# Chapter 3

## Acoustics and Characteristics of the Nature of Sound of Sitar

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## 3.1 Acoustics

The branch of science dealing with audible sound and its property is called **acoustics**. It covers the study of Sound, Waves, Sonic Booms, Musical Instruments, Vibrations, Microphones and Speakers, among many other topics. The Music itself is a science and therefore the musical instruments that produce it, are also based on scientific principles.

## 3.2 Musical Sound and Noises

All types of sound can be classified as '**Musical Sound**' or '**Noises**'. The sounds which produce pleasing effect on the ear are called as musical sounds while the sounds which produce a jarring and unpleasant effect are called as noises (Ghonghat). They can further be classified on the basis of the following factors:

i. Regularity or irregularity in shape of the curves.
ii. With or without a definite periodicity in the curve, and
iii. Absence or presence of any sudden change in their amplitudes.

Means the sounds which are produced with a series of similar impulses follow each other regularly at equal interval i.e., when a definite periodicity without any sudden changes in their amplitudes are called musical sound. Whereas the sounds which are having irregular periods and amplitudes in nature are called noises.

**Musical sounds are not free from the noise same way some noises have a more or less musical character.**

## 3.3 Characteristics of the Musical Sound

Musical sound may differ from one another in three respects, viz., in pitch[1], in loudness, and in quality.

Thirteen properties[2] of the sound is mentioned in 'Shreegurucharitra' and 'Sangeet Makarand'.

Scientifically the properties of the musical tone are Frequency, Pitch, Intensity, Loudness, Growth, Decay, Duration, Portaments (variations of frequency modulation) and Deviations (changes in all the properties mentioned above).

However the most important characteristics can be explained as following:

- **Pitch or Frequency.**
- **Loudness.**
- **Quality.**

[1] Musical acoustics by Charles A. Culver , fourth edition, page 83
[2]Physics of musical instrument by Varsha Joshi, Physics education July –September 2004

### 3.3.1 Pitch or Frequency

Pitch is the characteristic of the sound which distinguishes between shrill sound and a grave sound. It is actually a sensation conveyed to our brain by sound waves falling on our ears which directly depends on the frequency of the incident sound waves.

**Higher is the frequency higher is the pitch of sound note, and vice versa.**

The term **pitch and frequency** look same, but actually **they are not the same**. Frequency of a note is a physical quantity and can be measured easily and accurately. While pitch is merely a mental sensation experienced by a listener. So **frequency is a physical quantity** while **pitch is a physiological quantity**. Sound of a lion is of low pitch while sound of mosquito is of a high pitch.

The just noticeable difference in pitch is conveniently expressed in cents, and the standard figure for the human ear is 5 cents.

**Perfect Pitch** or '**Absolute pitch**' refers to the ability of some persons to recognize the pitch of a musical note without any discernable pitch standard, as if the person can recognize a pitch like the eye discerns the colour of an object. Most persons apparently have only a sense of relative pitch and can recognize a musical interval, but not an isolated pitch.

Rossing suggests that less than 0.01% of the population appear to be able to recognize absolute pitches, whereas over 98% of the population can do the corresponding visual task of recognizing colours with no colour standard present.

**Frequency is the number of occurrences of a repeating event over time.**

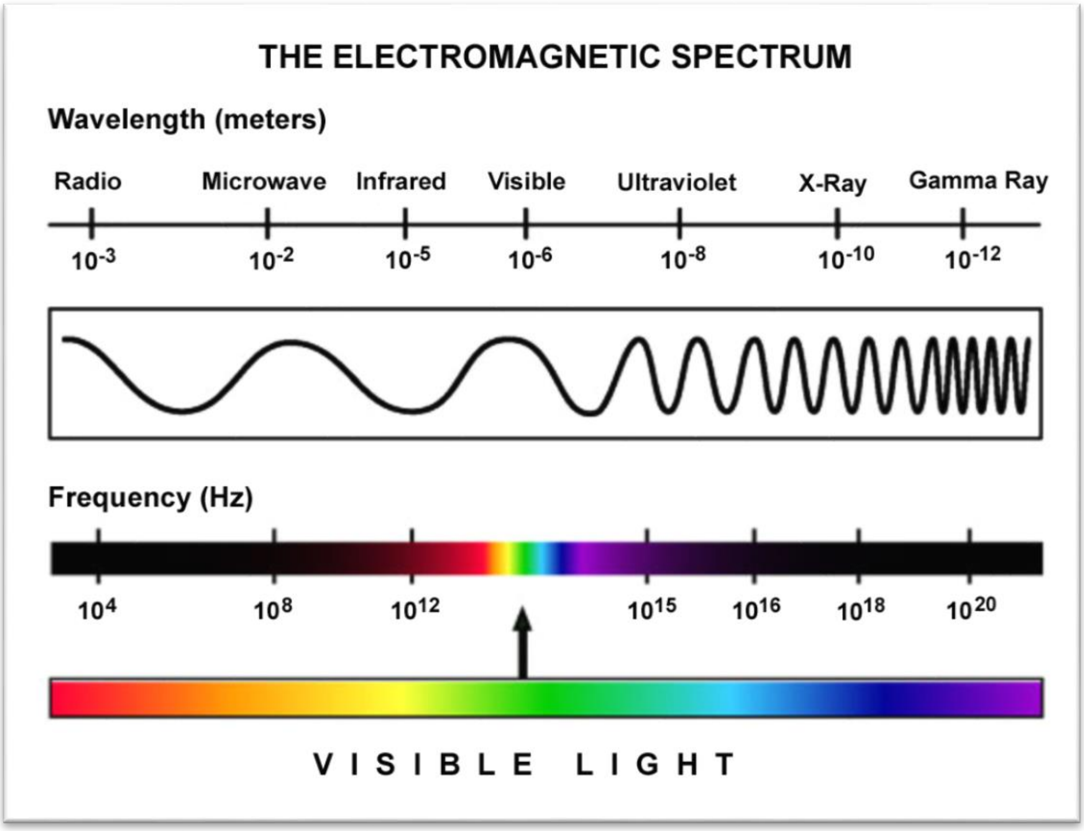



**Fig.3.1 Electromagnetic spectrum**

The frequency of '**sound**' as we know it (audible vibrations) is from just a little under **18 Hz to nearly 20 kHz** (20,000 cycles per second). These upper and lower **limits are not perfectly defined** and vary considerably depending on a person's gender and age along with several other factors including long term exposure to high-intensity sounds. Long term exposure to high intensity vibration within the human range of hearing (like rock bands) is known to result in a decrease of the ear's ability to hear sounds. Vibrations below the range of hearing may be detected by humans as pressure pulses but are so slow that it is not possible to assign them a "tone." The following chart shows the frequency range of various musical instruments and the human voice.

