24.31	174
3	125.00	0.13	24.61	189	135.00	0.16	18.51	116
4	120.00	0.12	27.78	231	115.00	0.16	21.73	136
5	120.00	0.12	27.78	231	130.00	0.20	15.38	77
6	100.00	0.14	28.57	204	110.00	0.16	22.72	142
7	80.00	0.11	45.45	413	105.00	0.15	25.39	169
8	105.00	0.13	29.30	225	120.00	0.20	16.67	83
9	95.00	0.10	42.10	421	90.00	0.15	29.63	198
10	115.00	0.14	24.84	177	130.00	0.20	15.38	77

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female voice)

Person	Consonant ঞ				Consonant ঞ			
	V _m (mv)	T (Sec)	K	B (Hz)	V _m (mv)	T (Sec)	K	B (Hz)
1	136.30	0.15	19.56	130	131.80	0.18	16.86	94
2	115.00	0.16	21.73	136	120.00	0.18	18.51	103
3	137.50	0.15	19.39	129.00	122.50	0.16	20.40	128
4	115.00	0.15	23.19	155	120.00	0.16	20.83	130
5	132.50	0.16	18.87	118	140.00	0.16	17.86	112
6	107.50	0.16	23.25	145	115.00	0.16	21.73	136
7	110.00	0.15	24.24	162	105.00	0.15	25.39	169
8	125.00	0.17	18.82	111	130.00	0.20	15.38	77
9	95.00	0.15	28.07	187	100.00	0.15	26.67	178
10	115.00	0.15	23.19	155	140.00	0.26	14.28	71

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female Voice)

Person	Consonant ক				Consonant খ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	127.30	0.18	17.46	97	127.30	0.15	20.95	140
2	110.00	0.15	24.24	162	120.00	0.16	20.83	130
3	140.00	0.15	19.04	127	120.00	0.10	33.33	333
4	117.50	0.16	21.27	133	110.00	0.12	30.30	253
5	140.00	0.18	15.87	88	130.00	0.10	30.77	308
6	110.00	0.15	24.24	162	105.00	0.12	31.74	265
7	110.00	0.14	25.97	186	75.00	0.10	53.33	233
8	132.50	0.19	16.88	84	105.00	0.15	25.39	169
9	105.00	0.16	23.81	149	85.00	0.12	39.21	327
10	115.00	0.20	17.39	87	95.00	0.15	28.07	187

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female voice);

Person	Consonant 'r'				Consonant 'f'			
	V _m (mv)	T (Sec)	K	B(Hz)	V _m (mv)	T (Sec)	K	B(Hz)
1	140.90	0.16	17.74	111	131.80	0.17	17.85	105
2	112.50	0.17	20.91	123	110.00	0.16	22.73	142
3	132.50	0.17	17.76	104	130.00	0.15	20.51	137
4	112.50	0.17	20.91	123	105.00	0.15	25.39	169
5	135.00	0.18	16.46	91	140.00	0.20	13.33	67
6	105.00	0.18	21.16	118	100.00	0.16	25.00	156
7	95.00	0.16	26.31	164	95.00	0.15	28.07	187
8	137.50	0.19	15.31	81	140.00	0.19	15.03	79
9	100.00	0.16	25.00	150	90.00	0.15	29.63	198
10	125.00	0.20	16.00	80	115.00	0.20	17.39	87

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female voice)

Person	Consonant ঝ				Consonant ঞ			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B(Hz)
1	140.00	0.15	19.04	127	135.00	0.15	19.75	132
2	107.50	0.20	18.60	93	120.00	0.16	20.83	130
3	130.00	0.17	18.09	106	140.00	0.15	19.04	127
4	107.50	0.16	23.25	145	115.00	0.15	23.18	155
5	145.00	0.18	15.32	85	145.00	0.15	18.39	123
6	105.00	0.18	21.16	118	110.00	0.15	24.24	162
7	100.00	0.15	26.66	178	90.00	0.13	34.18	263
8	125.00	0.20	16.00	80	140.00	0.15	19.04	127
9	97.50	0.15	27.35	182	90.00	0.15	29.63	198
10	120.00	0.20	16.67	83	107.50	0.20	18.60	93

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female voice)

Person	Consonant ঞ				Consonant ঞ			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B (Hz)
1	125.00	0.10	32.00	320	135.00	0.17	17.42	102
2	120.00	0.15	22.22	148	120.00	0.15	22.22	148
3	130.00	0.125	24.61	197	135.00	0.15	19.75	132
4	115.00	0.12	28.98	242	107.50	0.15	24.80	165
5	140.00	0.14	20.40	140	145.00	0.15	18.39	123
6	110.00	0.12	30.30	253	120.50	0.15	22.13	148
7	95.00	0.14	30.07	215	97.50	0.15	27.35	182
8	135.00	0.15	19.75	132	125.00	0.175	18.28	104
9	80.00	0.12	41.66	347	100.00	0.125	32.00	256
10	100.00	0.15	26.67	178	120.00	0.16	20.83	130

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female voice)

Person	Consonant ঙ				Consonant ঞ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	145.00	0.20	13.79	69	145.00	0.20	13.79	69
2	125.00	0.20	16.00	80	117.50	0.20	17.02	85
3	150.00	0.20	13.33	67	140.00	0.175	16.32	93
4	110.00	0.18	20.20	112	105.00	0.16	23.80	149
5	150.00	0.20	13.33	67	150.00	0.20	13.33	67
6	105.00	0.20	19.04	95	102.50	0.16	24.39	152
7	85.00	0.16	29.41	184	110.00	0.15	24.24	162
8	135.00	0.19	15.59	82	135.00	0.20	14.81	74
9	110.00	0.15	24.24	162	90.00	0.15	28.07	187
10	115.00	0.20	17.39	87	110.00	0.20	18.18	91

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female voice)

