The Relation Between Fundamental Frequencies and The Resonant Frequencies of the Vocal Tract

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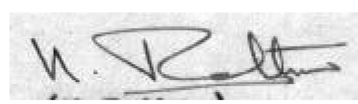
C E R T I F I C A T E

This is to certify that the dissertation "Relation between Fundamental Frequencies and the Resonant Frequencies of the Vocal Tract" is the bona fide work in part fulfillment for the Degree of M.Sc. (Speech and Hearing), carrying 100 marks, of the student with Register Number 17.



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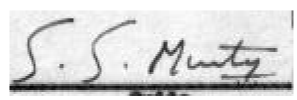
C E R T I F I C A T E

This is to certify that this dissertation has been prepared under my supervision and guidance.



Guide

DECLARATION

This dissertation is the result of my own study undertaken under the guidance of Sri S.S. Murthy, Head of the Department of Electronics, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

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CHAPTER I

INTRODUCTION

“Speech may be viewed as the unique method of communication evolved by man to suit the uniqueness of this mind. BY its great flexibility, it permits man to produce a variety of signals commensurate with the richness of his imagination. At the same time, the ability to think in terms of causality and purposiveness (time binding) enables man to expand enormously his use of reciprocal communication for the coordination of social activities.” (Eisenson, J., Auer, J.P., and Irwin, J.V., 1963). Speech is the acoustic end product of voluntary motions of the respiratory and masticatory apparatus.

One of gteh most important or most conspicuous characteri-stics of speech is the voice quality of the speaker. In normal voice production, the vocal organs are the lungs and traches, which act an bellows and windpipe, the larynx, a complex organ which forms the generator, and the vocal cavities, which form the resonator system driven by the glottis, generator in the larynx.

“The tone produced at the glottis is probably not loud enough to be heard very far away. This must be expressed as probability, because no one has been able to listen to vocal tones immediately on their release from the glottis, since no subject has been found who could phonate with his head cut off at that point. It is assumed that the vocal tone needs amplification because most sounds of musical instruments are quite weak without amplification. The process which amplifies and augments the intensity of the tone is called resonance.”

(Fisher, 1966; pp.89-90).

The tones which are initiated in the larynx are modified and reinforced or “built-up” in the structures beneath and above the vocal bands. The principal resonators are the cavities of the larynx, pharynx, mouth and nasal passages. Each of these principal resonators by virtue of its size, shape and tissue texture has special properties that enable it to make a unique contribution to the modification and reinforcement of the initial laryngeal tone and the production of the final or “finished” voice, that the listener hears.

If the vocal mechanism is considered to be the fundamental source for speech, then measurement of the acoustical signal which most directly reflects its properties, is of significance. The most fundamental functional data, about such a resonant system are the response frequencies. The frequencies of the peaks of the resonances approximate the natural response frequencies of the system. Scripture (1906), and more recently others (Fant, C.G.N., 1952; Huggins, W.H., 1950) have emphasized, that it is these peaks which are of primary interest in formant frequency evaluation.

Hence, study of the resonance characteristic of the vocal tract gains importance. In great part, resonance determines the final form of any speech sound. This holds good, whether the sound is produced as a result of the vibratory mechanism at the larynx, whether it be produced by the action of articulatory organs, or whether it is the combined product of phonation and articulation.

Ferkins, W.H. (1957) is of the opinion that phonation and respiration, without the help of resonance, even though possible, “would probably more closely resemble a squawk than a tone”. He states that the voice is “influenced mightly by resonator adjustment”. (p.843).

The vocal tract is an air filled tube and like all air filled tubes, acts as a resonator. This means that, the vocal tract has certain natural frequencies of vibration and that it responds more readily to a sound wave whose frequency is the same as its resonant frequency, than to a sound wave of another frequency.

The vocal cords produce a series of pulses. The spectrum of such a sound has a large number of components. All of them are more or less of the same amplitude and have frequencies that are whole-number multiples of the fundamental frequency. When such a wave is applied at one end of the vocal tract (at the glottis) and is transmitted towards the lips, the vocal tract responds better to those components of the vocal cored puffs, that are at or near its natural frequency. Those components will be emphasized and the spectrum of the sound emerging from the lips will “Peak” at the natural frequency of the vocal tract. The vocal tract has many natural frequencies. Therefore the vocal resonator will emphasize the harmonics of the vocal cord wave at number of different frequencies and the spectrum of the speech wave will have a peak for each of the vocal tract’s natural frequencies. The values of the natural frequencies of the vocal tract are determined by its shape; consequently, the amplitudes of the spectral components will peak at different frequencies. (Denes, P.B. & Pinson, E.M., 1963)

Resonances of the vocal tract are called formants and their frequencies, the formant frequencies. In general, the frequencies of the formants will not be the same as those of the harmonics, although they may coincide. The formant frequencies, are determined by the vocal tract, the harmonic frequencies by the vocal cords, and the vocal tract and vocal cords can move independently of each other.

The air column is set into vibration for a short duration with each discrete puff of air that is emitted by the vocal folds.

The rate at which the air column is driven into vibration, determines the pitch, while the frequency or frequencies at which the air column resonates, determines the quality of the tone.

All sounds, including those which are vocal, have four fundamental characteristics or attributes. These are loudness, pitch, quality and duration. The human voice is not limited to one given pitch, loudness, duration or even quality.

Fundamental frequency analysis or “Pitch extraction” (Janes Flanagan, 1972) is a problem nearly as old as speech analysis itself.

The fundamental frequency of voiced sounds, is an important feature of speech, conveying both linguistic and non-linguistic information.

It is accepted, that “each person in accordance with his unique physical vocal equipment, has a pitch level at which the greatest power and best resonance occur under the conditions of greatest physioacoustic economy. This pitch level is known as the optima or natural pitch.” (Murphy, 1964, p.44).

It has been claimed by many authors (West, R. et al (1968), Fairbanks (1940), Gray and Wise (1959), there is a pitch level at which there is relatively high potential for the resonances of the of the laryngeal tone and where there is the greatest efficiency. Then the locating of this pitch or frequency objectively will be of great importance. This was attempted by Nataraja (1972), where an objective method for locating optimum pitch was deviced. The study aimed at finding “the frequency of the vocal cords at which resonance (increased intensity of voice measured in terms of SPL occurs in the vocal tract of a particular individual”. The frequency at which maximum increase, occurs is the natural frequency of the vocal tract.

Here it could be possible, that, one of the harmonies of the fundamental frequency is the natural frequency of the vocal tract, or it could be, that, near the harmonics there is resonance.

Vocal tract is not a simple resonator. Resonances of the vocal tract are called formant frequencies. Thus the question here is whether the natural frequency of the vocal tract (measured is terms of SPL as mentioned above) is a formant and if so which formant. In some vowels like /a/ formant 1 and formant 2 are quite close to each other – in this case we should be able to get two peaks close together.

Thus, the present study was undertaken to find out the relation between natural frequency of the vocal tract as measured in Nataraja’s study and the formant frequencies.

With the change in fundamental frequencies, there is no change in formant frequencies. Another experiment was conducted to find out the relationship between fundamental frequencies and formant frequencies.

Statement of the problem

1) The problem was to measure the natural frequencies of the vocal tract (formants) and to find the correlation between the formants and the frequency at which the maximum increase in the intensity occurs.

2) To find out whether the formant frequencies are independent of the fundamental frequency when the same individual phonates a vowel at different pitches.

Method and Results

The method employed in the study to locate the natural frequency of the vocal tract was as used by Nataraja (1972). The procedure is mentioned in “Methodology”.

This experiment was followed by the recording of the phonation of the vowel /a/ by the subject. This recording was fed to the Sonograph and analysis of formant frequencies and fundamental frequency for the vowel /a/ was done.

In the second experiment subjects were asked to phonate vowels /a/ and /i/ each at three fundamental frequencies 110 Hz, 160 Hz, and 200 Hz for 5 secs. and recording was done. The fundamental frequencies were controlled by asking the subject to match the tones of 110 Hz, 160 Hz and 200 Hz respectively from the Bekesy audiometer. This recording was fed to the Sonograph and again the analysis of formant frequencies was done. Fundamental frequencies were analyzed to have recheck on subject's matching of the tone from Bekesy audiometer.

Limitaions

1) All limitations mentioned in Nataraja's study (1972).

2) Females could not be included to test the relationship between formants and fundamentals as at higher fundamental frequencies spectrograph shows harmonic pattern.

3) Subjects taken for the Experiment 2 could not be tested for the natural frequency of the vocal tract due to practical difficulties.

Hypothesis

1) Natural frequency of the vocal tract is a formant.

2) The formant frequencies are independent of the fundamental frequencies.

Implications

1) It provides information about the natural frequency of the vocal tract, measured in terms of increased intensity and formant frequencies.

2) It provides information about the fundamental freque - ncy measured by Stroboscope technique and Sonograph.

3) Information about the formant frequencies and fundamental frequency.

Definitions

The following definitions are used in the present study.

Natural Frequency of the Vocal Tract

The vocal tract, considered as a tube or cavity, responds more readily to a sound wave whose frequency is the same as its resonant frequency, than to a sound wave of another frequency, This frequency of maximum response is called the natural frequency of the vocal tract.

Fundamental Frequency of Voice

The concept of fundamental frequency as used and measured in the present study is the direct reading obtained from the Tacho Unit in combination with the SPL meter, Octave filter and the Stroboscope and also found from spectrograph using the required formula.

Formant Frerquencies

We can simply and accurately measure the formant frequency as the center of the formant band of a wide-band-spectrogram.

CHAPTER II

REVIEW OF LITERATURE

"Human speech, or the 'phonic substance' in which linguistic forms are manifested is a complex process." (Fry, D.B., 1970). One of the most important or most conspicuous characteristics of speech is the voice quality of the speaker. The normal range of voice qualities is immense. The quality of voice depends on the patterning of the over tones and their intensities. The differing sizes and shapes of many resonating cavites within different human heads contribute to the uniqueness which permits us to identify each other by listening to these tones.

The pitch is another important characteristic of speech. For every voice, there is a general pitch level known as optimum pitch, at which the voice will be found to be most comfortable or most effective. This level will vary, from person to person and each person will find it easily possible to make a considerable number of variation from this general level.

Information or inflection are two other characteristics of speech which go hand in hand with pitch. Inflection, is the shift in pitch during the utterance of a syllable.

Loudness or intensity is another aspect of speech. Loudness is the psychological correlate of intensity. Loudness depends on many factors, but the important factors which determine loudness, are intensity and frequency of the sound.

“These is a relation between the physical properties of the speech, sound waves and the linguistic and psychological consequences of prosodic features. Prosodic features are organized in each language into a system of functional units and these functional units are recognized or decoded through the medium of perceptual impressions. These impressions are themselves the results of the physical stimuli which arrive at the ear of the listener. In the case of complex tones, the only kind that occur in speech, the principal correlate of pitch is the fundamental frequency of the periodic sound, that is to say the lowest frequency in the complex wave and in the case of voiced speech sounds this corresponds to the frequency of vibration of the vocal cords.” (Fry, D.B., 1970).

Fundamental pitch and fundamental frequency, are not synonymous, but these terms can often be used interchangeably due to the close one to one correspondence. In more strict terminology, pitch is a tonal sensation and frequency a property of the sound stimulus. (Fant, C.G.M., 1960).

“Fundamental to many procedures employed in vocal retraining, is the belief that for each person, there is an optimum or natural pitch level at which an human vocal apparatus operates with the greatest efficiency.” (Thurman, 1958).

Various clinical techniques have been described for locating the optimum pitch level, prominent among which is the procedure of having the subject hum or sing scales to determine the level of tone or closely grouped series of tones at which, vocalization is produced ‘most efficiently’. In the most commonly recommended procedure, the client is instructed to hum up and down his total pitch range and the clinician or the client himself listens to the performance and identifies the tone or series of tones in which an involuntary swell f intensity occurs. This is taken to be an indication of the region of highest operating efficiency for his voice or the ‘optimum’ pitch level.