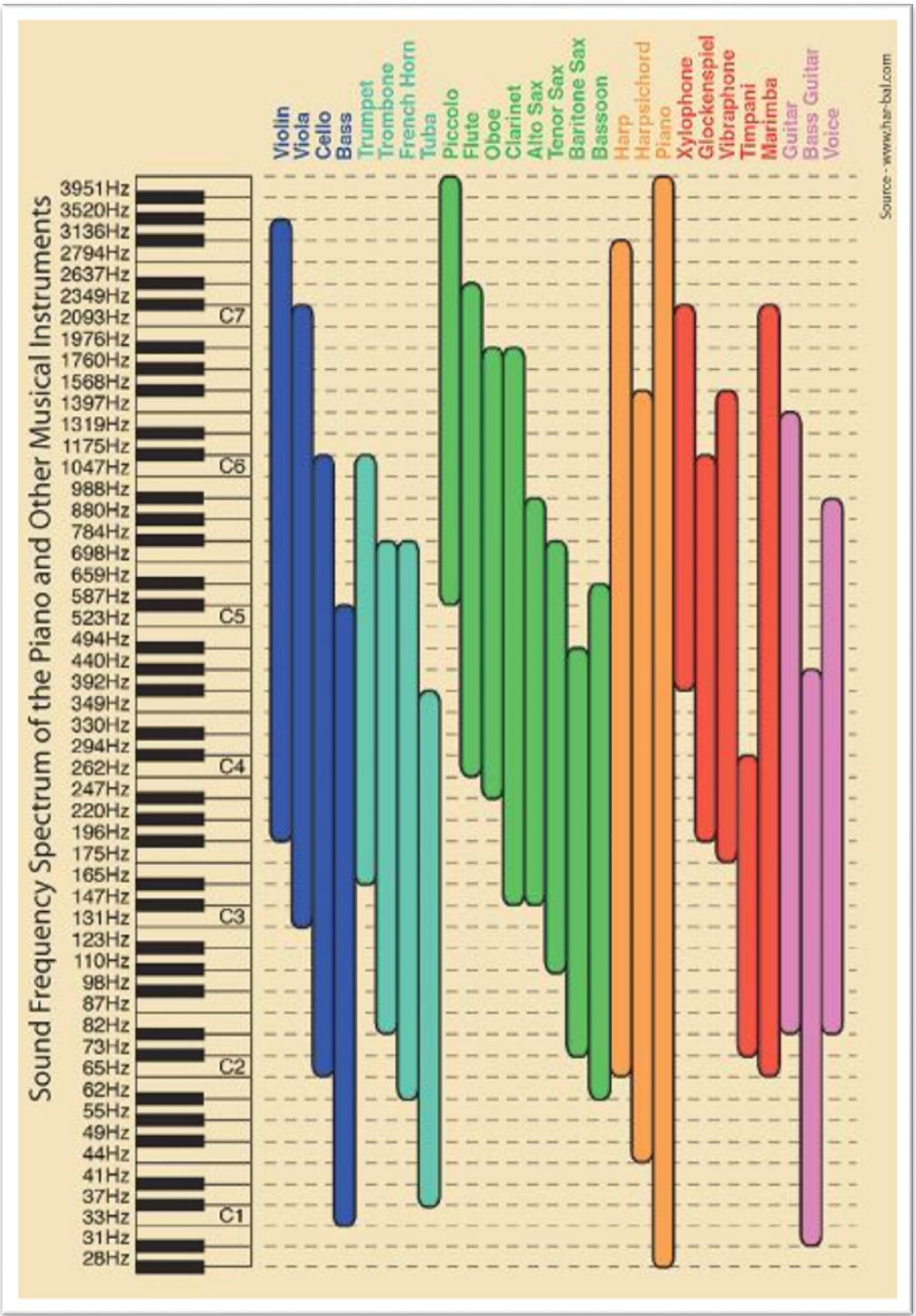
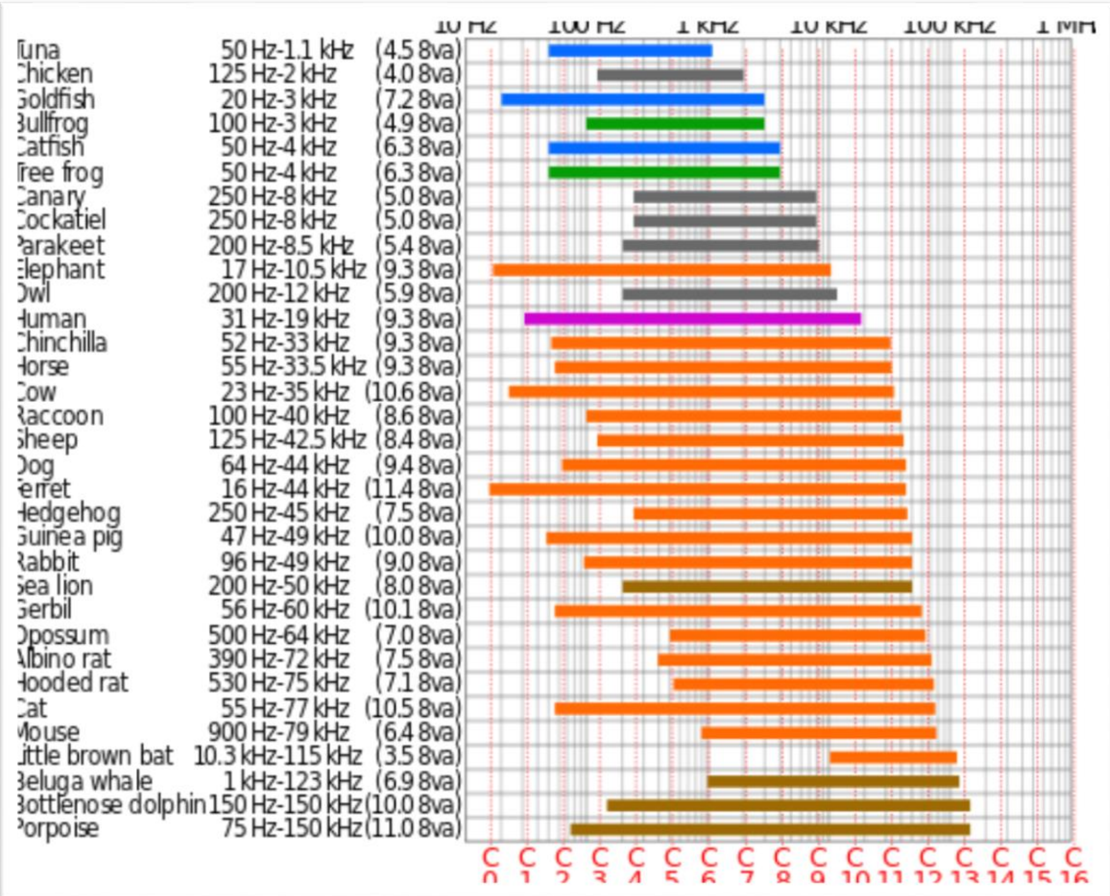



**Fig. 3.2 Frequency Range of Musical Instruments and Human voice**

The above chart shows the frequency range of the piano and other musical instruments as well as the human voice. The frequencies shown here are the primary tones, harmonics and overtones, which are responsible for the distinctive tonal qualities of the instruments, cover a broader range than that shown.