Persons	Consonants				Consonants			
	V_m (mv)	T(Sec)	K	B(Hz)	V_m (mv)	T(Sec)	K	B(Hz)
1	137.50	0.16	18.18	114	130.00	0.15	20.51	137
2	115.00	0.16	21.73	136	115.00	0.16	21.73	136
3	135.00	0.15	19.75	132	135.00	0.15	19.75	132
4	100.00	0.15	26.67	178	105.00	0.15	25.39	169
5	150.00	0.16	16.67	104	140.00	0.17	16.80	99
6	100.00	0.15	26.67	178	97.50	0.15	27.35	182
7	90.00	0.15	29.63	198	95.00	0.15	28.07	187
8	140.00	0.15	19.04	127	125.00	0.17	18.82	111
9	95.00	0.15	28.07	187	95.00	0.15	28.07	187
10	120.00	0.20	16.67	83	117.50	0.20	17.02	85

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons (Female voice)

Person	Consonant ঙ				Consonant ঞ			
	V _m (mv)	T(Sec)	K	B(Hz)	V _m (mv)	T(Sec)	K	B(Hz)
1	125.00	0.15	21.33	142	135.00	0.15	19.75	132
2	112.50	0.16	22.22	139	120.00	0.16	20.83	130
3	135.00	0.15	19.75	132	150.00	0.15	17.77	118
4	105.00	0.15	25.39	169	110.00	0.16	22.72	142
5	140.00	0.15	19.04	127	150.00	0.16	16.67	104
6	95.00	0.14	30.07	215	100.00	0.15	26.66	178
7	90.00	0.15	29.62	197	95.00	0.15	28.07	187
8	130.00	0.15	20.51	137	135.00	0.15	19.75	132
9	87.50	0.15	30.48	203	90.00	0.15	29.62	197
10	105.00	0.20	19.04	95	122.50	0.16	20.41	127

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female voice)

Person	Consonant \bar{v}				Consonant \bar{g}			
	V_m (mv)	T (Sec)	K	B(Hz)	V_m (mv)	T (Sec)	K	B(Hz)
1	127.50	0.18	17.42	97	135.00	0.16	18.51	116
2	110.00	0.20	18.18	91	120.00	0.18	18.51	103
3	135.00	0.175	16.93	97	132.50	0.175	17.25	99
4	115.00	0.18	19.32	107	120.00	0.17	10.60	115
5	155.00	0.20	12.90	65	155.00	0.20	12.90	65
6	110.00	0.16	22.72	142	112.50	0.16	22.22	139
7	112.50	0.15	23.70	158	110.00	0.15	24.24	162
8	140.00	0.19	15.03	79	130.00	0.21	14.65	70
9	115.00	0.15	23.18	155	105.00	0.15	25.39	169
10	115.00	0.20	17.39	87	120.00	0.21	15.87	76

TABLE 19.

Frequency Bandwidth of Bengali Consonants
pronounced by different persons(Female voice)

Person	Consonant e			
	$V_{m'}$ (mv)	T(Sec)	K	B(Hz)
1	125.00	0.10	32.00	320
2	110.00	0.12	30.30	253
3	130.00	0.10	30.77	308
4	117.50	0.10	34.04	340
5	155.00	0.14	18.43	132
6	110.00	0.10	36.36	364
7	85.00	0.10	47.65	471
8	120.00	0.15	22.22	148
9	100.00	0.12	33.33	278
10	115.00	0.12	28.98	241

TABLE 19.

Average Bandwidth of Bengali Consonants
in Female Voice.

Consonant	Bandwidth (Hz)
ক	137
খ	141
গ	115
ঘ	127
চ	130
ছ	132
জ	113
ঝ	146
ট	112
ঠ	129
ড	134
ঢ	139
ণ	257
ত	127
থ	140
দ	120
ধ	127
ন	231
প	114
ফ	133

TABLE 20.

Average Bandwidth of Bengali Consonants
in Female Voice.

Consonant	Bandwidth (Hz)
ব	120
গ	151
ম	238
য	149
ঝ	100
ন	123
ঞ	144
স	142
শ	156
ষ	145
ৎ	108
ঢ	111
ড	285

TABLE 20.

Average Bandwidth of Bengali Vowels
in Some Words in Male Voice

Vowel	Words	Bandwidth (Hz)
এ	অতি	1511
	অথচ	2275
	অধিকার	2337
আ	আম	430
	আগুন	1370
	আচরন	1871
ই	ইহা	2580
	ইতর	3154
	ইতিহাস	3465
ঐ	ঐদ	1485
	ঐগল	2590
	ঐদগাহ	3010
ঊ	ঊহা	1942
	ঊচিৎ	2801
	ঊৎসাহ	3244

TABLE 21.

Average Bandwidth of Bengali Vowels
in Some Words in Male Voice

Vowels	Words	Bandwidth (Hz)
ও	ওর্ধ্ব	2005
	ওর্ধ্বর	1371
	ওর্ধ্বশ্বাস	3122
ক	কন	1393
	কতু	2028
	কনগ্রন্থ	2240
এ	এই	871
	একটু	2513
	একমাত্র	2632
ঐ	ঐক্য	1863
	ঐশিক	1358
	ঐশ্বরিক	2363
ও	ওহু	1498
	ওহন	1485
	ওতপ্রোত	2240

TABLE 21.

Average Bandwidth of Bengali Vowels
in Some Words in Male Voice.

Vowels	Words	Bandwidth (Hz)
ঔ	ঔষধ	1099
	ঔজ্জ্বল্য	1728
	ঔদ্যাপীনা	1452
অং	অংশ	1241
	অংগ	1236
	অংগার	1226
অঃ	অধঃ	820
	উপঃ	762
	পুনঃ	714

TABLE 21.

Average Bandwidth of Bengali Vowels
in Some Words in Female Voice.