Wentworth (1940) found that there were eight different ways of finding the optimum pitch: (i) Finding the pitch at which increase in loudness occurs on the musical scale; (ii) Finding the note one-third up from the basal tone; (iii) Finding the note five tones up from the basal tone; (iv) Finding the note at which the speaker experience the greatest case; (v) Humming the scale and locating the loudest note; (vi) Considering the pitch at which the person coughs and laughs; (vii) Pronovost (1942) located median pitch levels in six superior male voices and found that they approximated a level that was about one-fourth of the total range; and (viii) Linke in a similar study of female voices, found, that the median pitch levels comprising one-fifth of the total pitch range.

These are some of the methods of locating optimum pitch. Clinically, subjective judgment is used to identify the optimum pitch. Hence, an attempt at an objective method of locating optimum pitch was done by Nataraja (1972).

His hypothesis was, that it would be possible to stimulate the vocal tract, with an external sound source and at the natural frequency of the vocal tract there would be resonance.

In the experiment the following instrument were used. Audio frequency analyzer to measure intensity. Audio frequency generator to give the tone with variable frequency. A miniature speaker and a condenser microphone were fixed to an acoustic tile so as to be at the same surface. The subjects were asked to keep their mouths in central vowel /a/ position and the speaker and microphone were kept close to their mouth opening. The notes of different frequencies ranging from 100 Hz to 5 KHz (natural frequency range of vocal tract) was given and the increase in output intensity was noted. It was found, that there were discriminative peaks for all the individuals at different frequencies. The experiment was repeated with good speakers and their fundamental frequencies were measured using Stroboscope, (It was presumed that they were using their optimum pitch.) A definite and consistent relationship of 8:1 was found between the optimum frequency and the natural frequency of the vocal tract.

What is the role of vocal tract in the production of voice?

Catford, J.C. (1970) states that the human vocal tract may be described as an apparatus for the conversion of muscular energy into acoustic energy. This process is carried out by means of two functionally distinct types of sound productive activities of the vocal organs; these are, on the one hand, bellow-like or piston-like movements which set the air in the vocal tract in motion, and on the other hand, valve-like postures or movements which regulate the flow of air and in so doing, generate sound-waves, or, in some cases, simply modulate sound-waves generated by other activities. For these two basic activities, term initiation and regulation have been used. Two varieties of latter activity are distingshable. Phonation and articulation.

Initiation is a bellow-like or piston-like movement of an organ or organ-group (an initiator) which causes a pressure change in an adjacent part of the vocal tract and consequently initiates a flow of air.

Phonation covers all regulatory activities occurring in the larynx; it thus includes such features as ‘breath; or ‘voicelessness’, voice, voice qualities. It excludes those laryngeal activities (glottal closure and vertical displacement of the larynx) which have an initiatory function in the production of glottalic sounds.

The buss-like sound produced by the vocal cords, is applied to the vocal tract. The vocal tract, is in effect, an air filled tuber and like all air filled tubes, acts as a resonator.

Resonance Principle:-_ When a periodic force is applied to an elastic system, the system will tend to vibrate with the frequency of the applied force, the nearer the periodic force is to the natural frequency of the elastic system, the greater will be the resulting amplitude of vibration. A Vibrating tuning fork held in the hand will give a barely audible tone. But, if it is held over the open end of a tube of proper length or over the mouth of a jar or bottle of the right size, the resulting tone will be quite strong and can be heard for some distance. The tube or the bottle is a resonator.

A resonator does not add energy, it merely permits the energy of the vibrator to be used up more rapidly. The reason why the presence of a resonator reduces the duration of vibration, is obvious. when a vibrator or any other source of energy, acts upon a mass so that an acceleration in the mass results, the vibrator itself is doing “work” and is using up energy, The greater the mass or the greater the acceleration, the more reapidly the energy is used up. Hence, a free vibrator with a resonator will vibrate for a shorter time than will one without a ersonator. (Gray and Wise, 1959).

The vocal tract, considered as a tube or cavity, has certain natural frequencies of vibration, and hence responds more readily to a sound wave whose frequency is the same as its resonant frequency, than to a sound wave of another frequency.

Considering that the vocal cords produce a series of pulses, the spectrum of such a sound has a large number of components all of them are more or less of the same amplitude and have frequencies that are whole number multiples of the fundamental frequency. When such a wave is applied at one end of the vocal tract (at the glottis) and is transmitted towards the lips, the vocal tract responds better to those components of the vocal cord puffs, that are at or near its natural frequency. These components will be emphasized and spectrum of the sound emerging from the lips will “Peak” at the natural frequencies of the vocal tract.

Gordon Peterson (1959) says that the parameters which may have basic importance in such a system are the fundamental driving frequency (and the input spectrum) of the generator and the frequency damping constants, and relative amplitudes of the resonances. Other parameters, such as anti resonance frequency may become important when the system is made more complicated an by the addition of the nasal passage ways in vowel formation.

Gray and Wise (1959) state, that the principal resonator of the human voice is the pharynx o throat which is of a given size for each individual and is subject to only small adjustment in size to retain a balance in muscular tensions. Hence, it is evident, that the individual's average vocal pitch should be chosen at the frequency level at which the pharyngeal cavity can resonate with maximum efficiency or without undue tensions in the muscles governing its size.

The timbre and quality of the voice are determined not only by the vibrations of the vocal bands, but also by the size of the air column, by its shape, by the coupling of two or more cavities of different sizes and shapes and by the texture of the pharyngeal walls. Tense rigid walls will emphasize the higher frequencies to "come out", thus contributing to depth and richness. Excessive laxity may result in heavy, dull muffled tones.

"The spoken utterance is an impact on the atmosphere, very short in duration and on a very small scale, in which the component sounds die away at different distances depending on their inherent energy…………. But these vibrations are of the utmost complexity. Acoustic analysis resolves this tortuous oscillations in a three-dimensional framework of frequency, intensity and time, in which each sound is characterized by a typical display of energy in various frequency regions along the unlimited time axis.” (Lotz, J…… 1961). This method of isolating and determining the essential characteristics, of the constituents in a complex tone is called harmonic analysis. “The Sound Spectrograph was the first truly dynamic device developed for the analysis of speech.” (Peterson, 1954).

The Formant:- The significant aspect of the Spectrograph is that it produces a readily usable graph of the “frequency bands which characteristically contain centroids of energy”, of which Block wrote, and to which has been given the designation of formants. The formant, in other words, consists of “two (Some-times three, seldom one) frequency regions of prominence in the speech sound as observed in the outside air. The frequency location of these regions of accentuated intensity, known as formants, is an important characteristic lending individuality to the various periodic sounds”. (Fletcher, 1953).

Zinkin (1968) states that the unit of measurement of the static elements of speech in the sound spectrum. “The spectrum envelop is defined as the curve drawn to enclose smoothly the contour of the intensity versus frequency section of the spectrum ignoring the fine structure, i.e., the individual harmonics, but preserving the individual formant pattern". (Fant, G.C.M., 1966). If the number of oscillations of each of the frequencies is a multiple of the lowest frequency, the spectrum forms a harmonic series, its component frequencies are called harmonics and the spectrum itself is limited or selective in character. This kind of spectrum is characteristic of vowels.

There is an optimal time and certain conditions for the formation of a speech sound under which its spectrum will retain the characteristic features recognized by hearing receiving the given quality of the sound as always identical. Such characteristic features of the spectrum are called the formants of speech sound.

Fant, G.C.M. (1964) says that a formant is not identical with any specific harmonic and the formant frequency is, therefore, not identical with the frequency of a specific harmonic. for practical purposes, dealing with male voices, we can simply and accurately measure the formant frequency as the center of the formant band of a wide band spectrogram. In case of high fundamental pitch, the formants will be poorly defined in a harmonic spectrum and the so called broad-band filter of the Sonograph will

Portray harmonics and not formants in these instance.

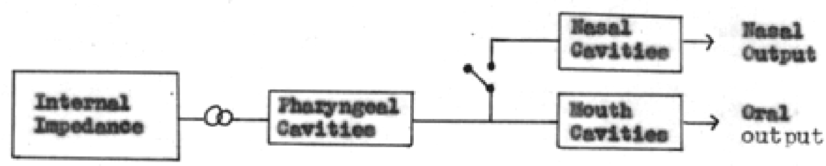
The presence of these formants apparently arises from the peculiar characteristics of the resonating system in the throat and mouth. The vocal tract may be thought of as “a series of cylindrical sections, with acoustical mass and compliance uniformly distributed along cach section”. (Dunn H.K., 1950). Together with connecting tubes, those sections form a coupled system which receives the energy supplied from the action of the vocal cords.

The vocal bands themselves serve to modulate the outgoing stream of air, referred to by Fletcher as direct current or d-c, by superimposing upon it a vibrating or fluctuating current, designated as an alternating current. This alternating current, or a-c, has frequencies ranging, with fundamental and harmonics, from approximately 80 cps to 8000 cps or more. “It is the ability of the (Vocal) cavities selectively to reinforce various groups of harmonics (formants) cavities selectively to reinforce various groups of harmonics (formants) at will, that enables one to produce various speech sounds.” (Fletcher, 1953).

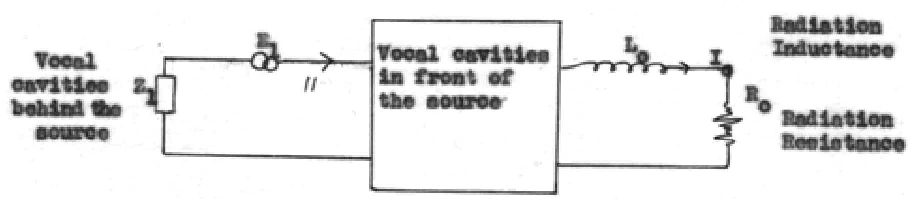
“It is the existence in the vocal tract of two major resonating cavites (throat and mouth). together with the narrow passages connecting them with each other and with the external air, that produces the ‘frequency regions of prominence’ in the speech sounds, and differentiates them one from another." (Gray and Wise, 1959).

Acoustically, the speech wave is the response of the vocal tract filter systems to one or more sound sources – this, expressed in terms of acoustics and electrical engineering, implies that the speech wave may be uniquely specified in terms of source and filter characteristics.

Speech production as filtering process



Schematic representation of the production of sounds employing a glottal source



Four terminal network representation of the production of any non-nasal sound irrespective of the source location

The complete filter function, referred to as transfer function is defined as the frequency dependent ratio of the pressure in the sound field at a specified point in front of the speaker to the pressure of the sound source or its volume velocity.

With the symbolic notations of S for source and T for the transfer function of the vocal tract filter, the product P = S.T represents the corresponding speech sound.

There is some degree of correspondence between the phonetic term phonation and the technical term source and similarly between articulation and fiter. A voice source is further characterized by its spectrum envelope S(f) which is a specification of the amplitudes of the source harmonics as a function of their frequency.

The glottis represents a high impedance termination of the vocal tract, and it is thus possible and convenient to define the voice source by the pulsating air flow through the glottis. The frequency selective transfer characteristics are introduced by the process of multiplying the amplitude of each harmonic /S(f)/ of the source spectrum by the value of the appropriate gain factor /T/(f)/ of the filter function at the frequency f,

$$/P(f)/ = /8(f)/ \quad /T(f)/$$

The phase of each harmonic is the sum of the phase of the corresponding source harmonic and the phase of the filter function

$$QP(f) = Qs(f)\ Qt(f)$$

The spectral peaks of the sound spectrum /P(f)/ are called formants. The frequency location of a maximum in /T/(f)/ i.e., the resonance frequency is very close to the corresponding maximum in spectrum P(f) of the complete sound. Conceptually, these should be held apart but in most instances resonance frequency and formant frequency may be used synonymously. (Fant, G.C.M., 1960).

Fant, G.C.M., has talked about the significance of cavity wall vibrations as a factor determining formant frequencies. At the frequency of a formant, there is always a pressure minimum an velocity maximum at the lips and a pressure maximum and velocity minimum at the glottis. At the frequency of the first formant, the standing wave pattern occupies ¼ of a full wave length and ¾ and ??? wave length of F_2 and F_3 respectively.

Role of cavity walls was initially suggested by Van den Berg. Fant, G.C.M., (1964) elaborated the theme that in sound with a very low F_1, there is substantial energy loss from sound transmission through the walls of the vocal tract, wherever these walls are thin enough to allow vibration to be set up.