It is seen that, the pure tone range of the human voice is from about 80 Hz to less than 1 kHz. The human voice is, however, also comprised of overtones and harmonics which reach beyond these limits. It surprising that the pure tone range of the human voice and musical instruments encompasses such a small portion of the human spectrum of hearing. This is especially true on the high end. The highest frequency piano note is still way below the limit of the frequencies that most humans can hear. Yet, a person's loss of the ability to hear frequencies substantially outside the range of the normal voice or musical spectrum can be debilitating. This indicates that these frequencies are critical to our ability to sense and interpret sounds in a way that may not be fully understood.

**Following chart shows the audible frequency range of animals[3].**




**Fig[4]. 3.3 Chart of Audible Frequency of Animals**

Below is a detailed overview of the **10 octaves of the frequency spectrum**. It also includes the types of instruments that will play in those ranges along with their center frequency. Also note the cautionary tones that a mix engineer would avoid while mixing a record. These are great to know so that you can better comprehend what you're listening to, especially while engaged in critical listening.

[3] https://en.wikipedia.org/wiki/Audio_frequency dt.16.07.17
[4] https://en.wikipedia.org/wiki/Audio_frequency dt.16.07.17

| Octave | Range | Center | Description | Instrument Types | Caution |
|---|---|---|---|---|---|
| 1 | 20-40 Hz | 32 Hz | Sub-bass, Punchy, Chest, Rumble | Kick Drum, Bass, Organ | Rumble |
| 2 | 40-80 Hz | 64 Hz | Low-bass, Depth, Thud | Kick Drum, Bass, Piano | Lose Definition |
| 3 | 80-160 Hz | 125 Hz | Fat, Boomy, Body | Adds size to any instrument | Boom, Unclear |
| 4 | 160-320 Hz | 250 Hz | Warmth, Fundamental notes from all instruments | Acoustic instruments, Vocals | Muddy |
| 5 | 320-640 Hz | 500 Hz | Horn, Honk, Texture, If this frequency range is lowered, the instrument will sound transparent | Texture balance on instruments, Horn effect on vocals | Honky |
| 6 | 640-1.25 kHz | 1 kHz | Whack, Attack, Distortion | Attack on snare drum, guitar, and percussion This is where you get the "phone" effect on vocals | Nasal |
| 7 | 1.25-2.5 kHz | 2 kHz | Crunch, Falling Rain, Crisp | Similar to the 1 kHz range, less aggressive Good for background vocals and instruments | Gritty |
| 8 | 2.5-5 kHz | 4 kHz | Clarity, Presence, Edge | Adds clarity to an instrument taking a solo, Vocals, Guitar, Acoustic Instruments, Snare | Listener Fatigue |
| 9 | 5-10 kHz | 8 kHz | Crystal, Metallic, Sizzle | Cymbals, Steel String Instruments, Snare | Sibilance |
| 10 | 10-20 kHz | 16 kHz | Air, Open, Light | Hi-Hat & Cymbals, Helps add ambience to all sounds which were recorded in a "dead" room | Hiss |

**Fig. 3.4 Table for Overview of the 10 Octaves of the Frequency Spectrum**

Once the frequency range is familiarized and each octave and their relative pitch or tone, one will be able to make adjustments within one's music system. It is much more compelling to alter the sound once one have had a chance to listen and study up. Always let your ears be the judge. If you feel your system could use slight adjustments or if you feel like having a trial and error session, just go into your receiver's menu settings and find the EQ. Most likely it has a fixed 10 band EQ (similar to below) adjustment and you can raise or lower a particular frequency range to your liking. And of course, always listen carefully while making adjustments because most likely your tweeter is not going to be happy with a major bump at 2 kHz and above, while your woofer may not like a big boost at 32 Hz.

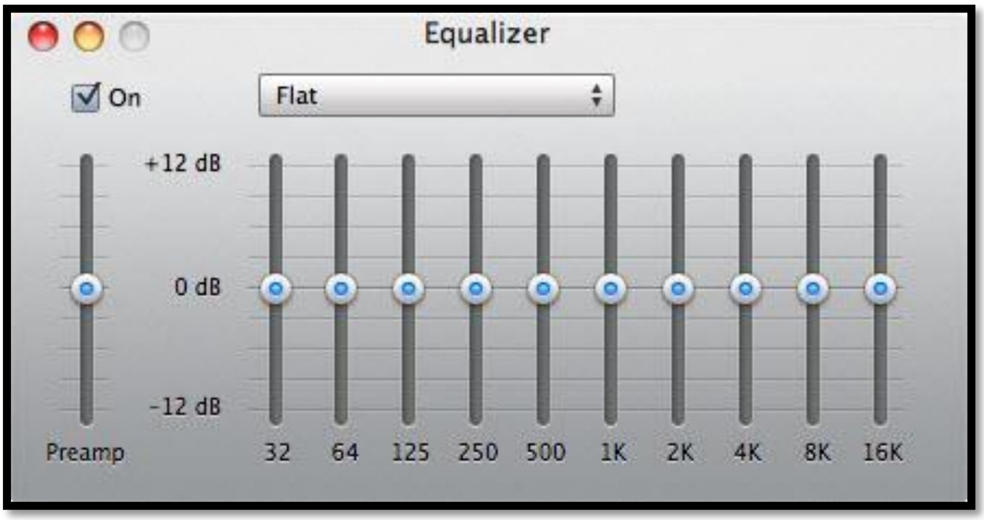



**Fig. 3.5 10 Band Equalizer**

In musical instruments pitch is the term used to define the position of musical note on a musical scale.

| **Note.** | **Sa** | **Re** | **Ga** | **Ma** | **Pa** | **Dha** | **Ni** |
|---|---|---|---|---|---|---|---|
| | **(C)** | **(D)** | **(E)** | **(F)** | **(G)** | **(A)** | **(B)** |
| **Frequency** | **256** | **288** | **320** | **341.3** | **384** | **426.7** | **480** |

As we go higher on the scale, pitch of the successive note rises.

#### 3.3.1.1 Standard of Musical Pitch[5]

The basic pitch ('A' above middle 'C') employed in musical literature has varied widely since Pere Mersenne (**Mersenne is considered as a father of acoustics**), the famous French scientist and mathematician first determined the pitch of a musical note. In his time (1648) the lowest 'church' pitch was 373. And the chamber pitch was 402.9.

Handel's standard pitch in 1751 was 422.5.

At one time so called 'concert' pitch of 461.6 was used. Probably the first highly accurate determination of the pitch of a sonorous body was made by Lissajous, another French physicist. Lissajous determined the frequency of the standard tuning fork of France, known as the 'diapason normal' of the French conservatory of Music. It was intended that this standard fork should execute 435 vibrations per second, but a later determination by the famous acoustician Rudolph Koeng, with improved facilities, showed that the diapason normal actually gave a frequency of 435.45 at $15^0$ C or $59^0$

[5] Musical acoustics by Charles A. Culver , fourth edition, page 85

F. Probably the first formal action to adopt a standard pitch occurred in Germany when meeting of physicist at Stuttgart in 1834 adopted a pitch of 440.

An orchestral ‘A’ of 435 was legalised in France in 1859 and this pitch was soon adopted by several important symphony and opera orchestras, including the Boston Orchestra (1883). In 1892 the piano manufacturer’s association adopted the French pitch of 435, as determined by Koenig and designated that value as ‘international pitch’.