Vowels	Words	Bandwidth (Hz)
ঐ	অতি	1189
	অথচ	1586
	অধিকার	1765
আ	আম	384
	আগুন	997
	আচরন	1385
ই	ইশা	2072
	ইভর	2654
	ইতিহাস	2886
ঐ ও	ঐদ	1086
	ঐগল	1911
	ঐদগাহ	2200
ঊ	ঊশা	1568
	ঊচিৎ	2053
	ঊৎসাহ	2414

TABLE 22.

Average Bandwidth of Bengali Vowels
in Some Words in Female Voice.

Vowels	Words	Bandwidth (Hz)
উ	উর্ধ্ব	1464
	উর্ধ্বর	983
	উর্ধ্বশ্বাস	2380
ঋ	ঋন	1050
	ঋতু	1663
	ঋনগ্রন্থ	1760
ঋ এ	এই	676
	একটু	1785
	একমাত্র	2035
ঐ	ঐক্য	1268
	ঐশিক	920
	ঐশ্বরিক	1485
ও	ওজু	1050
	ওজন	980
	ওতপ্রোত	1568

TABLE 22.

Average Bandwidth of Bengali Vowels
in Some Words in Female Voice.

Vowels	Words	Bandwidth (Hz)
ঔ	ঔষধ	720
	ঔজ্জ্বলা	1017
	ঔদাসীন্য	972
অং	অংশ	848
	অংগ	832
	অংগার	783
অঃ	অধঃ	618
	তপঃ	607
	পুনঃ	490

TABLE 22.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ক	কলা	1041
	কলম	1662
	কথা	1247
খ	খড়	640
	খরচ	1187
	খবর	1635
গ	গরু	909
	গর্জন	974
	গতি	1681
ঘ	ঘর	682
	ঘটক	1966
	ঘনিষ্ঠ	2497
চ	চক	550
	চকল	1613
	চতুর	2333

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ছ	ছবি	1547
	ছননা	1572
	ছন্দ	1913
জ	জল	399
	জগৎ	1191
	জটিল	1841
ঝ	ঝড়	356
	ঝগড়া	1347
	ঝলমল	1199
ট	টক	456
	টবক	1409
	টকর	1706
ঠ	ঠক	505
	ঠকানো	2367
	ঠনঠন	2041

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ড	ডর	437
	ডজন	1144
	ডবল	1235
ঢ	ঢক	506
	ঢল	475
	ঢনঢন	1511
ত	তখা	1558
	তটিনী	2272
থ	থলি	1622
	থতমত	2614
	থমথম	1886
দ	দল	469
	দবল	1343
	দক্কিন	2412

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ধ	ধন	590
	ধন্য	1783
	ধরনী	1018
ন	নতুন	1858
	নগন্য	1509
	নকশা	1621
প	পক্ষ	1602
	পকেট	1551
	পরিবার	1667
ফ	ফজর	1445
	ফটক	1486
	ফন্দি	1657
ব	বল	466
	বড়শী	1004
	বন্দ	1570

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ড	ডর	356
	ডাক	1359
	ডুডুতা	1504
ম	মঠ	470
	মজুর	1510
	মজলিশ	1505
য	যদি	1268
	যখন	1195
	যথেষ্ট	1634
র	রকম	952
	রকা	1110
	রমছান	1129
ল	লতা	902
	লবন	1281
	লটারী	872

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ক	কণ	1460
	কর	1258
	কতক	1627
খ	খল	1422
	খড়খন্দ	1161
গ	গর	384
	গরু	1411
	গরুণ	1491
হ	হর	504
	হরম	1517
	হত্যা	2405

TABLE 23.

Average Bandwidth of Bengali Consonants
in Some Words in Male Voice.

Consonant	Words	Bandwidth (Hz)
ক	লক	1276
	দক	1252
	পক	1268
ভ	বভ	808
	পভ	1040
ট	আষাট	872
য়	জয়	771
ং	হঠাং	1163

TABLE 23.

Average Bandwidth of Bengali Consonants in some words in Female Voice.

Consonant	Words	Bandwidth (Hz)
ক	কলা	727
	কনমা	1142
	কথা	836
খ	খর	446
	খরচ	812
	খবর	1132
গ	গর	596
	গর্জন	682
	গতি	1144
ঘ	ঘর	452
	ঘটক	1383
	ঘনিষ্ঠ	1676
চ	চক	374
	চন্দ্রাঙ্গল	1126
	চতুর	1642

TABLE 24

Average Bandwidth of Bengali Consonants
in some words in Female Voice

Consonant	Word	Bandwidth (Hz)
হ	হরি	1076
	হননা	1110
	হল	1352
জ	জন	276
	জগৎ	812
	জটিল	1288
ঝ	ঝড়	248
	ঝগড়া	922
	ঝলমল	820
ঢ	ঢক	319
	ঢনক	972
	ঢকর	1194
ঠ	ঠক	347
	ঠকানো	1656
	ঠনঠন	1430

Average Bandwidth of Bengali Consonants
in some words in Female Voice.

Consonant	Word	Bandwidth (Hz)
ড	ডর	305
	ডজন	782
	ডবন	854
ঢ	ঢক	358
	ঢন	327
	ঢনঢন	1057
ভ	ভবা	1048
	ভটিনী	1588
ধ	ধনি	1135
	ধতঘত	1874
	ধমধম	1320
দ	দন	321
	দহন	940
	দহিন	1668

TABLE 24

Average Bandwidth of English Consonants
in some words in Female Voice

Consonant	Word	Bandwidth (Hz)
ধ	ধন	412
	ধন্য	1248
	ধরনী	726
ম	নতুন	1312
	নগন্য	1056
	নকশা	1133
ব	বহু	878
	বক্রেট	1085
	বরিসহ	1163
ফ	ফজর	996
	ফটক	1040
	ফনি	1152

TABLE 24

Average Bandwidth of Bengali Consonants
in some words in Female voice.