The basic principle of the theory of voiced sounds is that, to a first order of approximation, the filter function is independent of the source. The formant peak will thus only accidentally coincide with the frequency of a harmonic. The formant frequencies can change only as a result of an articulatory change affecting the dimensions of the various parts of the vocal tract cavity system and thus the filter function.

In a study by Lindblons Sundberg (1971) on acoustical consequences of lip, tongue, jaw and larynx movements, he says with all other parameters kept constant, jaw movement alone was found to cause shifts in F_1 of Several hundred cycles per second. Second point noted was: changing the location of the tongue body downward along the tract can be an extremely effective means of lowering F_2 and contributes towards raising F_1 somewhat. An increase in the degree of constriction modifies primarily F_2.

The formant amplitudes are based on the amplitudes of the first formant of the vowel / / which has the highest phonetic power of all the vowels.

“The ratios of pitch among the formants measured in mels appear to be fairly constant over the range of speakers including men, women and children. Within limits, the ratios tend to characterize certain groups of vowels.” (Peterson and Branay, 1952).

In addition to the possible reference to the mouth as front cavity and to the pharynx as back cavity, there exists the possibility of dividing tract with reference to the sound source. An alternative division, in the case of vowels as subdivision, is in terms of the narrowest passage in the vocal tract. It should be observed that the point of articulation of vowels, when defined by the highest point of the tongue, may come far from the place of maximum narrowing, the latter constituting the acoustically relevant basis for a back cavity versus front cavity division. This discrepancy is apparent for back vowels. In the case of very open vowels, the division of the cavity system above the larynx into separate parts, lose some of its significance. The more open a vowel is, the less will the separate parts of the vocal cavities act as independent resonators.

It is generally proposed that the first formant is associated with the resonance of the back cavity and second formant with the resonance of the front cavity. There is limitation of this rule.

As a general rule, vowels are sufficiently specified by their F-patterns. “F-Pattern (F1, F2, F3………….) is simply the formant frequencies with specific restrictions needed for nasal coupling. More generally, the F-pattern is the set of resonance frequencies of the vocal tract.” (Fant, G.C.M., 1960).

F-pattern is independent of the location of source, whether glottal or in the vicinity of the artioulatory constriction, but the presence of a glottal source i.e. of voicing, emphasizes the F-patterns markedly. The average distance between two adjacent frequencies of the F-pattern of a male speaker is 1000 cps. which is inversely proportional to the length of the vocal tract and in general c/22, where ‘c’ is the velocity of sound (35,300 cm/sec.) and ‘1’ is the total length of the vocal tract from the glottis to the lips. Females have on the average about 15 per cent shorter vocal tracts and thus 15 per cent higher formant frequencies and 15 per cent larger formant frequency spacing than men.

“The most simple rule governing the relations between vocal tract configurations and F-patterns, is that, if a homogeneous tube is constricted at a place where one of its formants has a velocity minimum, there will follow an increase of the formant frequency whereas, a constriction at a place of velocity maximum results in a decrease of the formant frequency.” (Fant, G.C.M., 1964).

In the case of vowels there is for practical purposes, identity between the formant frequency and resonance frequencies. A shift down in F_1 (articulatory conditioned by a greater closure)is associated with a shift down in intensity of the entire spectrum envelop above F_1 by an amount of 12 dB per octave F_1 shift. When the two formants approaches, both increase in intensity. This rule applies to the difference between front and back vowels i.e. between vowels of high and low F_2 positions.

The normal range of variation of the formant frequencies of a male speaker taking into account all possible sounds, is as follows:

F_1 = 150 – 850 cps

F_2 = 500 – 2,500 cps

F_3 = 1,500 – 3,500 cps

F_4 = 2,500 – 4,500 cps

The frequency of the first formant F_1 is maximally low when the front part of the mouth is constricted and maximally high if the mouth is open and the mid and bottom parts of the pharynx are constricted by a tongue retraction. The second formant frequency F_2 is maximally low and close to F_1 in the case of a pharyngeal articulation and F_2 is maximally high and close to F_3 in the case of a midpalatal articulation. The effect of labialization i.e. lip rounding or lip protrusion, on the F-pattern is, to lower all formant frequencies to a smaller or greater degree, depending on the tongue articulation. For the prepalatal, high tongue position is lowered or the place of articulation is more retracted the effect will be greater on F_2. In the case of a pharyngeal or velar articulation the influence of labialization may be greatest on F_1.

In the case of the vowel /1/, the second formant is thus more dependent on the pharynx than on the mouth cavity and the physical origin becomes a half wavelength resonance of the back cavity (of frequency $c/2I_p$ where 'I_p' is the back cavity length). The degree of opening at the tongue constriction and the amount of lip rounding are thus not very crucial determinants of F_2 of /i/.

The above description shown that F_1, F_2, F_3 . . . . . . .depend on articulatory pattern. Thus different vowels have different articulatory patterns and depending on it, they will have F_1 ,F_2, F_3. . . . . . . patterns.

In a study of vowels by Fant, C.G.M., (1960) it is shown, how different vowels and their formants are determined. Thus F_1 of the vowels /e/, /i/ and / / is almost completely determined by the back cavity volume and the narrowest section of the mouth cavity. In the vowel /u/ F_1 is tuned by the lip section much more than by the tongue constriction section.

The second formant F_2 of /i/ is clearly a half wavelength vowels /u/, /o/ and /a/ is somewhat more dependant on the front Cavity than on the back cavity. The second formant of the back vowels /u/, /o/ and /a/ is somewhat more dependant on the front cavity than on the back cavity. Providing the cavity volume changes are introduced on a constant percentage basis, this tendency is apparent, but if the volume changes are performed by means of a constant length reduction, there is found an equal dependency of F_2 on the two cavities for /u/ and also for /a/.

In the case of /u/, F_2 is dependant much more on the relative dimensions of the tongue pass than on the lip section. These two parts of the compound resonator system have about the same effect on F_2 of both /a/ and /o/.

The third formant F_3 of /u/, /o/ and /a/, is chiefly dependant on the parts in front of the tongue constriction. This is also true of F_3 of /i/. F_3 of /i/ is essentially a quarter wavelength resonance on each side of the tongue constriction, which can also be interpreted as a half wavelength resonance of the tongue passage plus front cavity. F_3 of /u/ is a half wavelength resonance of the front cavity. In /a/ and /o/, F_3 is associated with a three quarter wavelength resonance of the cavity system in front of the tongue constriction.

The appreciable shift of F_1 of /a/ caused by a shortening of the front cavity length is shown and is attributed to the fact that the removed section had a function more like on inductance than like a capacitance. This effect should be compared with the change in resonance frequency of a single tube closed at one end. A small area change in the middle of the tube has no effect on the resonance frequency. An area increase at the closed end has a maximal lowering effect on the resonance frequency and a similar operation at the open end has maximal increasing effect.

In conclusion, Fant, G.C.M., (1960) says that double resonator theory should be used with great caution, and it is not possible to utilize this or any other theory for developing formulas for cavity formant relations which satisfy the requirements of both simplicity and general validity.

Potter and steinberg (1950) have charted the movements of the formants for the different sounds both for a single speaker and for twentyfive different speakers. Using a fundamental frequency of approximately 125 cps throughout, the single speaker showed for /i/, a first formant of about 250 cps, a second 2,250 cps and a third of somewhere near 2,800 cps. For /I/ the first rises to 400 cps, second drops to 2000 cp and third to 2500 cps. The formants of /a/ are close to 750 cps, 1,100 cps and 2,000 cps and those for /u/ are about 250 cps, 800 cps and 2,250 cps respectively.

The formants of the spectrum may differ in their signal meaning. Besides speech formants proper, which serve to distinguish the elements of the sound make up of words, one can also single out individual formants of voice which characterize the voice of a given person. These formants identify the speech source.

The signal meaning of the voice formant is sharply distinct from that of the speech formant proper. The Speech formant is established by the conventional norm of the given language and serves as a means of differentiating meaningful words; the voice formant is determined by the arrangement of the speech apparatus of the given person and ahs no significance in the differentiat -ion of the sound make up of words, provided all the sounds are correctly articulated. It serves as a means of recognizing people by their voice. The voice formant is a feature of recognition, the speech formant, a signal of the differentiation of the sound elements of a word, the latter being a sign of objective relationships.

Besides the two indicated types of formants, there exists a third type – specially developed formants. In the studies of Rsovkin, S.N. (1928) a special singer’s formant was found. It is formed when the organs of phonation are in a certain position. This proposition was recently well confirmed by the x-ray

Investigation of Dimtriev, L.B. (1955) who showed that in singing, those differences in the volume of the resonators which are characteristic of speech are considerably leveled out, as a result of which the special singer's formant appears. This specially developed formant is a sign of a cultivated voice and is determined by the conditions of its training.

In conclusion, the vibrating column of air in the vocal tract, must be analyzed as a homogeneous structure. For each resonance frequency of the whole column (vocal tract) there exists a specific function which is equal to the vibration of the local sound pressure movement. The resonance frequencies are not determined by the partial volumes of the vocal tract, but rather by its cross section. Each resonance frequency of the entire vocal tract creates a formant within the vowel spectrum. (Berlin, 1965).

However, at the natural frequency of the vocal tract, there is resonance (Nataraja, 1972) and thus, follows, that it should be a formant.

Acoustic theory of vowel production considers a vowel sound to be the result of excitation of a linear acoustic system by a quasi-periodic volume velocity source. The transfer function of the acoustic system is completely described by a number of poles whose frequency locations depend on the vocal tract configurat - ion.

In the light of the above review we can come back to our discussion on the objective method of locating the optimum pitch.

In the method, the natural frequency of the vocal tract is found by means of exciting the vocal tract by a pure tone (when it is in central vowel /a/ position) and taking the reflected energy the point at which resonance occurs (maximum increase in the intensity), is the natural frequency of the vocal tract.

The present study seeks information about the F-pattern of the central vowel /a/ and thus to incorporate the natural frequency of the vocal tract found in the above mentioned study with formants.

At the natural frequency of the vocal tract there will be resonance and hence there will be concentration of the energy at that particular frequency range. The definition of a formant also says that there will be concentration of energy at formant frequencies. So, the present study is planned to find out whether the natural frequency is a formant.

Even though there is change in fundamental frequency, the sounds will be identified as same vowels. Another experiment was conducted to see whether there will be any change in formant frequencies with change in fundamental frequencies.

CHAPTER III

METHODOLOGY

Experiment No.1

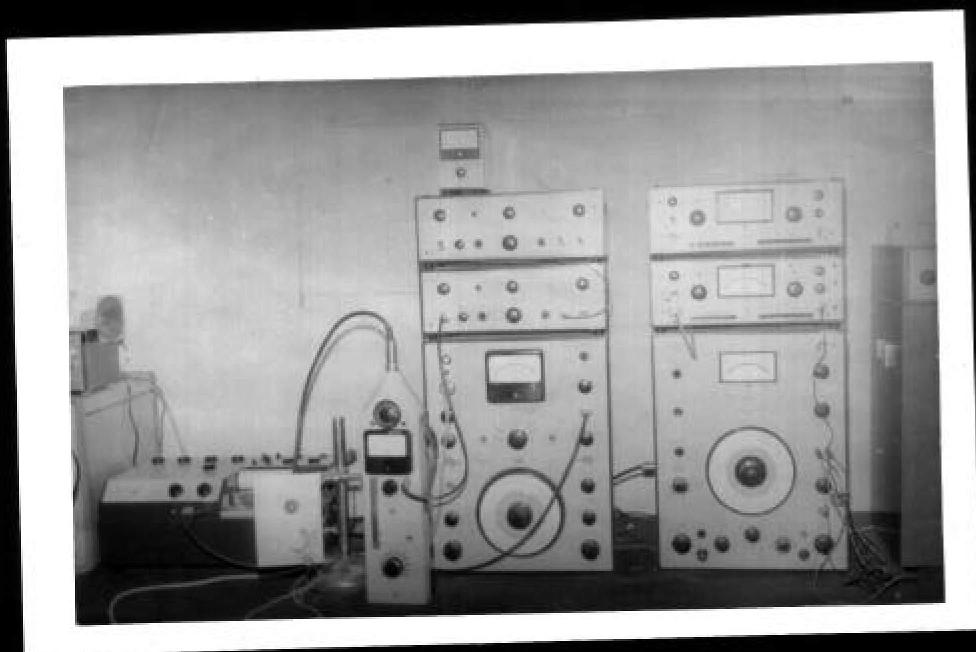
Experiment No.1 consists of 3 parts.