**In 1939 an international conference on pitch was held in London and it was unanimously agreed to recommend to all interested organisations that 440 be adopted as the standard of orchestral pitch. This pitch is now generally used in the world.**

In order to assist in maintaining an accurate pitch value, the bureau of standards at Washington, D.C., broadcasts several times daily, a standardising pitch of 440 by means of radio signals.

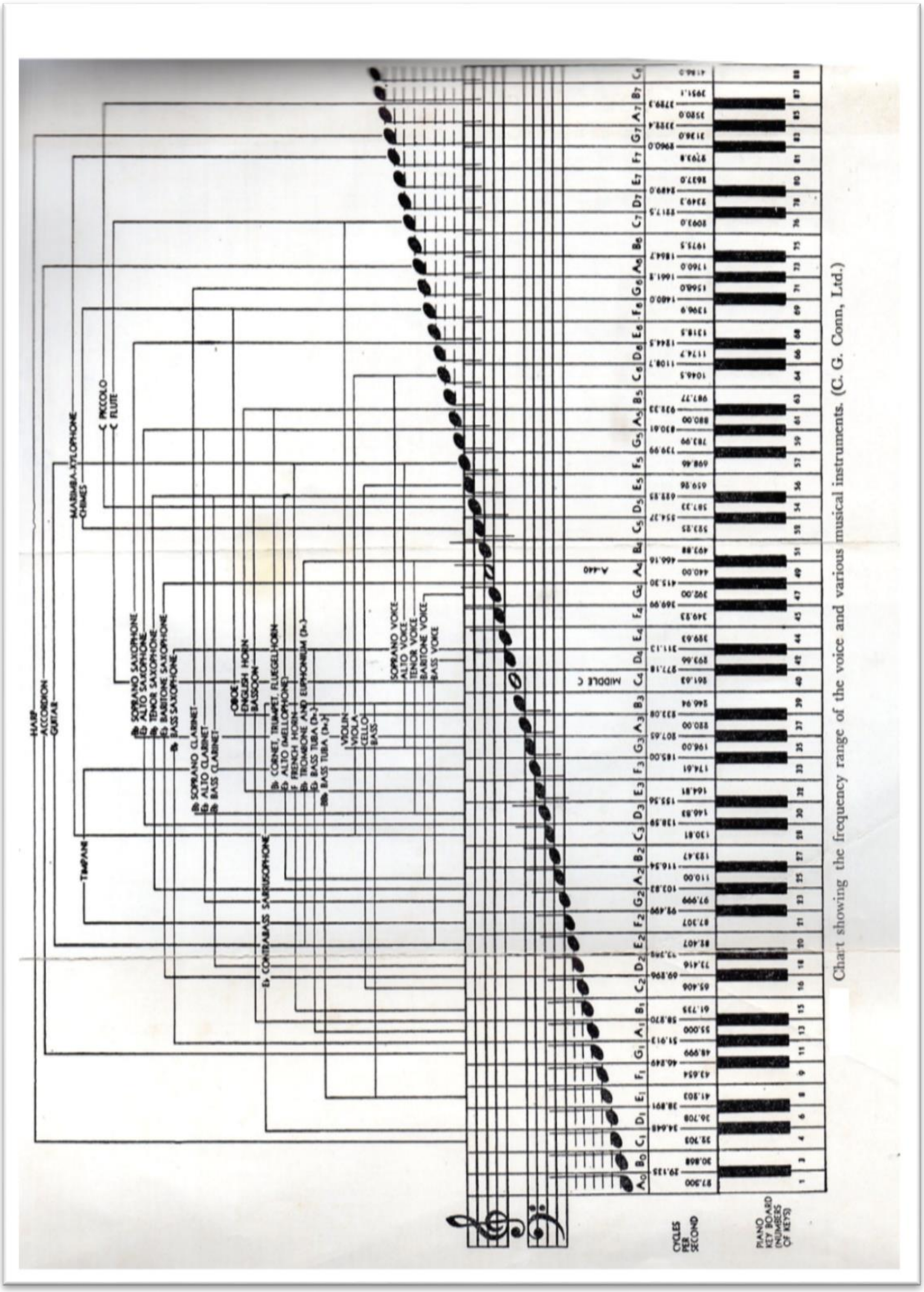



**Fig 3.6 Chart Showing the Frequency Range of the Voice and Various Musical Instruments**[6]

[6] Musical acoustics by Charles A. Culver , fourth edition, page 95

The diagram shows that the combined range of male and female voices totals about three and one half octaves (82-1046). It will be apparent that the average vocal soloist employs about twenty-five different notes.

Of the musical instruments the organ has the widest pitch range, extending from 16.4 vps, given by 32 ft. pipe, to 8372 vps sounded by a pipe whose speaking length is 3/4”. Some of the larger organs have a range of eight octave, but usually the span is seven octave or less.

The highest note employed in orchestral music in orchestra music is given by the piccolo, which has a pitch of $A\#_7$ (3729.3). The lowest orchestral tone is that of the bass viol, $E_1$ (41.2). The highest piano note is $C_8$ (4186), and the lowest $A_0$ (27.5).The ordinary pitches of the voice and of the more common musical instruments are indicated in the chart.

**In recent time Sitar is tuned to ‘D’ i.e. Safed 2**

| S/N | String | Pitch | Material | Gauge | Frequency Hz |
|---|---|---|---|---|---|
| 1 | Baaj /Open String D4 at Seven$^{th}$ Fret | G3 | Steel | 2 or 3 | 196 |
| 2 | Joda | D3 | Copper | 28 | 146.8 |
| 3 | Laraj | A2 | Brass | 24 | 110 |
| 4 | Kharaj | D2 | Mixed Metal | 21 | 73.4 |
| 5 | Pancham | A3 | Steel | 2 | 220 |
| 6 | Chikari | D4 | Steel | 0 | 293.7 |
| 7 | Chikari Treble/Octave | D5 | Steel | 0 | 587.3 |
| 8 | Tarab | As per tuning | Steel | 00 | |

## 3.3.2 Loudness:

Loudness of the sound is defined as the degree of sensation produced on the ear. It is quite different than the intensity of the sound.

The intensity of the sound is the energy of the sound wave crossing per unit time, through a unit area, perpendicular to the direction of the propagation.

Intensity of the sound is a physical quantity can be measured accurately.

Intensity of the sound depends on the following factors.

- The intensity of the sound is directly proportional to the square of the amplitude of the wave.
- The intensity is directly proportional to the size of the vibrating body. Larger the size of the vibrating body, more is the intensity hence louder is the sound.
- The intensity is directly proportional to the density of the medium through which it propagates.

  Means for the same vibrating body sound effect will be different if it is put in the air, than if it is put in liquid. This is also one of the reason why sound does not exist where there is a vacuum.

- The intensity of the sound is inversely proportional to the square of the distance from the sounding body.

  Means intensity of the sound will decrease as we move away from the sounding body.