Consonants	Word	Bandwidth (Hz)
ব	বন	326
	বড়শী	694
	বন্দু	1099
ভ	ভর	247
	ভক্ত	951
	ভট্টা	1058
ষ	ষঠ	328
	ষন্ধুর	1063
	ষজনিধ	1058
য	যদি	878
	যখন	836
	যথেষ্ট	1154

TABLE 24

Average Bandwidth of Bengali Consonants
in some words in Female Voice

Consonant	Word	Bandwidth (Hz)
র	রকম	658
	রহা	774
	রমজান	792
ন	নতা	631
	নবম	896
	নটালী	622
শ	শব্দ	1038
	শক	840
	শতক	1138
য	যষ্ঠ	985
	যজ্ঞযন্ত্র	812
স	সব	268
	সময়	984
	সন্মান	1063

TABLE 24

Average Bandwidth of Bengali Consonants
in some words in Female Voice

Consonant	Word	Bandwidth (Hz)
হ	হক	352
	হজম	1088
	হত্যা	1612
দ	দফ	892
	দফ	876
	পদ	885
ভ	বড়	566
	পড়	712
জ	জাঘাট	610
ঝ	জম	522
ঞ	হঠাৎ	814

TABLE 24

CHAPTER - 6CODING OF MESSAGES IN BENGALI LANGUAGE

6.1 Introduction

The amplitude and duration pattern and the bandwidth analysis of Bengali alphabet in the preceding chapters enable us to consider digital processing of messages in Bengali. In a digital communication system the analog signals are converted to binary pulses using analog to digital converters. The analog signal is first sampled at a rate which must be greater than or equal to twice the signal bandwidth. The sampled outputs are then quantized into a large number of discrete voltage levels which are strongly related to the amplitude and duration pattern of the signals. These discrete voltage levels are then coded into binary pulses for transmission. At the receiver the coded pulses are decoded using a digital to analog converter. The advantages of this type of communication over analog signal communication are as follows :

1. Information is carried by discrete symbols instead of continuously varying pulse amplitudes. So the signals may be regularly reshaped or regenerated during transmission.
2. All digital circuitry may be used in the entire system.
3. Signals may be digitally processed as desired.
4. Noise and interference may be minimized by appropriate coding of the signals.

The design of a code for efficient transmission of messages is rather difficult. However, coding has the advantage that it allows us to increase the rate of information transmission. Another advantage of coding is that it helps us to detect errors in transmission of messages and in some cases to correct errors. This is accomplished by properly designing the length of a code word by incorporating redundancy bits with the message bits.

6.2 Design Considerations for Digital Transmission of Bengali Messages :

From chapter 5 it is observed that the maximum bandwidth of the Bengali alphabet in voice signals is 3.465 KHZ.

So, for digitizing the symbols in Bengali messages by an analog to digital converter the sampler should have a sampling rate

$$f_c \geq 2 \times 3.465 \text{ KHZ}$$

or

$$f_c \geq 7.0 \text{ KHZ (app.)}$$

There are altogether 48 alphabet (Vowels and Consonants) in Bengali. If each symbol is equally likely to occur the information rate of a pulse code Modulation (PCM) system will be

$C_{av} \geq 7.0 \times 10^3 \text{ Log}_2 48 \text{ bits/sec.} = 39097 \text{ bits/sec.}$ which is the Shanon's limit.

Now since in practice the symbols are not equally likely

to occur, the rate of information should be

$$C_{av} \geq - 2B \sum_{j=1}^n P_j \text{Log } P_j \text{ bits/sec.}$$

where P_j is the probability of occurrence of the j th symbol.

Now the entropy component $- P_j \text{Log } P_j$ has been previously calculated to be 4.554 for Bengali Language by Das [3].
So practically

$$C_{av} \geq 7.0 \times 10^3 \times 4.554 \text{ bits/sec.}$$

$$\text{or } C_{av} \geq 31.88 \times 10^3 \text{ bits/sec.}$$

The redundancy factor for a language can be calculated from

$$R = \text{Log}_2 n + \sum_{j=1}^n P_j \text{Log } P_j$$

Which gives the difference between the theoretically maximum entropy and the practically occurring entropy of the messages. For messages in Bengali Language

$$\begin{aligned} R &= \text{Log}_2 48 - 4.554 \text{ bits} \\ &= 5.585 - 4.554 \text{ bits} \\ &= 1.031 \text{ bit} \end{aligned}$$

$$\begin{aligned} \text{The percentage redundancy is} &= \frac{1.031}{5.585} \times 100 \\ &= 18.46\% \end{aligned}$$

6.3 An Algebraic Coding Scheme for Bengali Messages:

There are various types of coding. One of them is the algebraic coding [9]. In this system information is transmitted along with redundancy bits which are meant for correcting errors during transmission. Let us suppose that when a binary '0' is to be transmitted we transmit a sequence of three 0's (000) and when a '1' is to be transmitted we actually transmit three 1's (111). These triplets of 0's or 1's are redundant. Because two of the 0's in 000 and two of the 1's in 111 carry no information to the message. Now let us suppose that not more than one error occurs in the above cases of triplet. Then if we receive 100, 010 or 001 we may be rather certain that the transmitted message was actually 000. On the other hand if we receive 1110, 101 or 011, we may be rather sure that the transmitted message was actually 111. So redundancy has actually helped us to detect the occurrence of an error.

Now let us suppose that we have M equally likely messages. We encode these in M message words each of length K where $M=2^K$. Each of these code word has no redundancy. Each bit in each message code word conveys an amount of information $I = 1$ bit. If we add r redundant bits to each message the transmitted code word will have $n = K + r$ bits. The total number of words is 2^n while the total number of possible messages is 2^K . A typical code word will have the form

$$a_1 a_2 a_3 \dots \dots \dots a_k C_1 C_2 \dots \dots \dots C_r.$$

Where a_i is the i th bit of the message and C_j is the j th

redundant bit. These redundant bits are called parity check bit, a_j and C_j both may assume the values 0 or 1.

