



Fundamentals of Acoustics



What you will Learn in this Lesson

- Sound power vs. pressure
- Decibels
- Octave bands
- Point, line and plane sound sources
- Source – Path - Receiver Concept
- Sound in confined spaces
- Sound transmission

Sound Basics

- Sound is a disturbance in an elastic medium that can be detected by the human ear
- Noise is sound we don't like
- Amplitude of sound wave is loudness

Wavelength and Frequency

$$\lambda = c_o / f$$

Where:

λ = wavelength in feet

c_o = speed of sound (1120 fps at sea level)

f = frequency (Hz)

$$\begin{aligned} 16 \text{ Hz} &= 70 \text{ ft Wavelength} \\ 16,000 \text{ Hz} &= 0.07 \text{ Ft} \end{aligned}$$

Sound Waves

- Sound waves are small pressure fluctuations above and below atmospheric pressure
- The amplitude is how loud the sound is
- The frequency (wavelength) is the pitch
- The denser the medium, the faster sound travels
- The speed of sound is 764 mph at standard conditions
 - Speed of sound in water is 3315 mph

Sound Waves

- Sound frequencies can be super imposed
- A single frequency of sound is a ***Tone***
- Almost all sounds are made up of many frequencies all at once
- Proper sound analysis requires looking at the individual sound frequencies

Human Response to Sound

- Human sound range is from 16 to 16,000 Hz
- Humans can hear sound levels from 0.00002 Pa To 20 Pa
 - Million times louder
- This is such a large range that logarithmic scale is used

Sound Pressure vs. Sound Power

- Consider a 5 kW electric heater
 - 5 kW rating is acoustic equivalent of sound power
- The space temperature provided by the heater is the acoustic equivalent of sound pressure
 - It will depend on the space
 - The 5 kW heater will have almost no effect in the Toronto Skydome
 - It would provide a comfortable temperature in a small room in a house
- Comparing a the kW rating from ABC company to the 123 company is straightforward but does not tell you if the occupant will be comfortable.
- If the ABC company says the occupant will be comfortable with a 5 kW heater, the fine print **MUST** define the room that statement is based on!

Sound Basics

- Decibel is logarithmic
- $L_p = 20\text{Log}(P/0.0002)$
 - P is sound pressure in pascals
- $L_w = 10 \text{ Log}(W/10^{-12})$
 - W is sound power in watts
- Every 3 dB is doubling sound power/pressure

When Two Decibel Values Differ By	Add The Following Number To The Higher Number
0 or 1 dB	3 dB
2 or 3 dB	2 dB
4 to 9 dB	1 dB
10 dB or more	0 dB

Octave Bands

16 and 31.5 Hz are not
part of traditional
“Octave bands”

Center Frequency	16	31.5	63	125	250	500	1000	2000	4000	8000
Max Freq. (Hz)	23	44	88	88	175	350	700	1400	2800	5600
Min. Freq. (Hz)	11	22	44	175	350	700	1400	2800	5600	11200
Wavelength (ft)	70	36	18	8.96	4.48	2.24	1.12	0.56	0.28	0.14

- Sound calculations are divided into 8 octave bands as shown above
- All the sound energy or pressure from the minimum to maximum frequency is summed in one band
- Some calculations are now based on 1/3 octave bands (24 data points)
- Sound is **NOT** evenly distributed across the octave bands!
- A tonal sound is a lot of sound energy at one frequency
 - Very annoying!

Human Response to Sound

- Human response to sound is NOT linear!
 - If you half the sound energy it would be just perceptible
 - To reduce the “Sound” in half, the sound must drop to 1/10 its original decibel level!
- Humans are more fussy about certain octave bands!
 - E.g. 1000 Hz (speaking range)
 - A 60 dB sound source at 1000 Hz will be more apparent than a 60 dB sound source at 63 dB

Sound Change Level (dB)	Acoustic Energy Loss	Relative Loudness
0	0	Reference
-3	50%	Perceptible Change
-6	75%	Noticeable Change
-10	90%	Half as loud
-20	99%	1/4 as loud
-30	99.9%	1/8 as loud
-40	99.99%	1/16 as loud