  The acoustician is usually interested in comparing the intensities of two sounds rather than in the absolute value of either. In doing this it has become the practice to deal with the ratio of the two intensities involved. The human ear is a remarkable physical organ. It responds to an extremely wide range of intensity. In fact, the ear will respond to a sound whose intensity is10 billion times that require to produce a just audible sound. Because of this wide range of sensitivity, it has been found convenient to make use of a logarithmic scale in comparing sound intensity. There is a general relationship known as the **Weber -Fechner law** to the effect, that the response of any sense organ is proportional to the logarithm of the magnitude of the stimulus. As applied to the sense of hearing this would mean that if one were comparing two sounds, one which had an intensity of hundred units with another whose intensity was 10 units the oral response in the first case would be the twice that due to the less intense sound. This is because the logarithm of 100 is 2 while the logarithm of 10 is 1.

$$N = 20 \log_{10} (I / I_0) \text{ db.}$$

Where;

**N** is the intensity in decibels (**db**),

$I_0$ is the assumed reference intensity.

In the above relation both intensity (I) under comparison and the reference intensity $I_0$ are expressed in watts or micro watts per square centimetre.

In considering the matter of intensity levels, it is to be noted that a change in sound intensity of one decibel is approximately the smallest change in energy content that can ordinarily be recognised by the human ear. This corresponds to the change in acoustic power of approximately 26 percent. **In other words, the intensity of a given sound must be increased by one decibel, or 26 percent, before ear can detect any change in the 'strength' of the sound.**

When the intensity of the sound reaches a value of 120 db the listener begins to experience the pain. If the ear is subject to a sound of such intensity for a considerable period of time, damage to the organ of hearing may result. The following table gives the intensity levels of various sources of sound as given by different investigations.

### 3.3.2.1 Noise Levels Commonly Encountered[7]

| Source of Sound | Intensity Level in db |
|---|---|
| Breathing | 10 (Barely Audible) |
| Whisper | 20 |
| Average office | 50 |
| Ordinary conversation 3 ft. | 65 |
| Average factory | 78 |
| Noisy factory | 85 |
| Heavy traffic | 90 |
| Diesel engine | 105 |
| Airplane engine | 110 |
| Hammer blow on steel | 114 |
| Sound becomes painful | 120 |

[7] Musical acoustics by Charles A. Culver , fourth edition, page 59

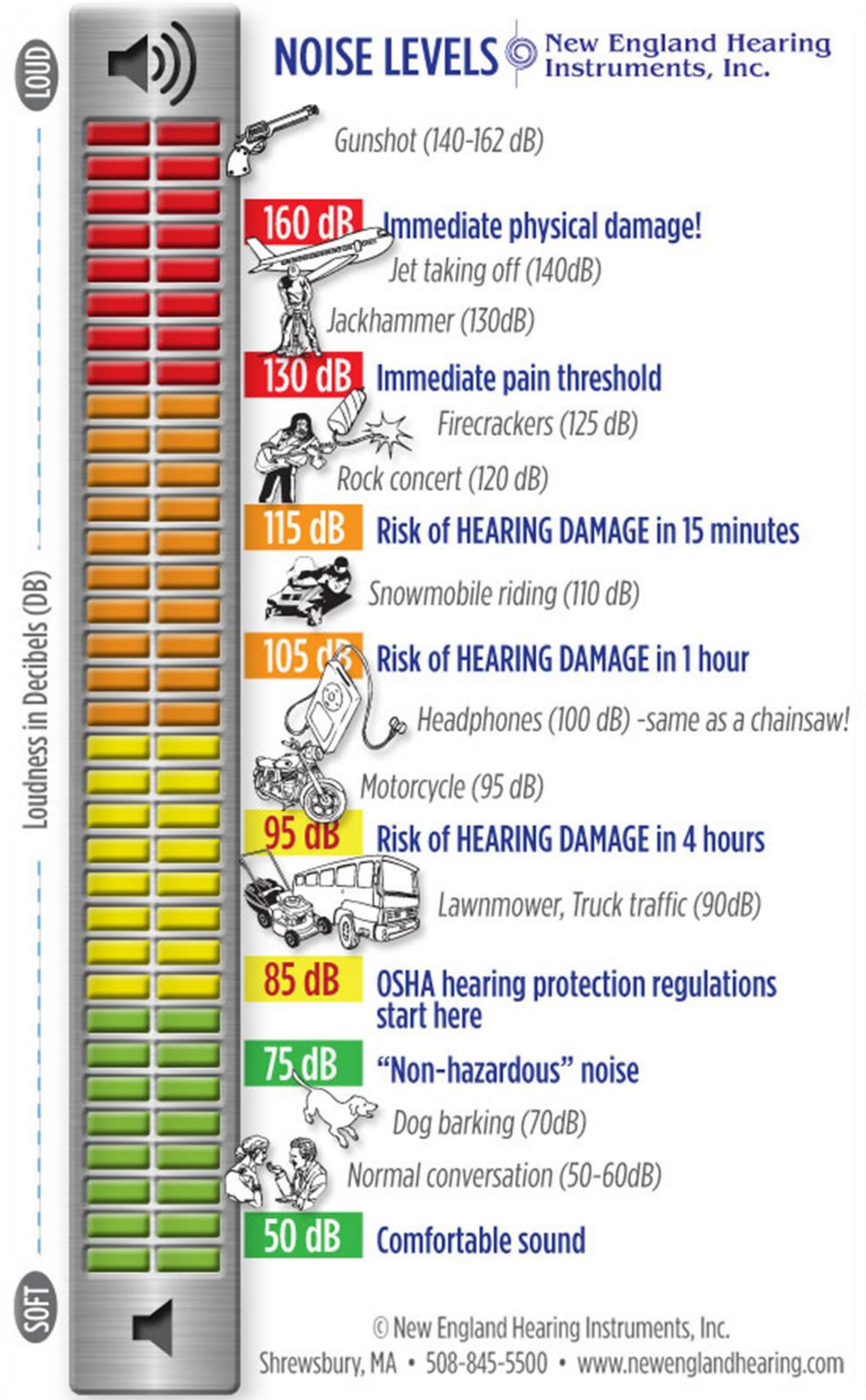



**Fig. 3.7 Chart of Noise Levels**[8]

[8] www.newenglandhearing.com

Acoustician uses a sound level meter to measure the intensity of the sound. Previously analog meters were in use. Now digital meters are in use.

**Loudness of the Sitar voice is varied by a Sitar player by varying the amount of force applied on the string by plectrum, or by changing the angle of application of the force, or by changing the point (place) of application of force on the string, or by combining all of them.**

The loudness changes from Sitar to Sitar even though all above factors are kept same.

### 3.3.3 Quality:

The quality of the sound is the property of the sound because of which we distinguish the musical notes produced by different musical instruments, or voices even though their pitch and loudness is same.

If same notes are produced by a Sitar or a violin one can feel the difference between them because of the quality.

French use the word '**Timbre'** to express this characteristic of a sound; and the Germans also have a word, **'Klangfarbe'**, a free translation of which is '**Tone colour**', which is used by them to designate what we term '**Quality**'.

Not only do our ears tell us that different sounds have different characteristics but the graphic representation of the corresponding sound wave also shows that definite differences exist.