The parity bits are selected to satisfy the linear equations,

$$0 = h_{11} a_1 + h_{12} a_2 + \dots + h_{1k} a_k + 1c_1 + 0c_2 + \dots + 0c_r$$

$$0 = h_{21} a_1 + h_{22} a_2 + \dots + h_{2k} a_k + 0c_1 + 1c_2 + \dots + 0c_r$$

$$0 = h_{r1} a_1 + h_{r2} a_2 + \dots + h_{rk} a_k + 0c_1 + 0c_2 + \dots + 1c_r$$

.....(6.3-1).

The co-efficients h_{ij} are either 0 or 1.

The rules of algebra are as follows

Addition: $0 + 0 = 0$

$$0 + 1 = 1$$

(6.3-2)

$$1 + 0 = 1$$

$$1 + 1 = 0$$

Multiplication: $0 \cdot 0 = 0$

$$0 \cdot 1 = 0$$

$$1 \cdot 0 = 0$$

(6.3-3)

$$1 \cdot 1 = 1$$

This differs from the Boolean algebra in the case $1 + 1$ which is equal to 1 in Boolean algebra.

One algebraic code is distinguished from another by the number of parity bits and the selection of the coefficients h_{ij} .

The \bar{H} matrix is defined as a rectangular matrix with r rows and n columns and is given by

$$\bar{H} = \begin{array}{c} \left| \begin{array}{cccccccc} h_{11} & h_{12} & \dots & h_{1k} & 1 & 0 & 0 & \dots & 0 \\ h_{21} & h_{22} & \dots & h_{2k} & 0 & 1 & 0 & \dots & 0 \\ \vdots & \vdots & & \vdots & \vdots & \vdots & \vdots & & \vdots \\ h_{r1} & h_{r2} & \dots & h_{rk} & 0 & 0 & 0 & \dots & 1 \end{array} \right| \end{array} \quad (6.3-4)$$

The column matrix \bar{T} representing the transmitted code word is defined as

$$\bar{T} = \begin{array}{c} \left| \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_k \\ c_1 \\ c_2 \\ \vdots \\ c_r \end{array} \right| \end{array} \quad (6.3-5)$$

Then equations (6.3-1) may be written as $\bar{H} \bar{T} = 0$ (6.3.6)

The column matrix \bar{T} is a vector, with components $a_1, a_2, \dots, a_k, c_1, c_2, \dots, c_r$.

Let us now suppose that the received message is \bar{R} which may or may not be the transmitted code word. Let us also suppose that at the receiver we have an appropriate apparatus to form the product $\bar{H}\bar{R}$. If $\bar{H}\bar{R} \neq 0$, we know that \bar{R} is not a possible message and error has occurred.

We have 48 alphabets in Bengali. So we can code any of the 48 alphabets by 6 binary digits excluding the redundant bits. We are to add enough redundant bits to allow correction of single error. It is quite apparent that a single redundant digit is not enough. If we add 2 redundant bits then we have $r = 2$ and $n = k + r = 6 + 2 = 8$. The H matrix has 2 rows and 8 columns. From the matrix arrangement we can see that it is not possible to have each of the 8 columns different from every other. Hence 2 redundant bits are not enough. Similarly 3 redundant bits are not also sufficient. If we add 4 redundant bits then $r = 4$ and $n = 6 + 4 = 10$. The H matrix will have 4 rows and 10 columns. With 4 digits in each column we have 16 possible different columns. We can choose any 10 of the 16 columns.

Let us form the H matrix as

$$\bar{H} = \begin{array}{c} \begin{array}{cccccccccc} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & c_1 & c_2 & c_3 & c_4 \end{array} \\ \left[\begin{array}{cccccccccc} 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \end{array} \right] \quad (6.37) \end{array}$$

Since $n = 10$, there are $2^{10} = 1024$ possible 10 digit sequences. The H matrix of equations(6.3-7) can be used to determine the required number of sequences of 10 digits which will actually be recognized as messages at the receiver. Let us consider one of the messages to be 101010. With 4 redundant bits let the complete message is 101010 $c_1 c_2 c_3 c_4$.

$$HT = H \begin{array}{c} 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \end{array} = 0 \quad (6.3-8)$$

We have,

$$\begin{array}{c} | 1+0 + 1 + 0 + 1 + 0 + c_1 + 0 + 0 + 0 \\ | 1 + 0 + 0 + 0 + 0 + 0 + 0 + c_2 + 0 + 0 \\ | 1 + 0 + 0 + 0 + 1 + 0 + 0 + 0 + c_3 + 0 \\ | 1 + 0 + 1 + 0 + 0 + 0 + 0 + 0 + 0 + c_4 \end{array} = 0 \quad (6.3-9)$$

So we get, $c_1 = 1, c_2 = 1, c_3 = 0, c_4 = 0$

The message is then represented by the code word 1010101100. In a similar way the complete code word for any message can be determined.

To see how coding may be used to correct single error let us assume that due to such an error the received sequence is 1010111100 instead of 1010101100. The error can be checked and corrected by evaluating the syndrome

$$\bar{S} = \bar{H} \bar{R} \dots\dots\dots(6.3-10)$$

generated with a shift register which is a cascade of storage of memory devices being capable of storing 1 binary digit. The 1 digit storage device may be a flip flop which stores the digit 1 or 0, depending on which of its two allowable states it occupies. A shift register using four 1 digit memories is shown in fig-13.