Part A:- Finding out the natural frequency of the vocal tract for males between the age ranged from 16 to 25 years.

Subjects: 30 male students of the Institute who were having good voices (as judged by trained speech therapists) were selected for the study. The subjects were free from auditory and speech problems. Further, they were also examined for any oropharyngeal deformities.

Instruments used in the Experiment No.1

1) Beat Frequency Oscillator (B & K type 1022)
2) Measuring Amplifier (B & K type 2647)
3) Hearing Aid Test Box (B & K type 4217)
4) Audio Frequency Analyzer (B & K type 2107)
5) Level Recorder (B & K type 2305)
6) Two, One-Inch Condensor Microphones (B & K type 4131)
7) Two Miniature speakers (Earphones made by Oticon Code No. s8-21)



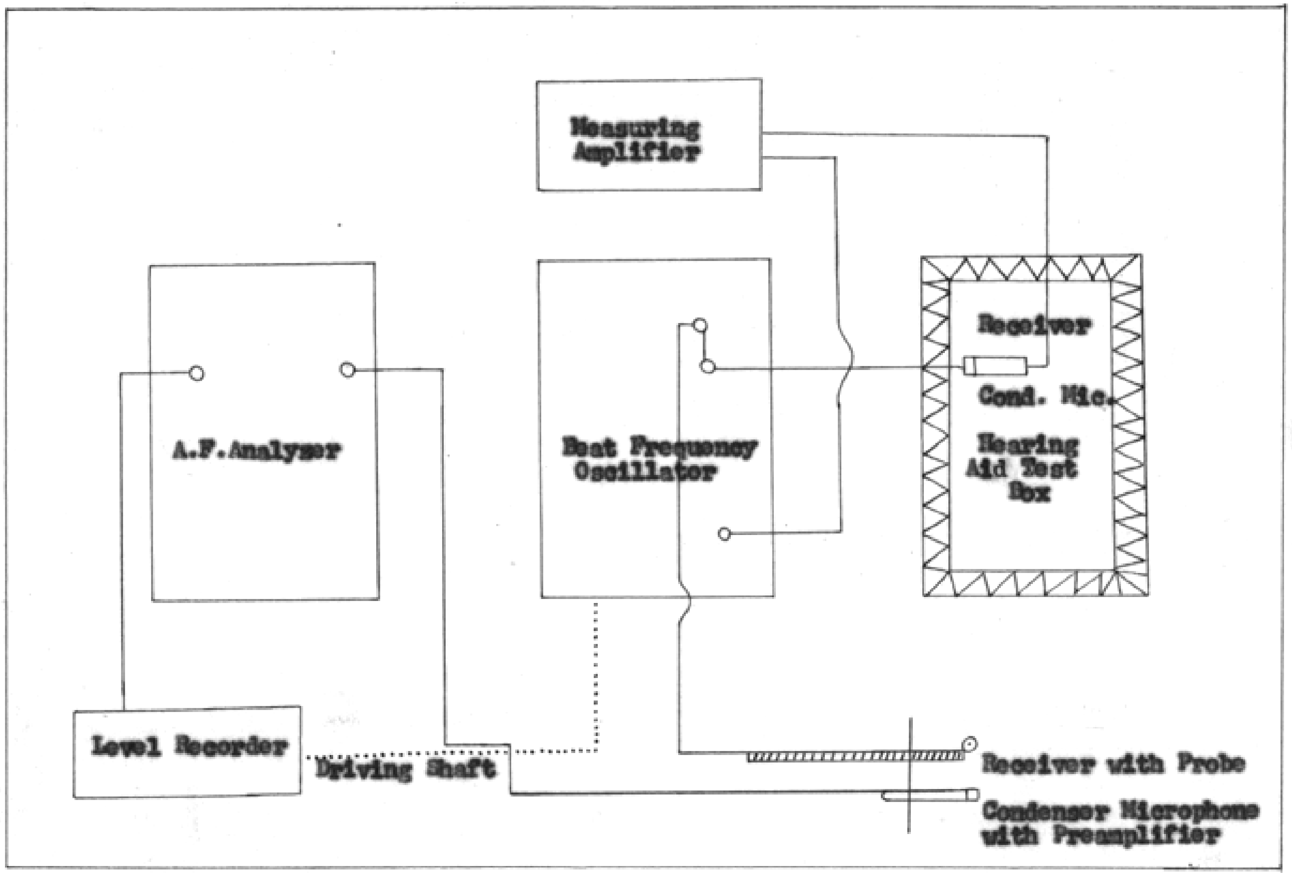
Photograph of the equipment used to determine the natural frequency of the vocal tract and the fundamental frequency by the Stroboscopic technique

The instruments were connected as shown in the Block Diagram No. I.

Desired frequency range for the study ranging from 100 Hz to 5 KHz were generated by the Beat Frequency oscillator. This was mechanically coupled to the level recorder by means of a flexible shaft which made it possible to scan the required frequencies automatically. The output of the Beat Frequency Oscillator was fed to the miniature speaker which was used for the study. To obtain a constant acoustical output-from this miniature speaker- a compressor voltage was provided by using another miniature speaker connected in parallel to the above miniature speaker, and this receiver was coupled to a condensor microphone connected to a measuring amplifier. To avoid the external noise, the above miniature speaker with coupler and condensor microphone were placed inside the Hearing Aid Test Box. The output of the measuring amplifier was fed to the Beat Frequency Oscillator as compressor voltage.

The miniature speaker and the condensor microphone were fixed to a stand. The response of the vocal tract was picked up by the condensor microphone of the audio frequency analyzer. The output of the audio frequency analyzer was fed to the level recorded which gave a graphical representation in terms of frequency versus intensity changes, over the scanned frequency range.

Block diagram showing the schematic arrangement of the equipment for the measurement of the Resonance of Vocal Tract



<u>Calibration of the Instuments</u>

1) The Audio Frequency Analyzer was calibrated using its own self calibration system. It is reachecked by using Pistonphone (B & K type 2240). The accuracy of calibration was 0.2 dB and distortion was less than 3 per cent.

2) The Beat Frequency Oscillator was calibrated with its self calibration system. It is rechecked by using the Audio Frequency Analyzer.

<u>Test Room</u>

The study was carried out at the Electroacoustics Room of the Electronics Laboratory in the Institute. The noise level of the room was measured by means of the SPL meter. The maximum noise level during the experiment was 43 dB on ‘c’ scale.

<u>Validating the experimental set up</u>

Using a known resonator, the instrumental set up was validated. Frequencies ranging from 100 Hz to 5 KHz were Scanned automatically by the Beat Frequency oscillator, and were introduced into the known resonator, (Kundt’s tube). Increase in intensity due to resonance was noted at the resonance frequency of the Kundt's tube.

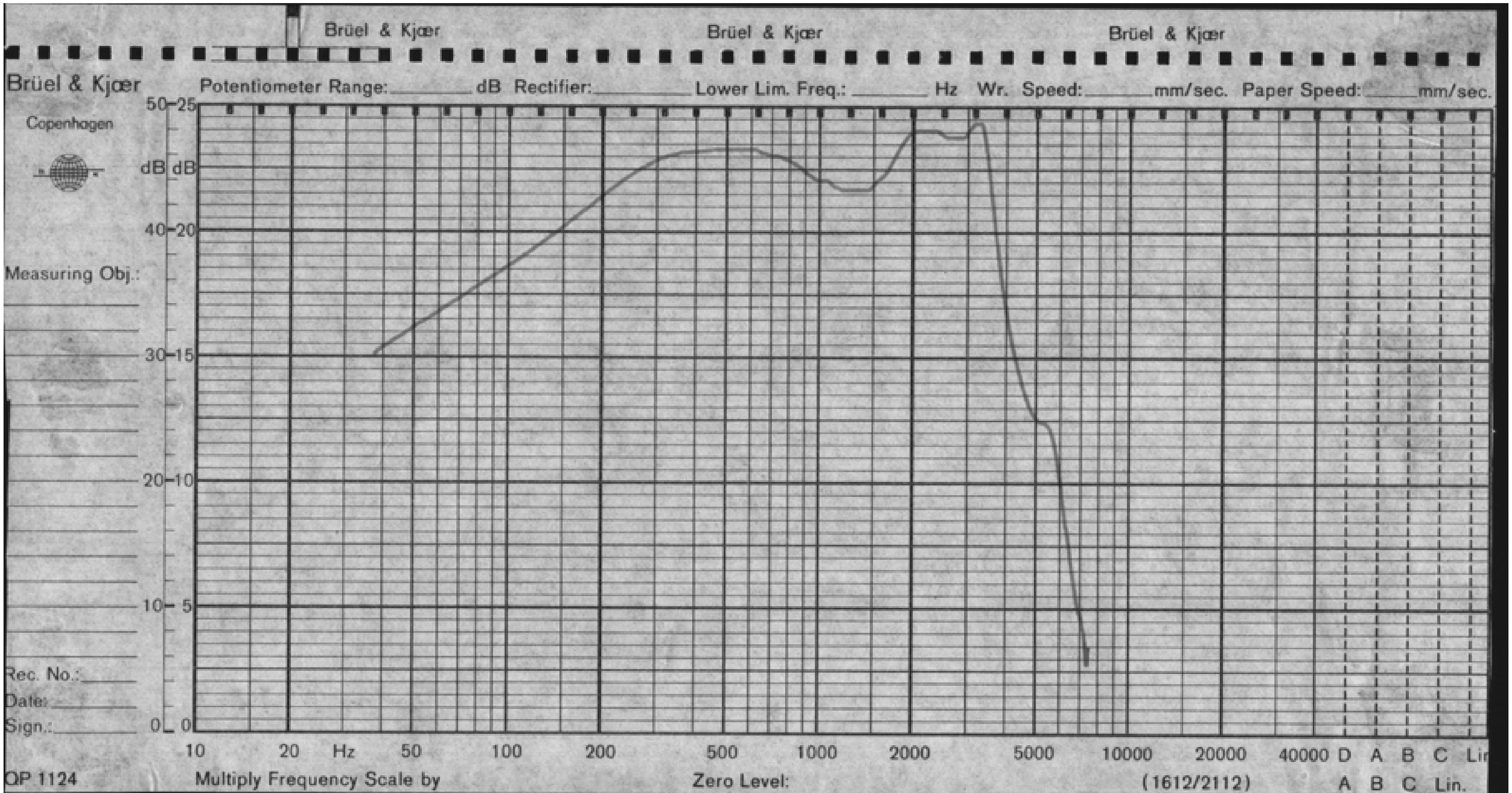
Procedure

Before the start of the experiment proper, the base line of the miniature speaker was determined by coupling the miniature speaker to the condensor microphone of the audio frequency analyzer. The frequency range from 100 Hz to 5 KHz was scanned from the Beat Frequency Oscillator and the response of the miniature speaker was recorded by the level recorder. This was done several times prior to the beginning of the experiment. This procedure gave the response of the miniature speaker for different frequencies in the absence of any resonator. This was taken as the base line. Thus resonance effect, measured in terms of increase in intensity displayed on the calibrated paper of the level recorder, of a cavity (in this case the vocal tract) could be measured against this base line. A recording of a base line is shown in Graph No.1. The test proceeded in the following manner :-

Locating the natural frequency of the vocal tract in the position of the central vowel /a/.

Step 1

The subject was asked to sit on the chair and he was instructed in the following manner :-



Graph showing the base line of the tone (without resonator)

Instructions:-

"In the test you are about to undergo, we are trying to locate the natural frequency of your vocal tract. For this purpose we will be introducing a pure tones of varying frequency through the miniature speaker. What is required of you is to adjust your mouth around the miniature speaker and the condensor microphone behind the miniature speaker in such a way that no part of the miniature speaker or condensor microphone is in contact with any part of your mouth. Then phonate the vowel /a/ continuously in your normal speaking voice without any variation in pitch. Then we will ask you to stop phonating, but maintain the position of your mouth, tongue and lips around the miniature speaker in the same way as when you phonated the vowel /a/. The test tone will be introduced into your vocal tract and you have to keep your mouth in the above position until we scan the desired frequency range."