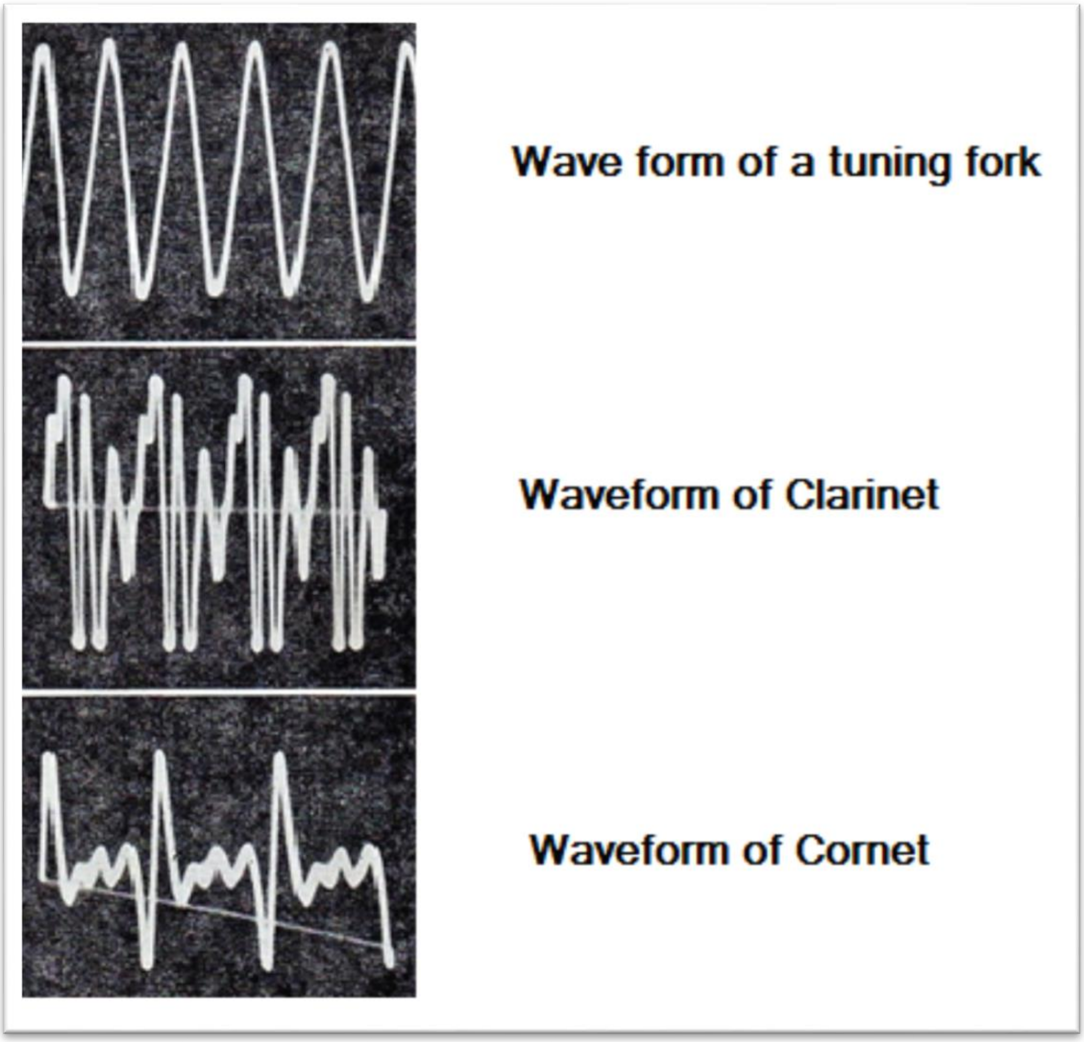
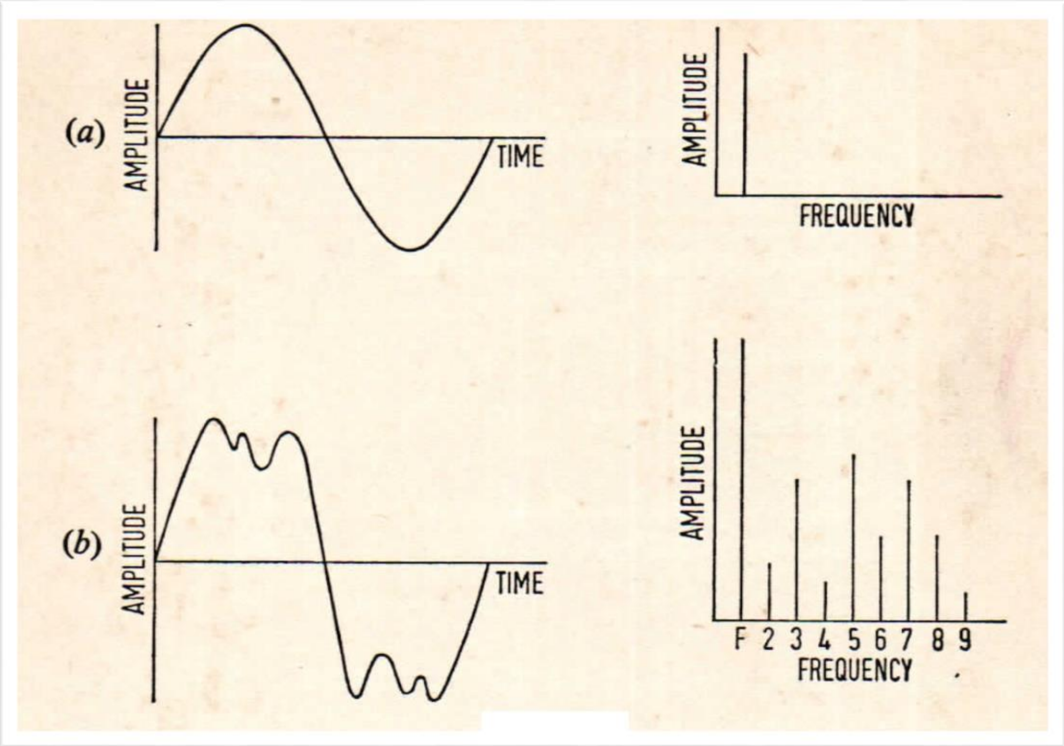



**Fig. 3.8 Waveforms of Tuning fork (top), Clarinet (middle), and Cornet, (bottom) each at a Frequency of 440, and at Approximately the Same Intensity**

In fig 3.8 the recorded wave forms of the sounds emitted by three well known sources are shown. In making these recording the pitch and the loudness level was held approximately equal in all the three sources. The marked difference in waveform indicates, that some factor or factors other than pitch and loudness, give rise to the difference in tone character what we refer to as quality or timbre.

Now it will be understood that why does, one sound particularly a musical sound differs in character from another similar sound?

It is agreed that a musical sound consist of a periodic motion in some medium, usually air. This means that the motion of the particles constituting the medium repeats itself once during each single period, and this regardless of the character of the motion. It is thus evident that, even though we hold the pitch and intensity constant, a wide variety of motions might give rise to a sound. Prof. G.S. Ohm a German physicist and mathematician first pointed out the physical basis of quantity. According to Ohm the motion of the particles of the transmitting media corresponding to a composite musical sound is in reality the sum of a group of simple periodic motions; and for each such simple oscillation there exists a simple tone, of a definite pitch, which the ear can detect. It accordingly follows that all but simple (pure) tones are composite.