A stream of binary encoded data is applied to M_1 . It stores the latest input bit and indicates its state on its output line. At the end of each bit interval the bit stored in each of the memory devices shifts one stage to the right. The code is generated by combining the outputs of a K-stage shift register employing a V modulo-2 adders. In fig.13. $K = 4$ and $V = 3$. V_1 , V_2 and V_3 are the outputs of the adders.

$$\begin{aligned} V_1 &= S_1 \\ V_2 &= S_1 + S_2 + S_3 + S_4 \\ V_3 &= S_1 + S_3 + S_4 \end{aligned} \quad (6.4 -1)$$

The first bit of the input data is entered into M_1 . During this message bit interval the commutator samples, in turn, the modulo-2 adder outputs V_1 , V_2 and V_3 . Thus a single message bit yields three coded output bits. When the next message bit enters M_1 , the bit initially in M_1 transfers to M_2 and the commutator again samples the V adder outputs. The process continues until the last message bit enters M_1 . Then in order to ensure that every message bit may proceed entirely through the shift register and hence be involved in the complete coding process, enough 0.'s

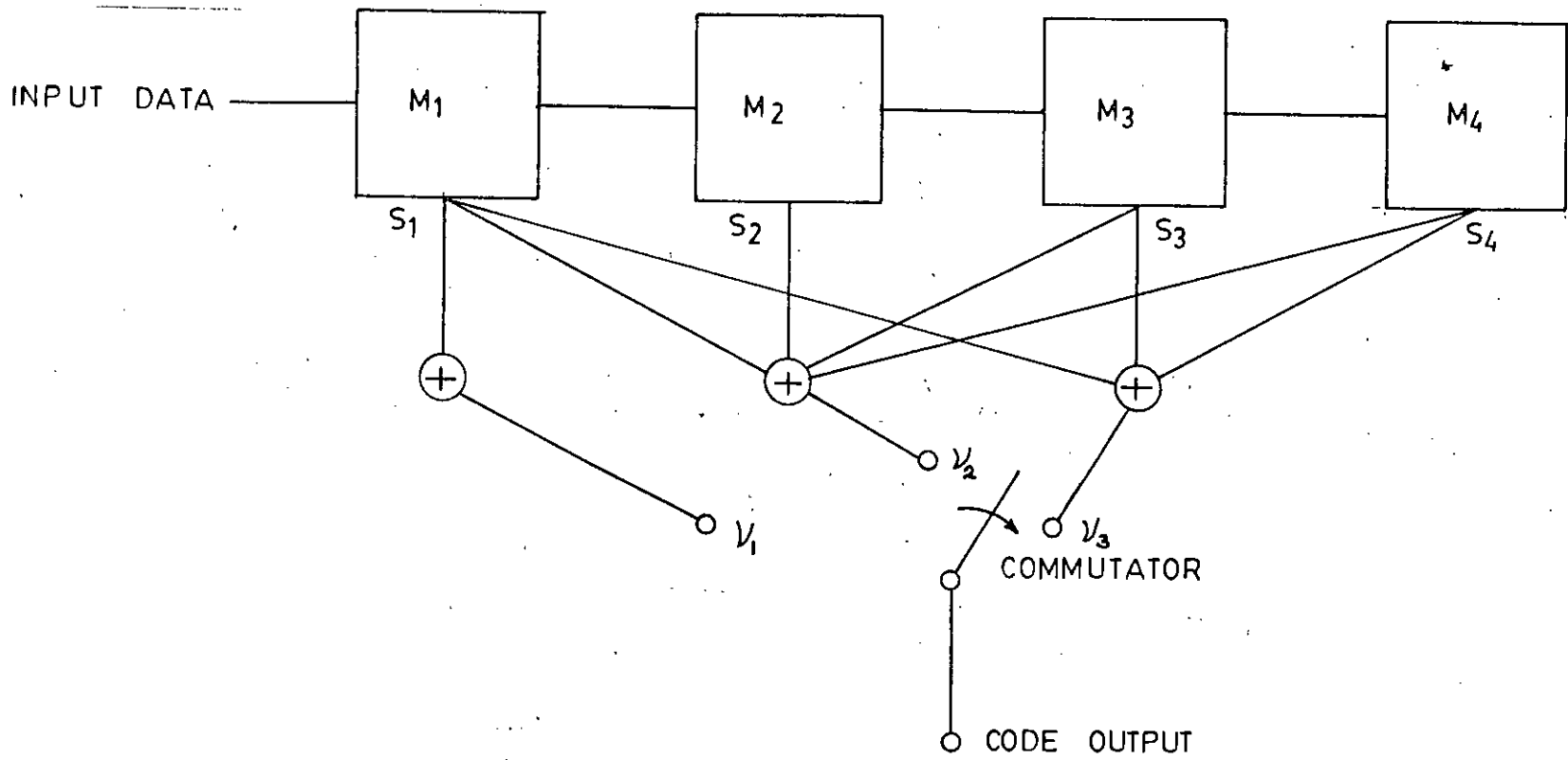


Fig.13 An example of a Convolution Coder.

are added to the message to transfer completely the last message bit through M_4 and hence out of the register. The coded output bit stream for 101010 will be

$$C = 111 \ 010 \ 100 \ 001 \ 100 \ 001 \ 011 \ 011 \ 000 \ 000 \quad (6.4-2)$$

If the number of bits in the message stream is L , the number of bits in the output code is, $V(L + K)$. In practice L is very large compared to K . So we have $V(L + K) \approx VL$. This means that the number of code bits is equal to V times the number of commutator segments.

Even if the input message bit stream consists of millions of bits the stream would be run continuously through the encoder.

6.5 A Complete Code Tree for Bengali Messages.

A complete code tree for Bengali alphabets is shown in table 25. Out of the 64 coded symbols, 48 can be used to represent the Bengali messages. This code tree applies to the convolutional encoder of figure 13 for which $K = 4$, $V = 3$ and which is constructed for the case $L = 6$ corresponding to a 6 bit message sequence for encoding Bengali messages.