Sound Measuring Systems

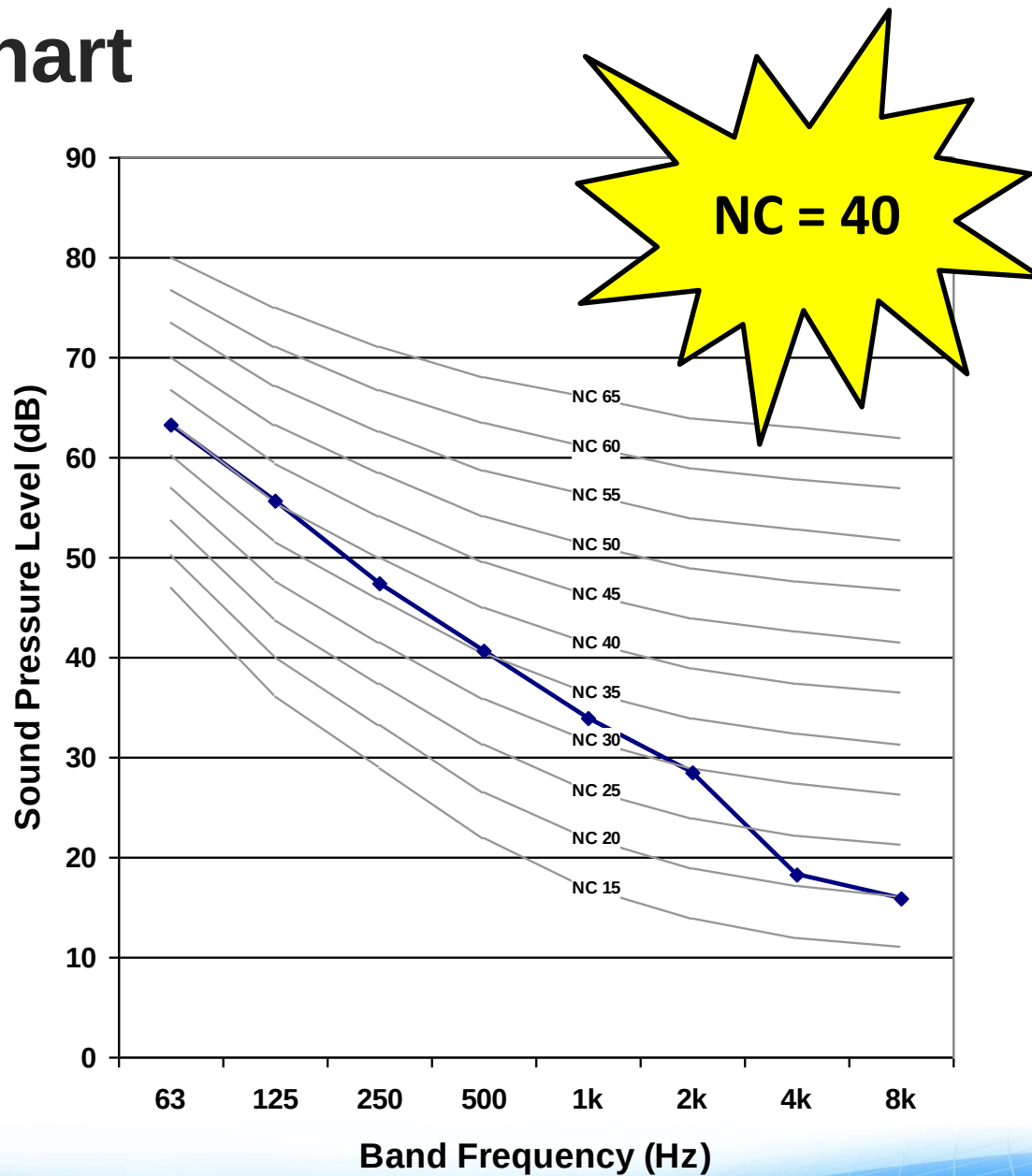
- The following are common sound measuring systems that attempt to take into account how humans behave to certain frequencies and sound quality
 - NC (Noise Criteria)
 - RC (Room Criteria)
 - NR (Noise Rating - ISO standard)
 - dBA (A weighted sound pressure)

dBA

Band	63	125	250	500	1000	2000	4000	8000
Adjustment	-26	-16	-9	-3	0	1	1	-1

- The above correction factors are added to each octave band and then the octave bands are logarithmically added together to a single value
 - E.g 75 dBA
- Everybody likes it because it is just one number
- Commonly used for property line (outdoor) calculations
- If you have a problem dBA level, you will not know how to fix it