**Fig[9].3.9 The Wave Form of a Pure Note, e.g. from a Tuning fork. The spectrum diagram (right) shows the single line at the frequency of the note.**

[9] Acoustics by G.W. Mackenzie, first publication, page 44

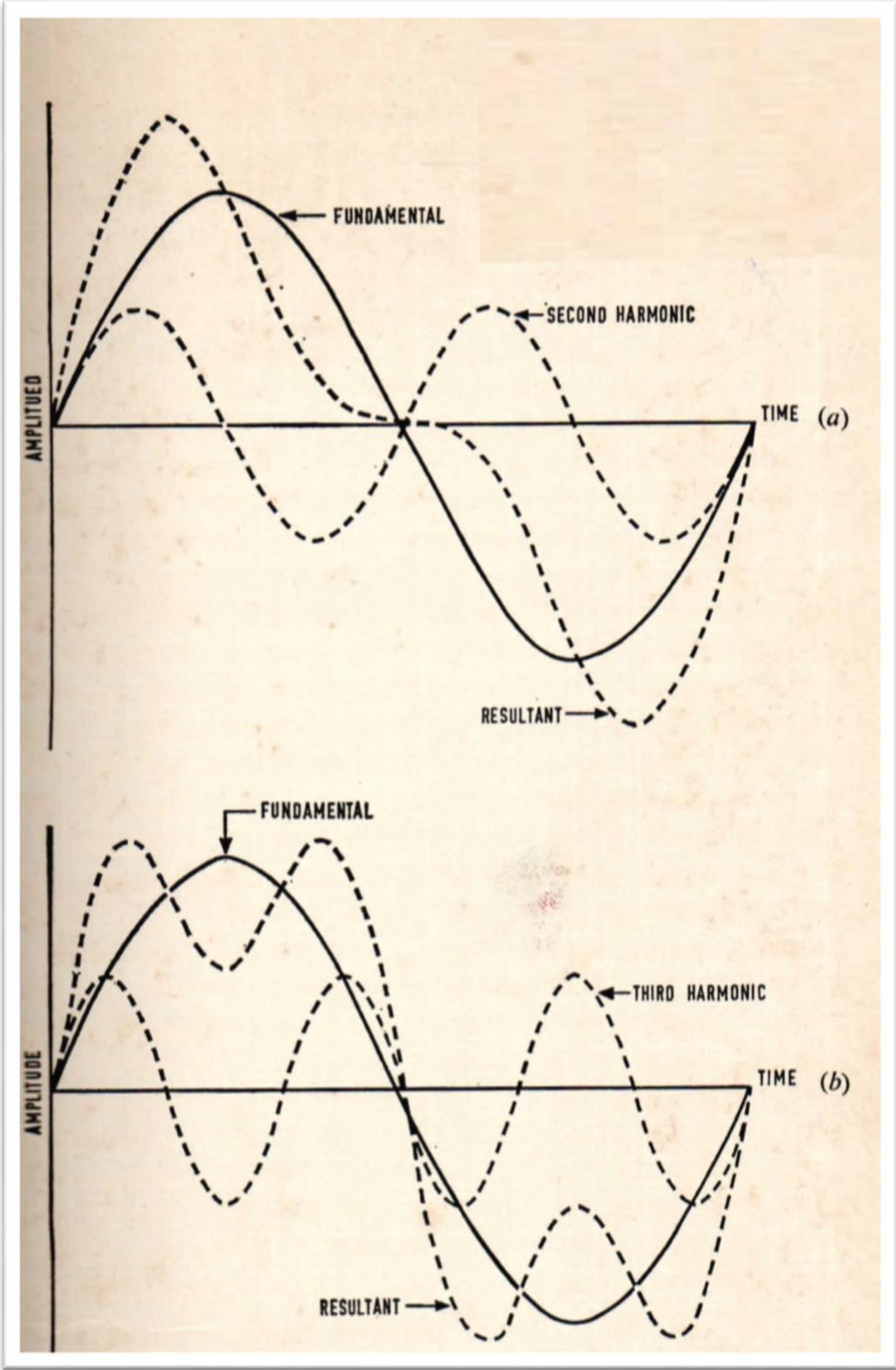
**(a) The wave form of a clarinet shows much more complicated wave and the spectrum diagram gives the amplitudes of the fundamental and the harmonics.**

If we take a tuning fork and examine its output on an oscilloscope, we find that it has a smooth sinusoidal wave form. Suppose we now take a clarinet and sound the same note as the fork. Not only will it sound very different, but we shall find that the wave form is quite different too. Instead of the smooth shape produced by the fork, the wave shape is such that although the cycle repeat in the normal way, the shape of each cycle is irregular. The sound of the fork is said to be '**Pure**' while that of the clarinet is 'Complex'. The note of the fork consists of only one frequency whereas the clarinet sound is a mixer of several frequencies.

This difference could be demonstrated by the means of a spectrum analyser, an instrument which separates the frequency present in a sound and can display them as spaced vertical lines. The height of each vertical line gives the amplitude of that particular frequency. The fork will show only one line, at the frequency marked on the fork, but the clarinet produces the several frequencies simultaneously and there will be a series of lines. The lowest frequency of the series will be the same as the fork; this called the fundamental. The other frequencies are the overtones of the fundamental. The spectrum analyser would show that all the overtones do not have the same amplitude, some being stronger than others. It is the presence of overtones and their relative strengths which gives the clarinet its characteristic tone.

In other words we can say that the several components which go to mark up such a complex sound structure are called **Partials Tones**, or briefly, partials; the partials having the lowest frequency is designated as the **Fundamentals**. The partials having frequencies higher than the fundamentals are referred to as **Upper Partials or**

**Overtones.** In many cases the frequency of the overtones are exact multiples of that of the fundamentals; and in such cases the fundamental and the upper partials together are called **Harmonics**.