Step 2

The height of the microphone stand holding the miniature speaker and condensor microphone was adjusted in each case such that the miniature speaker and the condensor microphone were at a level with that of the subject's mouth. Then the subject was asked to lean forward and adjust his mouth around the miniature speaker and the condensor microphone in the central vowel /a/ position with least discomfort.

Step 3

The test tone was introduced into the vocal tract by means of the miniature speaker from 100 Hz to 5 KHz and the response of the vocal tract picked up by the condensor microphone at the lips was recorded on the calibrated paper of the level recorder. The peak having the maximum response was taken as the natural frequency of the vocal tract. A typical graph indicating the natural frequency response of the vocal tract of a subject is shown in Graph No. 2. Resonance was said to have occurred at this frequency. The recording of the increase in intensity was done automatically by the level recorder which was set to R.M.S. value.

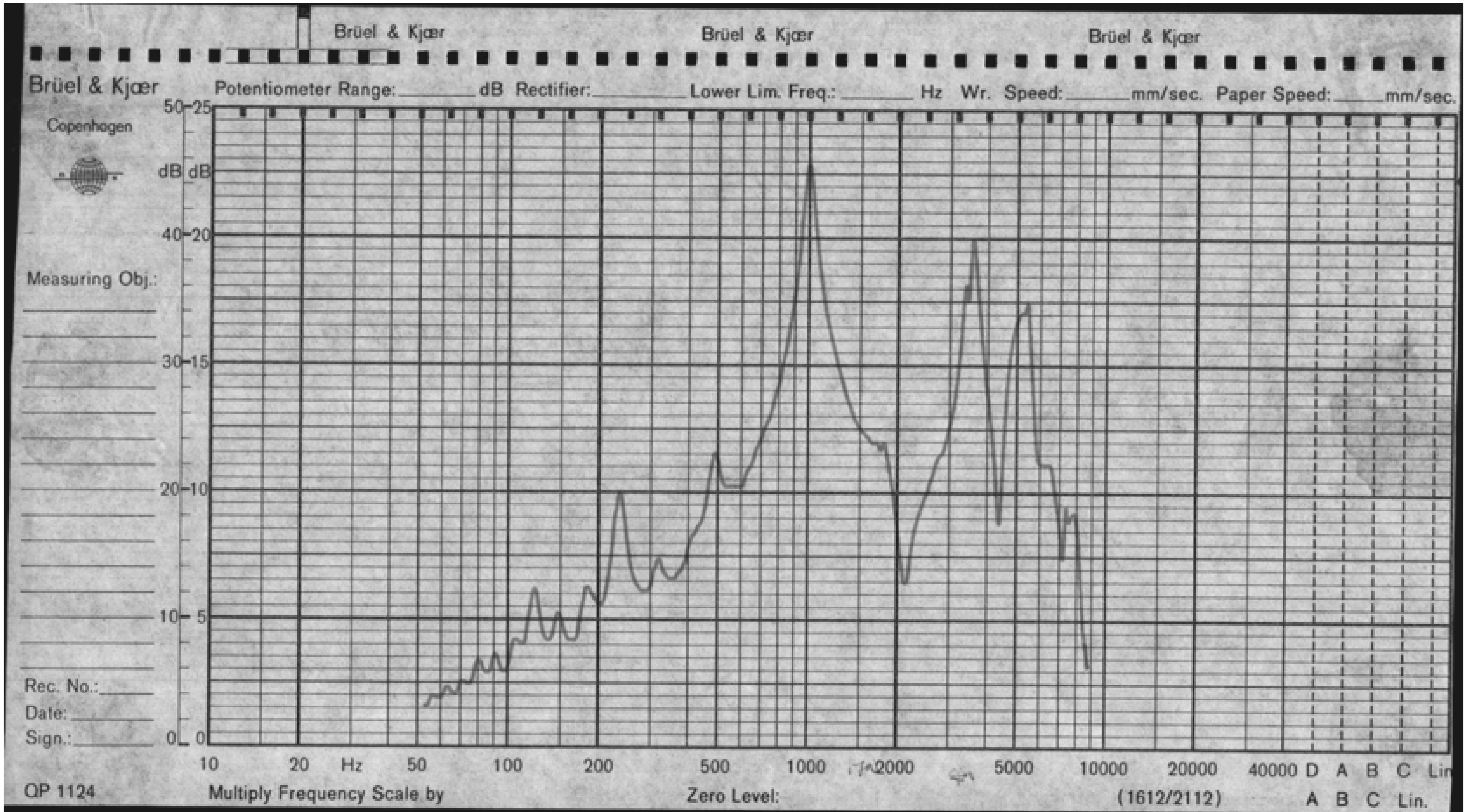
In some subjects, trail tests were given to familiarize the subjects with the test procedure.

Part B:- Finding out the fundamental frequency.

Instruments used

1) SPL meter (B & K type 2203)

2) Octave Filter Set (B & K type 1613)



Graph showing the frequency response of the vocal tract for the frequency range from 100 Hz to 5000 Hz

3) Motion Analyser (Stroboscope B & K type 5066)

4) Tacho Unit (B & K type 5527)

5) One inch condensor microphone (B & K type 4131)

Instrumental Set-up

The instruments were connected as shown in Block Diagram No. II The SPL meter was connected with one inch condensor microphone and an octave filter unit. The output of the SPL meter was fed to the Stroboscope as an external trigger. The Stroboscope was connected to the Tacho unit to measure the frequency of the input triggering of the Stroboscope. The octave filter was used with the SPL meter to cut off the unwanted frequencies.

Test Room

The experiment was carried out in the same room as mentioned in Part A of Experimetn No. 1.

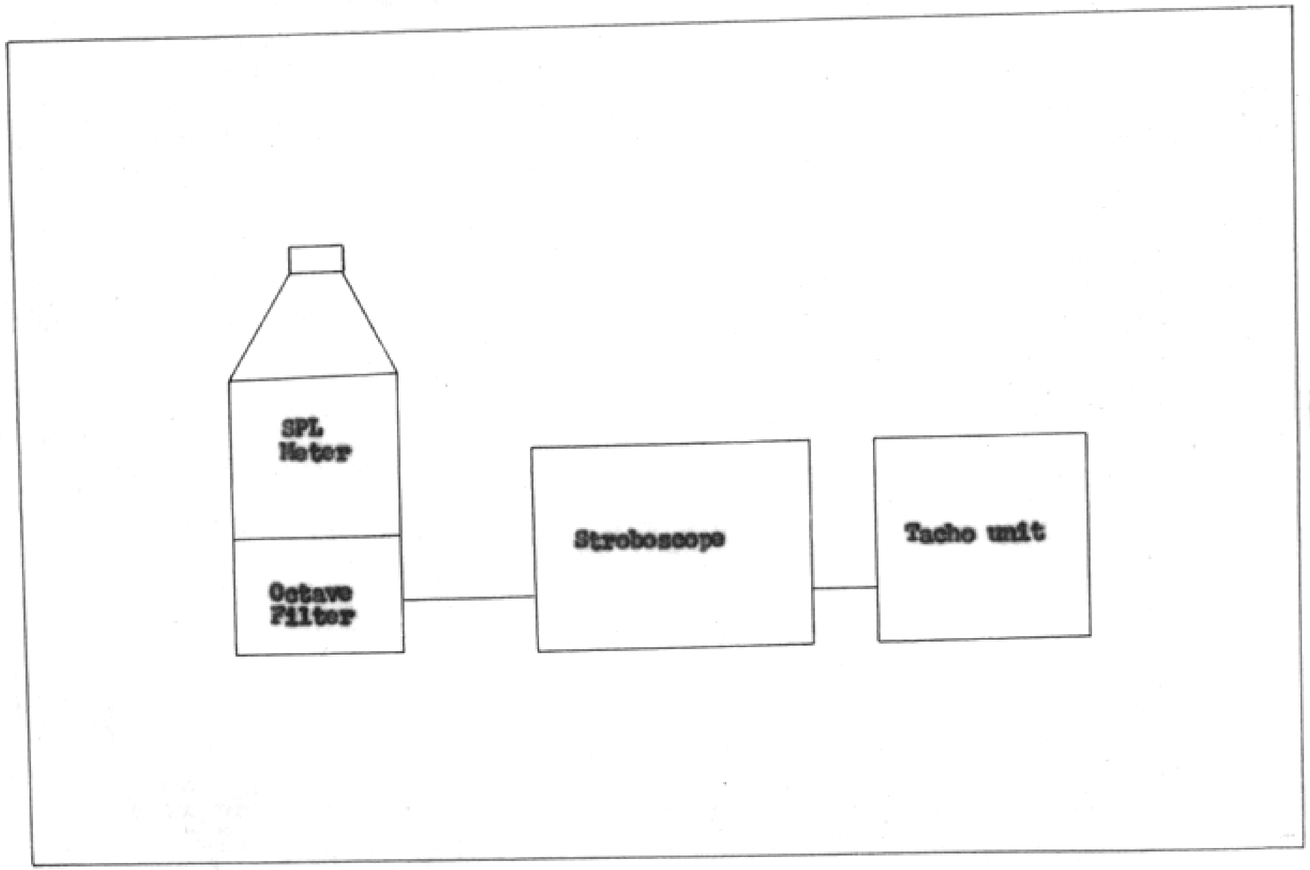
Calibration of Instruments

SPL meter was calibrated by using a pistonphone (B & K type 2240). The Stroboscope with the Tacho unit was checked by feeding a known frequency from Beat Frequency Oscillator.

Procedure

Finding the fundamental frequency for the central vowel /a/.

Block diagram showing the schematic arrangement of the equipment for the measurement of Fundamental Frequency of Voice



The subject was asked to phonate the vowel /a/ in front of the condensor microphone of the SPL meter; by making the necessary adjustments of the SPL meter and the octave filter, the fundamental frequency was read directly from the Tacho unit.

Part C:- Finding out fundamental and formant frequencies of the central vowel /a/.

Instruments used

1) Ampex Tape Recorder - 1100 Series

2) Sonograph type B/ 65 – Kay Electric Company

Instrumental Set-up

The Ampex Tape Recorder was installed in the same test room mentioned in Parts A And B. The Sonogram was installed at B.Y.L. Nair Hospital, Bombay. The test conditions at B.Y.L. Nair Hospital were satisfactory. The pre-recorded samples of the 30 subjects were taken to Bombay for the study.

Proceduro

Step 1

Instructions:- The following instructions were given to all the subjects before recording on the magnetic tape.

"Sit comfortably and phonate the vowel /a/ normally for 5 seconds. I am going to record this on a magnetic tape. Please do not change the pitch and try to keep it constant."

Step 2

The recording was carried out for all the subjects; the magnetic tape was carried to Bombay with all the precautions to preserve the normal recording characteristics on the tape. Precaution was also taken during recording to avoid any distortion.