NC Chart



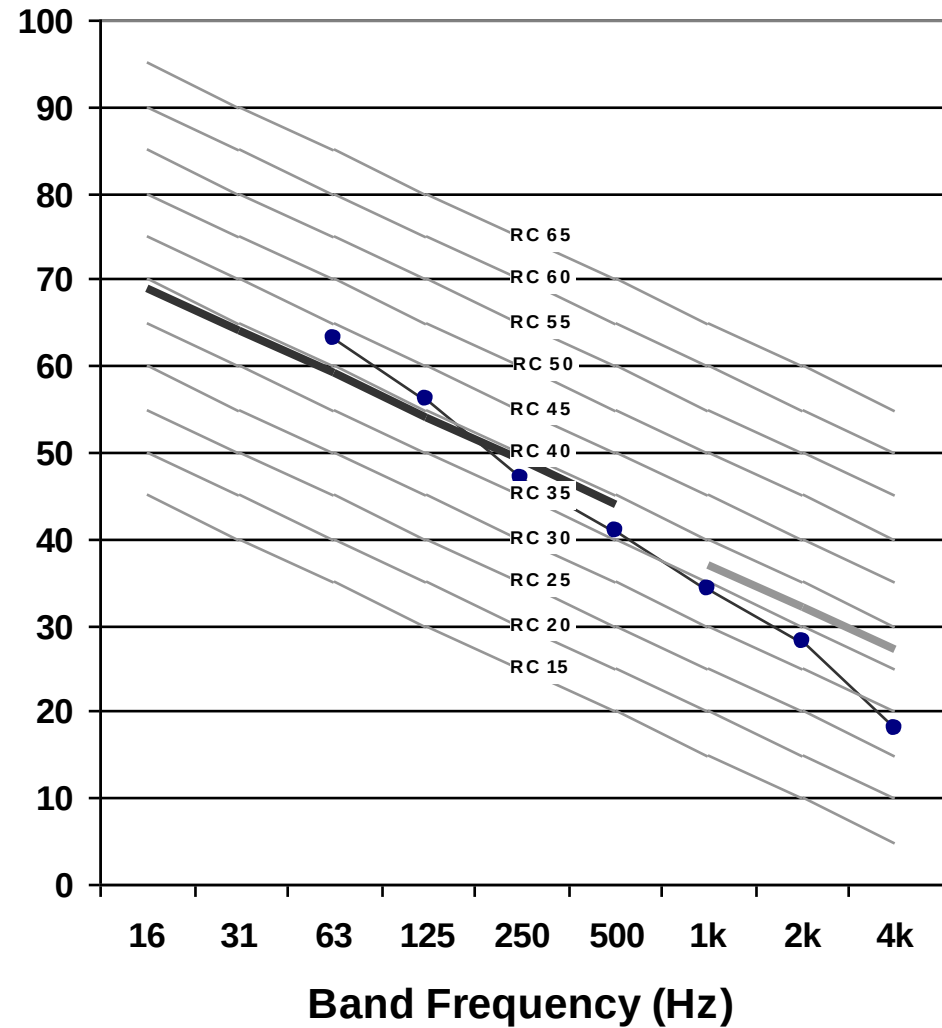
NC Chart

- Most common system in HVAC
- It is:
 - Sound pressure measured in the space
 - Measured at the 8 traditional octave bands
 - Takes into account the human response to sound sources
 - Curved shape of NC lines
 - More tolerant of low frequency sounds
 - NC Level is based on the highest sound level measured at any given octave band
 - Tangent rule
 - Not the “average”

Room Criteria

RC = 34R

Lp (dB RE 20 μ Pa)



● Sound meter Lp — Hiss Threshold
— Rumble Threshold

RC Chart

- ASHRAE System that enhances the NC charts by taking into account:
 - Lower 2 octave bands (16 and 31 Hz)
 - Quality of sound
- RC value is based on average of 500, 1000 and 2000 Hz bands
- R = Rumble
 - Occurs when any value is more than 5 dB greater than standard curves 500 Hz and below
- H = Hiss
 - Occurs when any value is more than 3 dB greater than standard curve values above 500 Hz
- N = Neutral
 - Between the dead bands

Acceptable Indoor Sound Levels

Space	RC(N)	NC
Private residences, apartments, condominiums	25-35	25-35
Hotels/Motels		
Individual rooms or suites	25-35	25-35
Meeting/banquet rooms	25-35	25-35
Halls, corridors, lobbies	35-45	35-45
Service, support areas	35-45	35-45
Office Buildings		
Executive and private offices	25-35	25-35
Conference rooms	25-35	25-35
Teleconference rooms	25 max	25 max
Open plan offices	30-40	30-40
Circulation and public lobbies	40-45	40-45
Hospitals and Clinics		
Private rooms	25-35	25-35
Wards	30-40	30-40
Operating Rooms	25-35	25-35
Corridors	30-40	30-40
Public areas	30-40	30-40
Performing Arts		
Drama theaters	25 max	25 max
Concert and recital halls	A	A
Music teaching studios	25 max	25 max
Music practice rooms	25 max	25 max