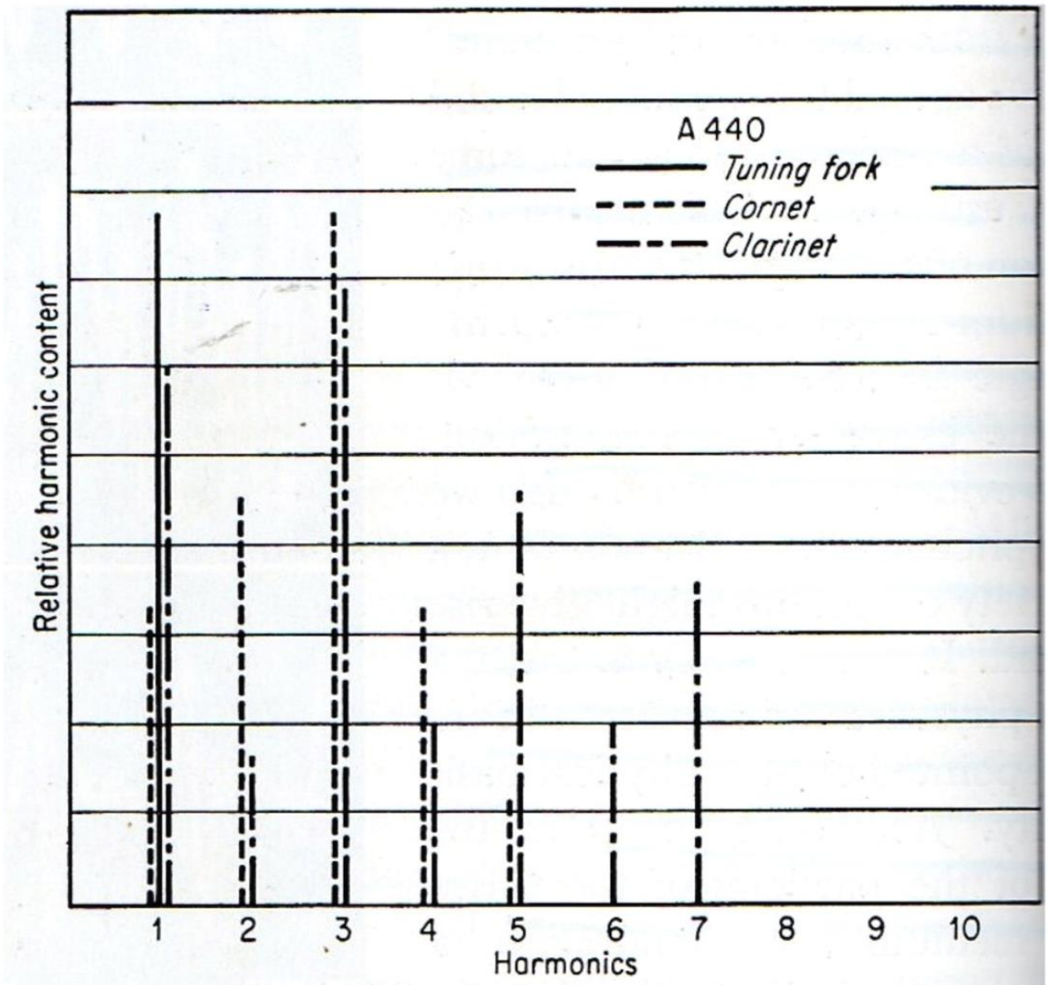

**Fig[10] 3.10 (a) In Addition of a Fundamental and Its Second Harmonics Gives 'Complex' Wave. The Exact Shape of this Resultant Depends On**

[10] Acoustics by G.W. Mackenzie, first publication, page 45

**the Relative Amplitude and Phase of the Fundamental and Second Harmonic. With Complex Sound Wave the Ear Ignores the Changes of the Phase, So that Even Though the Phase Relation of the Two Components Alters and the Wave Shape Changes There is No Difference in the Tone Quality.**

**(b) The Complex Wave produced by Adding a Third Harmonic to its Fundamental has quite a Different Shape from that shown in (a).**

In those cases where the frequency of the overtones are not exact multiple of the fundamental, the elemental tones are indicated by the term **Inharmonic** partials.




Spectra of instruments referred in previous diagram

**Fig. 3.11 Spectra of Instruments Referred in Previous Diagram**

The diagram shows the fundamental and upper partials of the tone emitted by three instruments whose waveforms are depicted in previous figure 3.8. Such charts are known as **Sound Spectra**. The length of the vertical line indicates the relative strength of several harmonics.

**Helmholtz** carried out a long and carefully devised series of experiments for the purpose of testing the validity of ohm's law of acoustics. His work was published in English with the title 'Sensations of the Tone'. This was able to draw the important law that, "**Difference in musical quality of tone depends solely on the presence and strength of partial tones and in no respect on the differences in phase under which these partial tones enter into composition".**

In general the sound produced by any source is complex in the nature. It is consisting of the fundamental tone (having lowest pitch), and overtones (Higher pitch). The quality of the sound depends on the number of overtones present with the fundamental, and their relative intensity and pitch. For example, an open pipe produces overtones forming a full harmonic series, while a closed pipe produces only odd members of the series. Hence note of an open pipe is sweeter than that of a closed pipe.

**Tonal Quality of the Sitar Depends on Following Factors as Per My Opinion and Experience.**

- The components and material used to make a Sitar.
- Design of a Sitar
- Length, Thickness and metal type of the string.
- Resonator type and size of the Sitar.
- The way string is put on to the vibration.
- Playing style of a Sitar player.

## 3.4 Consonance and Dissonance:

When two or more than two notes are sounded together or one after other, the resultant note is called '**Chord**'. When the effect produced by a chord is pleasant, then it is called as '**Consonance**' or '**Concord**', but if it produces unpleasant sound it is known as '**Dissonance**', or '**Discord**'.

When two or more than two notes are sounded simultaneously to produce a pleasant effect it is called as '**Harmony**'. But if they produce pleasing effect only when sounded one after another they are known as the' **Melody**'.

In Sitar, when it is played on the first string, by pressing the frets one after another by a finger produces Melody.

But when we play the stroke in which more than one string sounds together, it produces the Harmony. So Sitar strings are tuned in accordance with this theory, and to particular note respectively. In seven string Pt. Ravi Shankar style Sitar, strings are tuned in consonance of Sa, Pa, and Sa**.** , where as some of the artist tune them for consonance of Sa, Ga and Pa forming a western type of the chord.

## 3.5 Vibrato:

This effect is to be observed most frequently in connection with the vocal renditions and in playing of the string instruments. Here this aspect will be studied in reference of Sitar as a string instrument. The effect consist of periodic variation of the tone, the frequency of the fluctuations being two or five per second. Extensive studies carried on this shows that the vibrato is essentially a frequency modulation effect. There is also evidence to the effect that there sometimes exists a simultaneous amplitude-modulation effect. When both frequency and the amplitude modulations occur concurrently, the waveform will likewise undergo a periodic change. In the case of human voice, the vibrato effect appears to be largely involuntary, and possibly may be associated with a periodic lessening of the muscular tension required to produce a sustain note. The emotional content of the passage seems to have some bearing on the degree of the vibrato effect. In the case of Sitar vibrato effect is deliberately produced by the player as he brings about a periodic alteration of the length of the vibrating string by movement of his finger on the string. For doing so Sitar player moves his finger slightly on the string so effective length of the string varies, varying the frequency of produced sound.

This effect is wholly frequency modulated phenomena. The voice produced because of the vibrato is more pleasing than that of the sustained, at a constant level of pitch and amplitude. The effect on the auditor is to some extent at least, a psychoacoustical one. In any event, the reaction of the listener is in favour of a tone that is subject to a slight modulation effect; it seems to be more rich and satisfying. Undoubtedly there are subtle, and somewhat intangible, elements that enter into the determination of tonal quality; and vibrato appears to fall in this category.

**A good vibrato is a pulsation of pitch, usually accompanied by synchronous pulsations of loudness and timbre, of such extent and rate as to give a pleasing flexibility, tenderness, and richness in the tone[11].**

This is a definition of a good vibrato. But vibrato may be good, bad, or indifferent. A bad vibrato is any periodic pulsation of pitch, loudness or timbre which singly or in combination, fails to produce pleasing flexibility, tenderness, and richness of tone.

[11] In search of beauty in music by Carl E. Seashore, page 56

The definition describes its function, which is to give a pleasing flexibility, tenderness, and richness to the tone. These three aspects are universally recognised as desirable and fundamental in musical aesthetics. Each holds a distinct and definable place in any psychological classification of the expression of feelings.