The code tree starts from the left position and corresponds to the situation before the occurrence of the first message bit, which may be either a 1 or a 0. When the input bit is 0 we shall diverge upward and when the bit is 1 we shall diverge downward. For the message 101010 the first is 1. Entering the tree at the node A we move downward to the lower branch

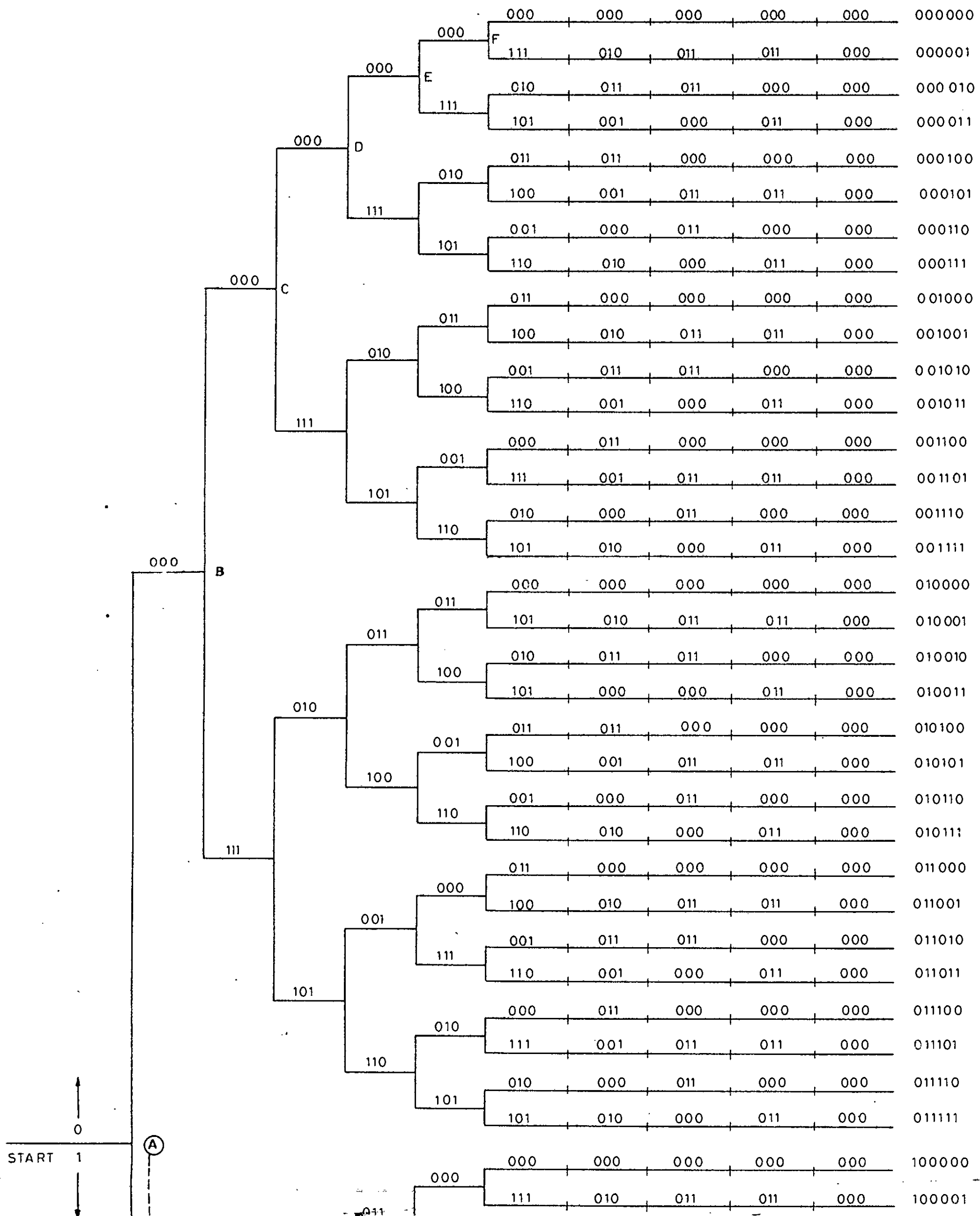
and to node B. From equation (6.4-2) we find that when the first input bit is 1, the output of the coder is 111. So the lower branch associated with node A in table 25 is marked as 111. The second bit is 0. We now diverge upward from node B. We see again from equation (6.4-2) that when the first two input bits are 10, the encoder output during this second input message bit interval is 010. So the upper branch diverging from node B is correspondingly marked 010. Following this procedure we find that the message 101010 indicates a downward divergence from node C to node D, an upward divergence from D to E, a downward divergence from E to F, an upward divergence from node F and from there out to the end of one of the branches of the tree. The path through the tree is shown by the dotted line. Reading in order, the bits encountered from entrance to exit of the tree, we can find the code given in equation (6.4-2) for the message 101010. In decoding process the message is reconstructed from the path taken through the code tree.

6.6. Discussion:

In this chapter an attempt has been made to develop digital coding schemes for Bengali messages considering the time amplitude pattern of the Bengali alphabets. It has been found that for an analog to digital converter the sampling rate should be 7 KHz and for Bengali language the Shanon's limit for a binary transmitter is 39097 bits/sec. As there are 48 alphabets, six bits are to be allocated for coding the individual alphabet. However for checking errors during transmission at least 4 redundancy bits are required to design an algebraic coding scheme. Alternatively if a convolution

coding scheme is adopted a stream of 30 bits are to be transmitted for each alphabet. A code tree for the purpose of convolution coding has been illustrated which will help in choosing a proper encoder and decoder for digital communication in Bengali language.