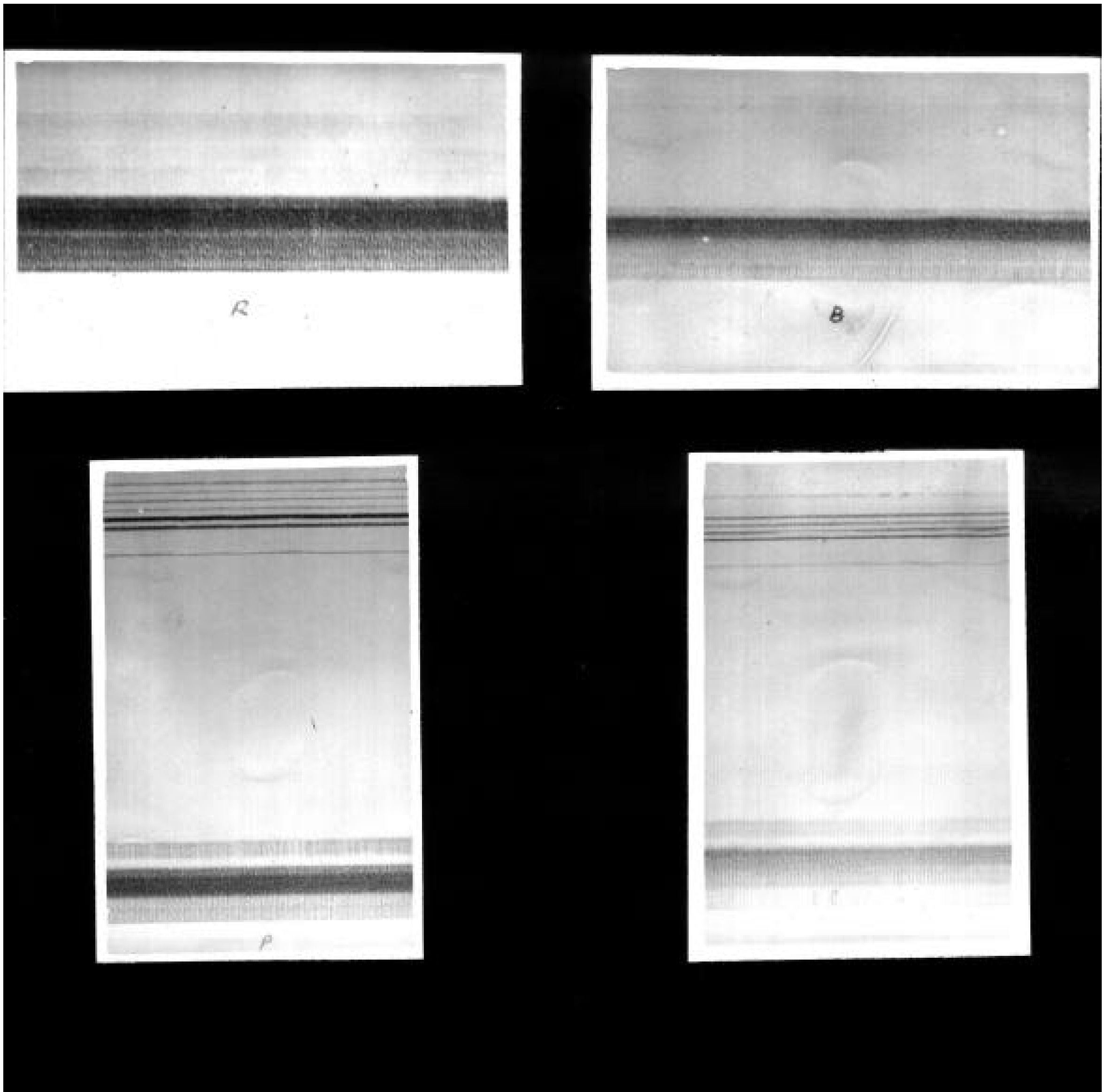
Step 3

The recorded samples were fed to the B/65 Sonograph and analysis of the recording was carried out for wide band and narrow band and wherever necessary sectionor was taken. Fundamental frequency was determined using the formula

$$F_0 = \frac{??G}{?G} \times \frac{?}{?}$$

where 'n' = number of vertical striations in a distance of X centimeters. This formula follows from the fact that one full rotation of the drum corresponds to 31.7 cms. for the time period of 3.3 secs. Formant frequencies were calculated using the formula

$$F = \frac{???}{?} \times x$$



Photographs of the sample of the subjects' phonating the vowel /a/

where x is the distance in millimeters from the base line to center of the formant band under consideration. This is based on the fact that the calibration tone of the Spectrograph of 500 Hz corresponds to a distance of 6 mm.

Experiment No. 2

Instruments used

1) Bikday Audiometer (Grason and Stadler co.)

2) Sonograph (B/65 Key Electric co.)

3) Ampex Tape Recorder (1100 series)

Instrumental Set-up

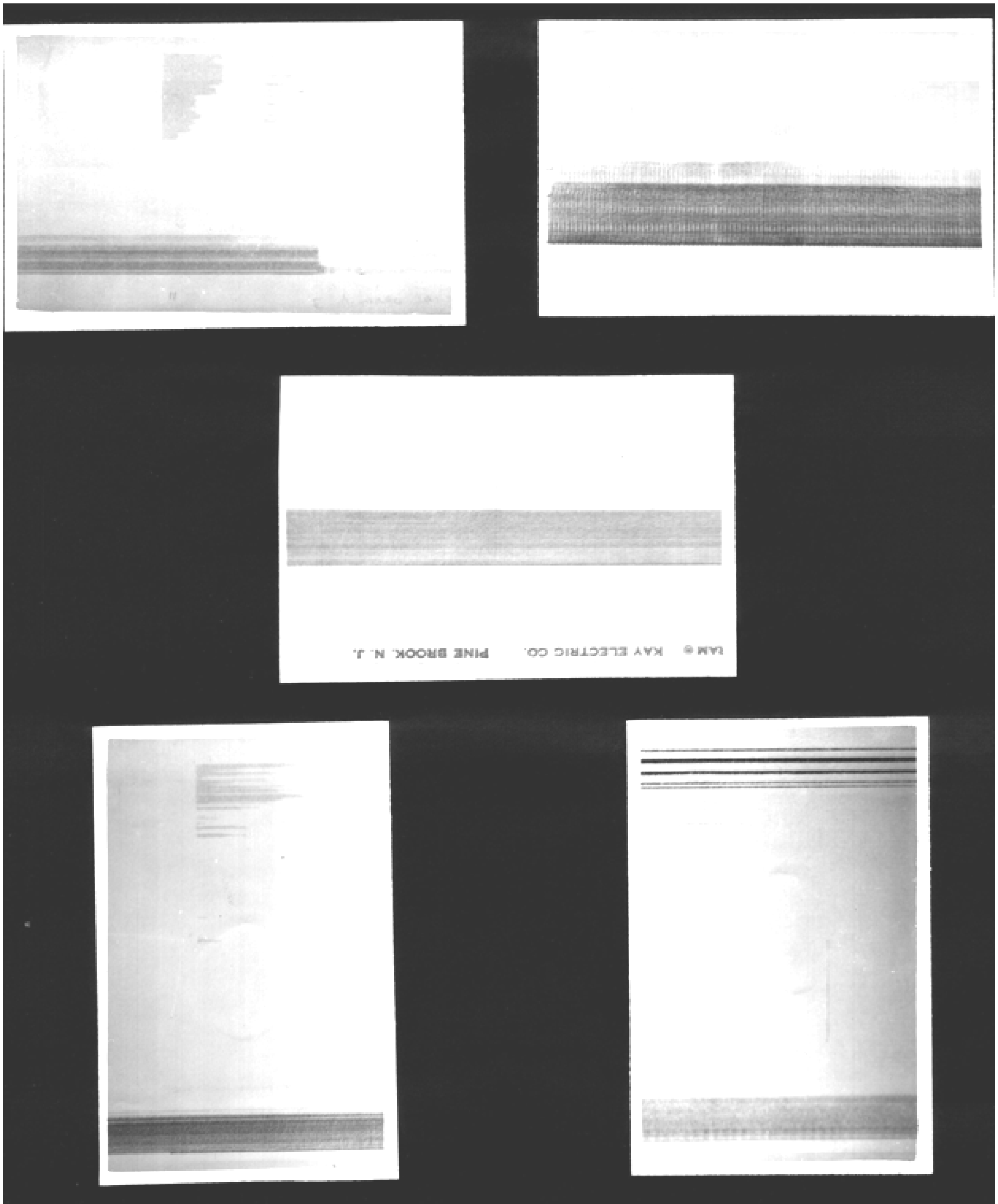
Ampex tape recorder was installed at B.Y.L. Hair Hospital. Sonograph and the Bikday audiometer were also installed in the same room. The noise condition was satisfactory for the testing purpose.

Subjects:- 5 males with age group of 20-25 years were selected from the T.H.Medical college, Bombay. These 5 Subjects could phonate at any given fundamental frequency (model tone was presented through the earphone of the Bikisy audiometer).

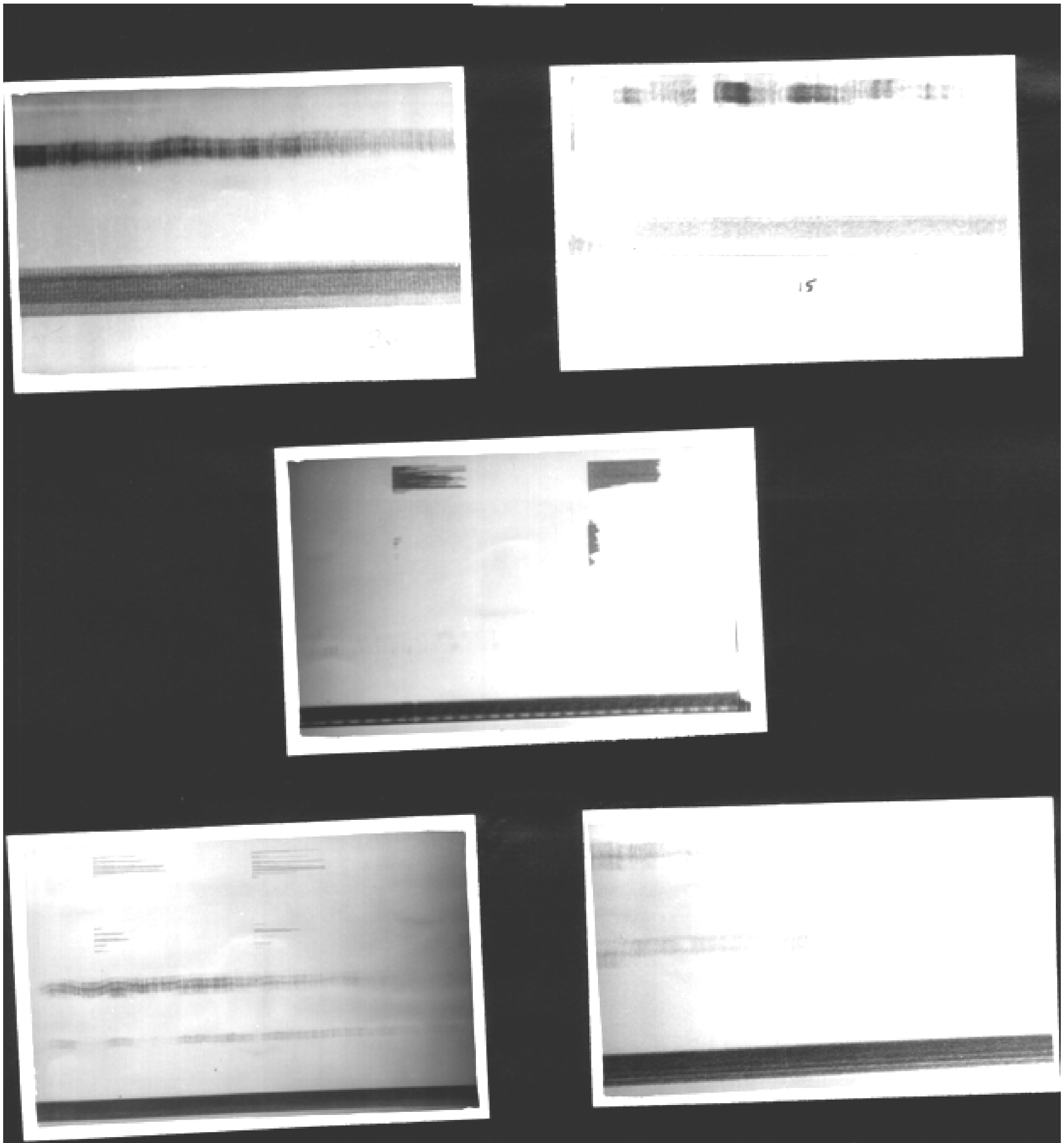
Step 1

Instructions

All the subjects were instructed before the start of the



Photographs of the sample of the subjects' phonating the vowel /i/ in the three given fundamental frequencies



Photographs of the sample of the subjects' phonating the vowel /i/ in the three given fundamental frequencies experiment. The instructions were,

> "When you hear a pure tone through the earphone, you have to match your voice to this tone and say the vowels /a/ and /i/ for a duration of 5 secs. for each vowel. You have to give a gap 15 secs. between the two vowels. you are requested to keep the pitch constant during the phonation of the vowels. We are going to record it for the purpose of research work."

Step 2

The subjects were given a tone of 110 Hz with the help of the Bikdsy audiometer through the earphones. The subject phonated the vowels /a/ and /i/ for the duration of 5 secs. This was recorded on a magnetic tape. Precaution was taken while recording to avoid distortion.