A CODE TREE FOR BENGALI MESSAGES



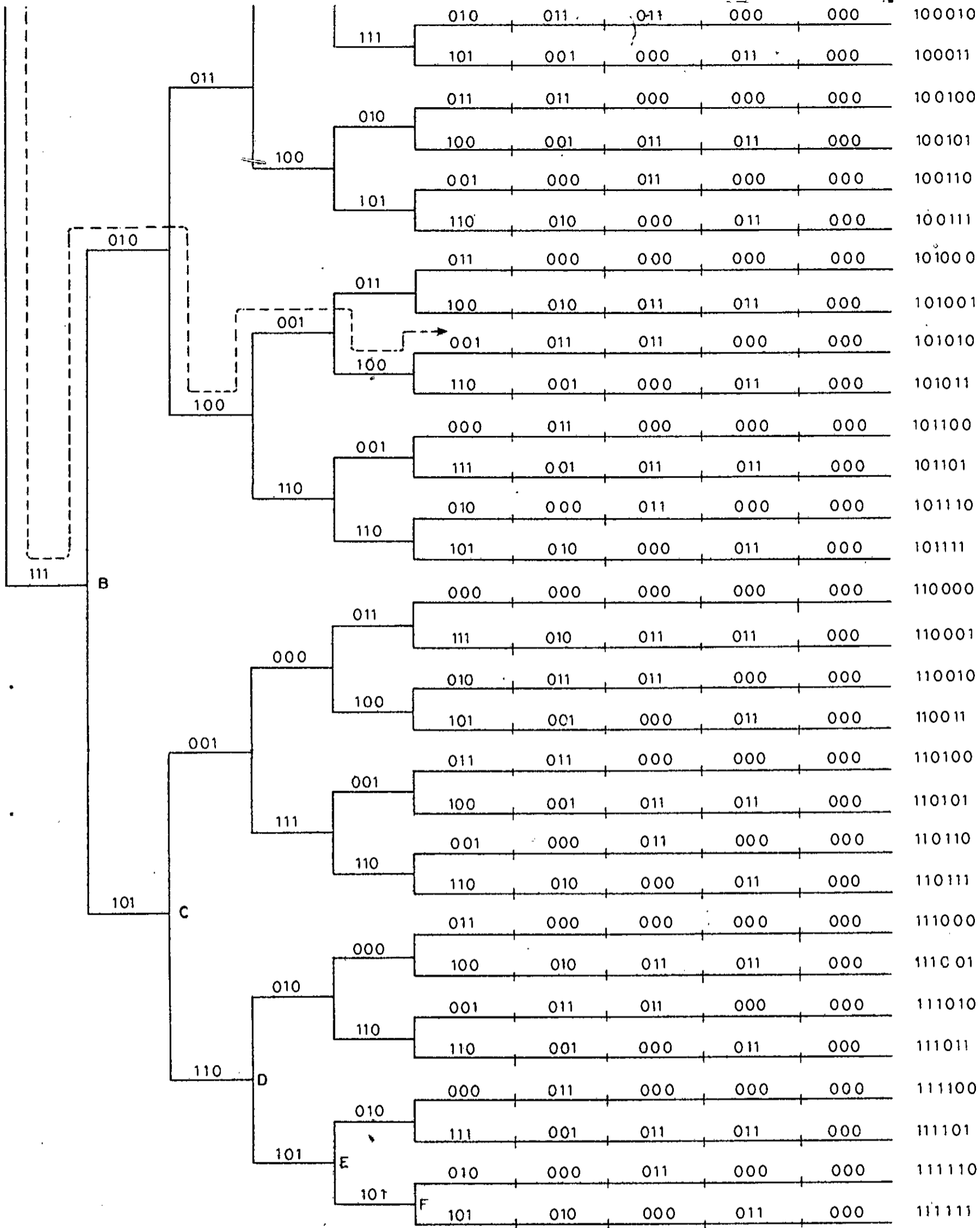


TABLE 25

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSION

7.1 Concluding Remarks.

A statistical analysis has been carried out on Bengali alphabet in voice signals recorded from twenty Bengali persons of different ages and profession. We have mostly chosen average standard educated speakers as informants. Most of the speakers possess a command over their own dialectal forms. But we have not tried to separate the **dialectal** features if any from their spoken discourse.

From the recorded data the electrical characteristics of the alphabet such as signal amplitude, duration and bandwidth were calculated for all the 48 letters (Vowels and Consonants) in Bengali language. Since the data varies from person to person a statistical average was made on amplitude, duration and the bandwidth for speech samples recorded from ten males and ten females. The data from male and female voices were processed separately. We have studied the letters uttered both individually and occurring in words. 39 words were selected for studying vowels and 94 words for consonants. There is a clear declination of both amplitude and duration of a letter used in words compared to its isolated utterance. The amplitudes and duration pattern was discussed from the phonetic point of view. From the time amplitude pattern of the signals their bandwidths were studied by the method of Gaussian spectrum

VJ

analysis. The bandwidth of an alphabet increases considerably in words in comparison with its bandwidth in individual pronunciation. The results of this statistical analysis are shown in tables 1 - 24. From the data of bandwidth analysis we can suggest that the bandwidth of a telephone channel which will pass the Bengali Voice Signals distinctly and smoothly should be 3.5 KHZ. Statistical determination of the signal pattern and the frequency bandwidth of Bengali alphabets enabled us to think over developing digital transmission schemes for Bengali messages. For this purpose an algebraic coding scheme incorporating 6 message bits and 4 redundant bits for Bengali messages has been suggested. Also a 6-bit Convolution Code Tree with 30 bit stream has been developed for coding and decoding of Bengali messages.

7.2 Suggestion for Future Works

The following works may be suggested for future research related to the present work:-

- (1) Synthesis of speech from analytical data by the method of prediction.
- (2) Artificial Voice generation from statistical speech signal pattern.
- (3) Vocal therapy by recognizing the signal pattern of fine and sweet voices.

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4. Mr. Syed Kamrul Islam
5. Mr. Motaharul Huq
6. Mr. Satya Prashad Majumder
7. Mr. Mujibur Rahman
8. Mr. A.K.M. Wahiduzzaman
9. Mr. Abdur Rahman
10. Mr. Syed Ziaul Huque

Female:

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2. Mrs. Zebunnessa
3. Miss Nasima Parveen
4. Mrs. Shahrin Khalek
5. Miss Wajiha Shirin
6. Mrs. Nilufar Begum
7. Miss Syeda Rownak Jahan
8. Miss Tanjima Rahman
9. Mrs. Sarah Tasneem
10. Mrs. Rumana Khan