Using the above procedure, the same vowels /a/ /i/ were recorded by presenting 160 Hz and 200 Hz as model frequencies.

The fundamental frequencies and the formants were calculated by using the standard procedure.

Analysis of Data

Data collected from Experiment No.1 and Experiment No.2 were analyzed using standard statistical procedure as mentioned below.

Experiment No. 1

Arithmetic mean was calculated for the peaks one, two, and three, Formant one and Formant two, and the fundamental frequencies derived from both Stroboscopic technique and Spectrographic analyses.

Standard deviation was calculated for the fundamental frequencies (both techniques), Formant one and Formant two and Peak one. The Coefficient of Correlation was found out by the Product Moment Method for F_0p_1, F_1P_1 and F_2P_1, $\frac{?_? ? ?_? ?_?}{?}$

	F_0	F_0
	Stroboscopic	Spectrographic

Correlation is given by the formula,

$$? = \frac{?? ?^? ?^? ?? ? ??}{?^? ? ? ?^? ?}$$

This was calculated so as to find out the relation between formant frequencies and Peak 1, and fundamental frequency and Peak 1, and fundamental frequencies by the two methods.

Experiment No.2

This is a 2 X 3 factorial design.

F_0 – Frequency

Vowel			100	160	200
	a	F1 F2			
	i	F1 F2			

By applying Bartelett’s test it was found that the variances in the groups were same for /a/ and /i/ vowels. Hence analysis of variance was feasible.

So, the data were analysed by using Analysis of Variance for both /a/ and /i/ vowels.

CHAPTER IV

RESULTS AND DISCUSSION

Experiment No.1

Locating the natural frequency of the vocal tract in the vowel /a/ position.

A definite increase in intensity was observed in the response of the vocal tract to the stimulating tone as seen on the calibrated paper of the level recorder. The response characteristic of the vocal tract is almost the same for different vocal tracts. Each group revealed on prominent peak and other, less prominent peaks. The prominent peak was consistent within $\pm$ 10 Hz for each subject on several readings.

It was assumed that these maximum intensity increases came about when the stimulating frequency was near the natural frequency of the vocal tract. The prominent peak and the other peaks showed harmonic relationships.

Spectrographic analyses of vowel /a/ of 30 subjects showed formant frequencies range from 600 cps to 900 cps for Fermant one and 1,000 cps to 1,4000 cps for Formant two.

The raw data of the fundamental frequencies both by the stroboscopic technique and the Spectrographic technique, formant frequencies (Formant 1 and Formant 2) and the natural frequency, i.e., Peak 1 and the other two Peaks in the same vowel position are given in Table 1.

The mean and the standard deviation of the fundamental frequencies (both techniques), the natural frequency of the vocal tract (Peak 1), Formants 1 and 2, the correlations of the

Formant 1 and Peak 1,

Formant 2 and Peak 1,

$\frac{??????????????????}{?}$ and Peak 1,

Fundamental frequency and Peak 1,

Fundamental frequency Stroboscopic and Fundamental frequency Spectrographic

are given in Table 2.

<u>Statistical Examination</u>

The mean of the fundamental frequency found by Stroboscopic method is 129.00 Hz and that found by Spectrographic method is 135.37 Hz. The means by two methods are close with a difference of only 6 Hz.

Correlation between fundamental frequency by Stroboscope and the fundamental frequency by Spectrograph was 0.5711. This correlation is significant. The correlation between F_0 and Peak 1 is 0.12. This low correlation may be, because, the subjects were perhaps not using their optimum pitch. If they were using their optimum pitch, as per Nataraja, (1972) there would have been a ‘definite and consistent relationship’.

The correlation between Formant 1 and Peak 1 was -0.12. The correlation between Formant 2 and Peak 1 was 0.11 and the correlation between averages of Formant 1 and Formant 2 and Peak 1 was -0.03.

Thus, this shows that there is no relation between Formant 1, Formant 2 and Peak 1, and also between averages of Formant 1, Formant 2 and Peak 1.

To test the hypothesis, the Wilcoxon Matched Pairs Signed Rank Test was used. The null hypothesis formulated for this problem was rejected at 0.01 level and 0.05 level.

The Z value being 5.20 and 5.19 which is greater than the Z score of 4, given in Table A, whose P Value is 0.00006. This rejects the null hypothesis and confirms H_1.

The Natural Frequency thus obtained is not a Formant and it is also not correlated with the Formants 1 or 2. Other Formants were not checked because the Natural frequency Peak fell between Formant 1 and Formant 2.

Table 1

Raw Data for Fundamental Frequencies, Formant Frequencies and Peaks

Sl. No.	F_0		F_1	F_2	Peak 1	Peak 2	Peak 3
	Tacho meter	Spectro - graph					
1	120	140	833	1332	978	3467	-
2	130	137	583	1182	955	2000	3388
3	130	130	791	1248	1288	2089	2248
4	140	135	833	1416	1148	1905	3548
5	150	140	833	1248	1175	3631	-
6	110	101	833	1332	1122	2000	3548
7	130	133	749	1248	1259	2089	3388
8	125	122	791	1332	1072	3020	3802
9	135	140	874	1416	1035	2089	3311
10	125	137	833	1332	1047	1862	3236
11	130	137	666	1082	1072	1905	3548
12	145	155	749	978	1000	2138	3162
13	120	124	833	1416	1023	3020	-
14	145	143	916	1416	1047	2000	3162
15	135	128	749	1166	977	2089	3236
16	115	101	833	1332	1138	2045	3981
17	140	140	833	1248	1202	2000	-
18	140	160	749	1332	1259	2000	3631
19	120	130	833	1082	851	1349	2089
20	115	128	666	1248	1175	2291	3311
21	110	128	833	1332	1000	3020	3467
22	145	160	749	1332	1148	2089	3162
23	145	140	833	1332	977	2042	3162
24	115	122	833	1332	1000	3162	5000
25	135	123	833	1416	1000	2000	3000

26	125	140	916	1416	1000	3020	4199
27	130	135	916	1499	977	3236	4786
28	130	183	666	1249	1122	2399	3020
29	120	140	749	1332	1148	2291	-
30	115	137	833	1499	1122	3467	-

Table 2

Statistical Analyses of Fundamental Frequencies, Formant Frequencies and Peaks

	F_0 Tachometer	F_0 Spectr o-graph	F_1	F_2	Peak 1	Peak 2	Peak 3
Mean in Hz	129.00	135.37	798.03	1304.2	1077.2	2390.4	3446.04
Standard Deviation a	11.28	15.77	35.62	121.11	104.18	-	-
Product Moment Correlati-on ?	F_0 & Tacho Meter	F_0 Spectr-ograph	F_0P_1	F_1P_1	F_2P_1	? ? ? / ?	& P1
	0.5711		0.12	-0.12	0.11	-0.03	

Experiment No.2

5 subjects were asked to phonate the vowels /a/ and /i/ at 110, 160 and 200 Hz (Model tone). Table 3 gives the values of model fundamental frequencies versus actually phonated fundamental frequencies.

One subject could not phonate vowel /a/ at 110 Hz.

Formant frequencies analyses of the vowels /a/ and /i/ at three different levels of fundamental frequencies (mentioned above) are given in Table 4.

Statistical Analysis

Bartelett's test was used to find out the homogeneity of variance. The hypothesis tested here was variances are same.

Values are:

T = 1.879

Vowel /a/ : Tabulated X^2 = 15.086 at 1% level

Tobserved < X^2 table value

T = 13.497

Vowel /i/ Tabulated X^2 = 15.086 at 1% level

Tobserved < X^2 table value

By application of this test the hypothesis was accepted. Thus, the test showed that variances in the groups were same.

Hence, the analysis of variance was applied in both /a/ and /i/ vowel analyses.

The data collected for /a/ and /i/ vowels were treated for the above mentioned test.

Since vowel /a/ was not phonated by one subject at one particular level (110 Hz), the formula used for analyses of /a/ vowel was different from that of /i/ vowel.

Table 3

Model Fundamental Frequencies versus Actually Phonated Fundamental Frequencies

Name	Vowel	Fundamental Frequencies in Hz		
		110	160	200
G.G	a	110	148	198
	i	106	146	196
E.M.	a	106	148	208
	i	108	148	195
S.P.	a	107	160	182
	i	106	167	202
N.T.	a	110	153	198
	i	109	145	196
J.	a	-	147	174
	i	106	138	172

TABLE 4

Formant Frequencies Analyses of /a/ and /i/ vowels

Name	Vowel		Fundamental Frequencies in Hz		
			110	160	200
G.G.	a	F_1	583	666	749
		F_2	1249	1082	1166
	i	F_1	333	291	291
		F_2	2249	2332	3000
E.M.	a	F_1	833	833	750
		F_2	1249	1332	1332
	i	F_1	291	291	333
		F_2	2415	2665	2665
S.P.	a	F_1	749	749	749
		F_2	1332	1332	1499
	i	F_1	291	291	333
		F_2	2500	2500	2500
N.T.	a	F_1	749	833	833
		F_2	1332	1499	1416
	i	F_1	291	291	270
		F_2	2332	2374	2500
J.	a	F_1	-	250	291
		F_2	-	2665	2665

Table 5 gives the Analysis of Variance for /a/ vowel and Table 6 Analysis of Variance for /i/ vowel.

Table 5

Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F Value
Rows (Formants)	1			
Col. (f_o)	2			
Interaction	2	3402.0	1701.0	6.1176
Error	22	228932.8	10406.04	
Total	27	32516580.0		

F observed = 6.1176

Tabulated value of F = 19.447 with df (22,2) at 5% level

F observed < F Tab. Value

Hence, accept the hypothesis, i.e., there is no interaction.

Table 6

Analysis of Variance Table

Source of Variation	Degrees of Freedom	Sum of Squares	Mean sum of Squares	F Value
Rows (Formants)	1			
Col. (f_0)	2			
Interaction	2	97866.06	48933.03	3.824
Error	24	307118.00	12796.58	
Total	29	37578322.17		

F observed = 3.824

Tabulated value of F = 5.61 with df (2.24) at 1% level

F observed < $F_{2,24}$ (tabulated)

Hence, accept the hypothesis, i.e., there is no interaction.

Thus, the results here show that there is no interaction between Formant 1 and Formant 2 and Fundamental Frequencies. Therefore, Formant Frequencies are independent of Fundamental Frequencies.

CHAPTER V

SUMMARY AND CONCLUSIONS

The study was concerned with the frequency response of the vocal tract. This was undertaken on assumption that the vocal tract is an acoustical system having a series of coupled resonance elements with resonance peaks in the response frequencies. These resonance peaks are given by formants, and these formants were compared in turn with the natural frequency of the vocal tract (Maximum increase) in the intensity when the vocal tract was stimulated with an external source) as found by Nataraja (1972).

The study was also concerned with finding out the effect of change in fundamental frequencies on formant frequencies.

It was also attempted to see whether fundamental frequency found by Stroboscopic technique and Spectrographic analysis tallied.

In order to study these aspects the following hypotheses were advanced.

1) Natural frequency of the vocal tract is a formant; and

2) The formant frequencies are independent of the fundamental frequencies.

In order to study these hypotheses the following experiments were undertaken. The natural frequency of the vocal tract was found out by using Nataraja’s technique.

The subjects of the above experiment were asked to phonate /a/ for 5 seconds. This was recorded and fed to the Sonograph. Formant analyses was done.

The fundamental frequency was measured directly from the Tacho meter which was used in combination with a Stroboscope, SPL meter and Octave Filter.

To test the hypothesis (2), 5 subjects (males) were taken. They were asked to phonate vowels /a/ and /i/, each for 5 seconds. A tone of 110 Hz, 160 Hz and 200 Hz was given for matching through the earphones of the Bikday audiometer. Vowels /a/ and /i/ were recorded in the Ampex Tape Recorder at the three levels mentioned above.

The Spectrograph analysis of formant frequencies and fundamental frequencies were done.

Hypothesis (2) was accepted.

Conclusions

1) The natural frequency of the vocal tract do not coincide with any of the formants.

2) On statistical examination: 30 subjects taken for the study showed that there is no correlation between the averages of F_1 F_2 and the natural frequency found by Nataraja (1972).

3) Means of fundamental frequencies found from the Stroboscopic technique and the Spectrographic analyses were closer. Mean of the two methods showed 6 Hz difference. The correlation between Fundamental Frequencies obtained by Stroboscopic technique and Spectrographic analysis was 0.5711.

4) Formant frequencies are independent of the fundamental frequencies. That is, if the same person phonates vowel /a/ in different fundamental frequencies still, you perceive it as vowel /a/.

Recommendations

1) Objective confirmation of the frequency located as optimum pitch by studying the physic-acoustic economy at this level by using E.M.G.

Recommendations – contd.

2) To study the effects of the changes in resonators on normal and abnormal changes in pitch.

3) Validating the natural frequency and the dimensions of the vocal tract by means of analogues technique.

4) In subjects with good voices, to correlate fundamental frequencies found from purdue pitch meter, Sonogram, Stroboscope and the natural frequency of the vocal tract.

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TECHNICAL DATA

BEAT FREQUENCY OSCILLATOR (Bruel & Kjaer type 1022)

The Beat Frequency Oscillator type 1022 is a precision signal generator using solid state circuitry throughout. it covers the range 20 – 20,000 Hz and is designed for acoustical, Vibrational and electrical measurements.

The 1022 works on the heterodyne principle using two high frequency oscillators one of which operates at a fized frequency while the frequency of the other can be varied. The required audio frequency is then obtained by mixing these frequencies to produce beat frequency.

The output impedance can be varied to give maximum power (2.5W) in a load of 6-60-600 or 6000.

The 1022 may be swept continuously through its frequency range by means of an external motor drive. If it is driven by the Level Recorder 2305 it can also be automatically synchronized with frequency calibrated paper.

A Compressor amplifier can be switched in, to control the regulating amplifier so that constant output level is obtained. When the instrument is being used for instance to power a loudspeaker the compressor circuit can be used with a microphone to maintain a constant sound pressure level.

FREQUENCY ANALYZER (Bruel & Kjaer type 2107)

Type 2107 is an AC operated audio frequency analyzer of the constant percentage bandwidth type. It has been designed especi- as a narrow band sound and vibration analyzer, but may be used for any kind of frequency analysis and distortion measurement within the specified frequency range. When used together with a Level Recorder type 2305, frequency amplitude diagrams can be recorded automatically on preprinted frequency calibrated recording paper. In addition, it is supplied with the weighting networks for sound level measurements “A”, “B” and “C”, and a 7-pin input socket for connection of a Bruel & Kjaer condenser microphone or preamplifier as required.

The instrument is supplied with an output switch, by means of which the rectifier and meter circuit can be switched to measure either the peak, the arithmetic average or the true RMS value of the input signal.

MEASURING AMPLIFIER (Bruel & Kjaer type 2607)

The 2607 Measuring Amplifier is capable of an extensive range of sound, Vibration and voltage measurements. It combines extreme versatility with a wide measurement range of laboratory precision.

It is basically a wide range measuring amplifier for linear as well as logarithmic operation an includes true RMS and Peak rectifier circuits. The rectifier circuits contain time consta-nts ranging from 0.1 to 3000 sec. which can be directly or remotely selected to give averaging times for RMS Measurements and decay times for Peak measurements. A display meter with interchangeable meter scales on which the range setting is automatically indicated facilitates the direct calibration of the 2607 for sound pressure level, acceleration and voltage measurements.

HEARING AID TEST BOX (Bruel & Kjaer type 4217)

The Hearing Aid Test Box type 4217 consists of a miniature anechoic enclosure with a built-in loudspeaker and a transistori-zed oscillator and amplifier section.

The anechoic enclosure is set up with thick layers of glass wool to obtain essentially free field conditions.

In the present study, only the anechoic part of the Hearing aid Test Box was used to keep the microphone and the speaker, which provides a compressor voltage to the B.F.O. (type 1022) through the Measuring Amplifier (type 2607).

LEVEL RECORDER (Bruel & Kjaer type 2305)

The Level Recorder type 2305 has been designed for accurate recording of signal levels in the frequency range 2 Hz to 20 Khz. Typical fields of application are the recording of frequency response characteristics, reverberation decay curves, noise and vibration levels, spectrograms, and polar diagrams.

Recording can be made by means of ink, either on lined paper or on frequency calibrated paper, or by means of a sapphire stylus on wax-coated paper. A synchronous motor is used for the paper drive, and by means of a gear-box 12 different paper speeds are available. The operation of the Recorder is based upon the servo principle.

Electronically the Recorder type 2305 mainly consists of an output circuit, a Range Potentiometer, a direct-coupled AC input amplifier, the special Bruel & Kjaer signal rectifier arrangem-ent, and a DC output amplifier section which drives the electrodynamic writing system.

PRECISION SOUND LEVEL METER (Bruel & Kjaer type 2203)

The Precision Sound Level Meter type 2203 is a highly accurate instrument designed for outdoor use as well as for precise laboratory measurements. It is easily portable, battery driven and completely self-contained for ordinary sound level and vibration measurements. Used in conjunction with a suitable filter set, e.g., the Bruel and Kjaer Octave Filter Set type 1613, the instrument becomes a handy and easily operated frequency analyzer.

The Bruel & Kajer type 2203 covers the range 18 to 134 dB (or 39 to 148 dB using a ½″ microphone). All the three weighting networks (A, B and C) are included in the instrument as well as a linear characteristic and means for connecting external filter circuits for further shaping of the frequency characteristic, if necessary.

THE FILTER SET (Bruel & Kjaer type 1613)

The Octave Filter Set is a compact, portable unit containing

Only four screws are used for joining the units together and the electrical connection is provided by a connection bar.

The Filter Set type 1613 contains 11 filters with centre frequencies in accordance with ISO standards as follows: 31.5 – 63 – 125 – 250 – 500 – 1000 – 2000 – 4000 – 8000 – 16000 and 31500 Hz. The overall range of the Filter Set is thus 22 Hz to 45 Khz.

MOTION ANALYZER (Stroboscope) (Bruel & Kjaer type 4911)

The Motion Analyzer type 4911 is designed for use in observing and measuring periodic mechanical phenomena such as mechanical resonances, observing the functioning of the larynx, and many other complicated mechanisms.

The flash of the type 4011 may be synchronized by any extenal electrical signal which is periodic with a pulse width greater than 20 sec., a frequency in the range of 5 Hz to 10 Khz, and a voltage level in the range 100 mV to 280 V peak-peak. If no external signal is available the instrument may be triggered from either the line frequency or an internal signal generator with a frequency range of 5 Hz to 105 Hz.

TACHO UNIT (Bruel & Kjaer type 5527)

The Tacho Unit (type 5527) is a reliable RPM measurement used along with the Stroboscope (type 4911). The Tacho Unit incorporates speed, reading simultaneous with visual observati-on, with four speed ranges for accuracy. There is no need for manual adjustments to follow the speech variations.

The Tacho Unit is combined with the Stroboscope and the SPL meter, in the present study, to get the required readings. The Tacho Unit is connected to the Stroboscope by a cable from the “output f” socket, the saw tooth signal from which exact synchronism with the input pulses is fed to the Stroboscope. The number of input pulses, as received by the Stroboscope from some kind of triggering device, is measured and indicated in RPM.

CONDENSER MICROPHONE (Bruel & Kjaer type 4131)

The Condenser Microphone’s operating characteristics of high stability, flat linear response, and reasonably high sens-itivity, combine with its minimal effect on the sound fields in which it is placed to measure sound pressures. They are designed for use with a range of instruments: microphone amplifiers, fre-quency analyzers, precision sound level meters, etc., to give a complete analysis of the sound fields measured.

A complete microphone consists of a microphone and a cathode follower for impedance conversion, allowing long cables and relatively low input impedance amplifiers to be used between the microphone and the measuring instrument. The microphone cartridge is screwed onto the housing of the cathode follower making a small, rugged unit.

The microphone may be directly connected to the different Bruel & Kjaer measuring instruments which are provided with a Condenser Microphone input socket fitting the microphone connecting plug. Stabilized plate and heater voltages for the cathode follower and polarization voltage for the cartridge are available on this seven-pin socket.

TWO HEARING AID RECEIVERS (Denmark S 821)

Since a probe speaker was not available, two hearing aid receivers were used in the present study. They were chosen primarily because of a flat frequency response in the frequencies from 100 Hz to 5 KHz.

SONOORAPH (type B/65 – Kay Electrical Co.)

The Principle of sound spectrum spectrography involves two basic steps. First, The signal to be analyzed is heterodyned with a variable frequency, sine wave oscillator; second, the result is inserted into a narrow band pass filter and the beat frequency output is measured. The signal to be analyzed is recorded on a magnetic drum which is capable of storing approximately 2.5 seconds of material. In order to shorten the analyzing time, the recording is played back at several times the recording speed.

In the analysis, the recorded signal is played back many times as the variable frequency oscillator slowly shifts in frequency. The signal frequency necessary to produce an output from the band pass filter is equal to the difference between the carrier oscillator frequency and the center frequency of the band pass filter. The output of the band pass filter is amplified by a marking amplifier and fed to a stylus which marks on electrically sensitive facsimile paper. The density of the line marked is roughly proportional to the logarithm of the amplitude of the beat frequency component. The paper is wrapped around metal cylinder which rotates in synchronism with the magnetic drum. Since a mechanical linkage slowly moves the stylus across the cylinder, the picture is constructed of a series of parallel lines. in this manner, it is possible to make permanent frequency amplitude versus time portrayal of the recorded signal.

The Sonograph can provide two alternative degrees of frequency – selectivity, either so-called ‘narrow-band’ analysis by means of a 45 cps wide band pass filter or a ‘broad band’ analysis by means of a 300 cps wide band pass filter.

Since the facsimile paper is capable of only a 12 decible range from the lightest gray to the darkest black, a means of marking a frequency versus amplitude portrayal at any point along the time dimension is also provided. This technique is known as amplitude cross sectioning.

The cross sections show frequency along the horizontal axis, the relative amplitudes of the harmonics are shown in dB by the lengths of the spikes. An amplitude cross section is obtained by inserting a comma on the marking drum at the point to be sectioned.

In the time frequency – intensity spectrogram produced with a broad filter the formants are seen as black bands oriented la-rgely in a horizontal direction. They carry the major spectral energy. Providing the voice fundamental frequency F_o is low, there appears in the broad band spectrum a fine structure of vertical evenly spaced running through the spectrogram. Each line reflects the excitation of the vocal cavities by a single air pulse of the glottal flow produced by an opening and closing movement of the vocal cords. The duration of one such period T_o is the inverso of the fundamental frequency $F_O = 1/T_O$.

AMPEX TAPE RECORDER (1100 Series)

The Model 1160 is a solid state “instant-on” 4 track, self-contained stereo tape recorder complete except for speakers.

Performance Specifications

		1160/1165 Average Perform.	1150 Average Perform.
Overall Record/ Reproduce Frequency Response (Pre-Amplifier only)	7½ ips	_4db 50 cps to 15 KC	_4db 50 cps to 15 KC
	3¾ ips	_4db 50 cps to 7.5 KC	_4db 50 cps to 7.5 KC
SIGNAL TO NOISE (from peak record level to broad band noise) (preamplifier only)	7½	46 dB	46dB
	3¾	43 Db	43 dB
TONE CONTROL RANGE		20 dB	
at 100 cps		-0 6	
At 10 KC		-10 to 10	-10 to 10
POWER OUTPUT: Continuous rms per Channel	6W		
E1A Voice and Music Power per channel	7.5W		
Peak Per channel	15 W		
Peak both channels combinaed	30 W		

Performance Specifications – contd.

		1160/1165	1150
		Average Perform.	Average Perform.
FLUTTER: (Flutter & Wow comb. measured according to ASA stds.)	7½	0.15%	0.15%
	3¾	0.2%	0.2%
Speed Accuracy	7½	2%	2%
	3¾	3%	3%
Fast Wind Times (1200′ of Tape)		160 sec.	160 sec.
Line Input Impedance:		High	High
Microphone Input Impedance		High	High
Line Input Level:		0.2V min. 2V Max.	0.2V min. 2V Max.
Microphone Input Level:		3mV min. 30mV max.	3mV min. 30mV max.
Line Output Impedance:		Low (Less than 1K)	Low (Less than 1K)
Line Output Level:		0.3V	1V
Power Amp Output Impedance:		8 ohms	Non-Applicable