Acceptable Indoor Sound Levels

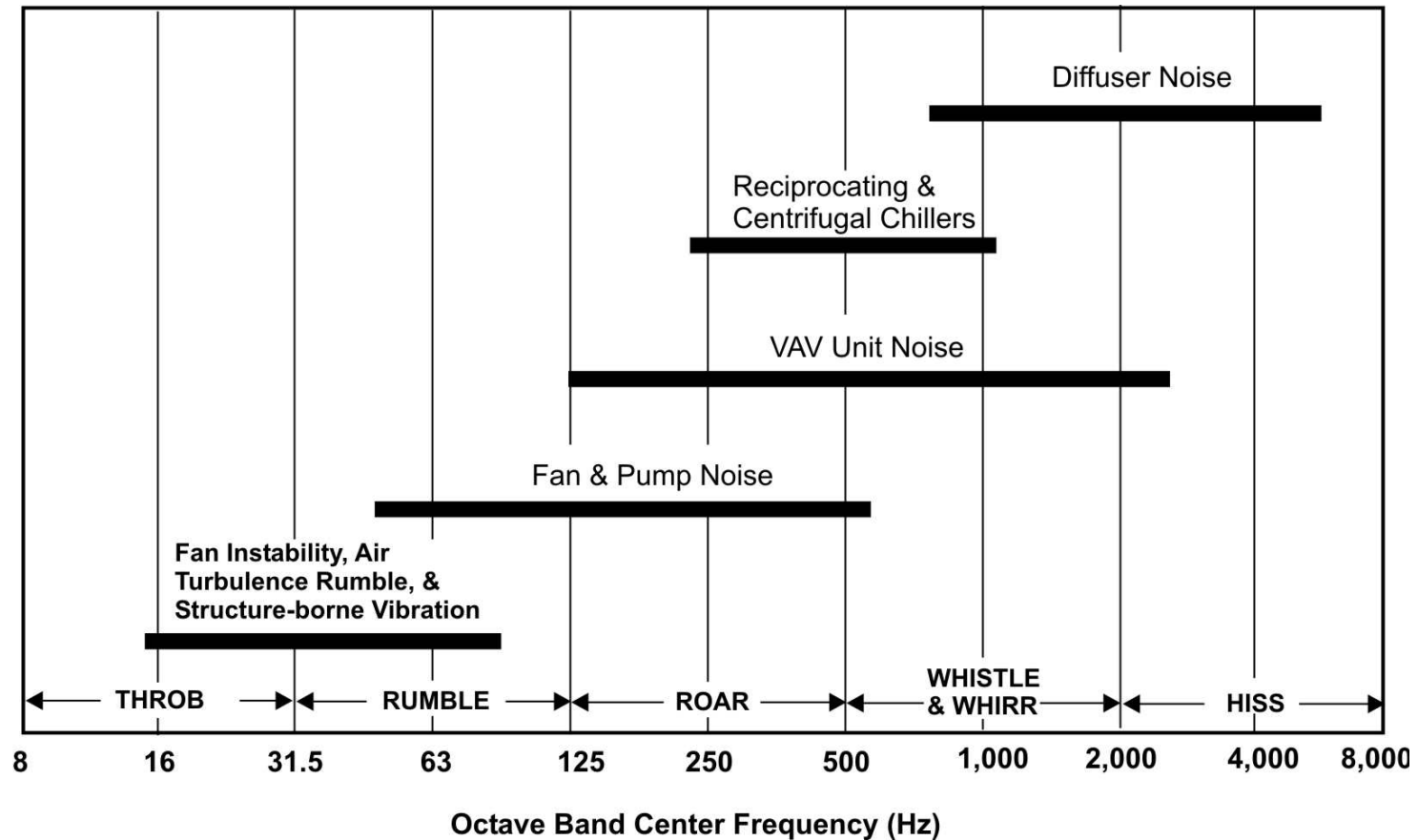
- Often general specs for equipment will require ***“Space shall not exceed NC 35...”***
- This is the same as saying ***“air conditioning equipment shall maintain 75°F...”***
- It is how the equipment interacts with the space that will determine the sound level.
- Watch this specification
 - Its purpose is to make the engineers problem your problem!

Acceptable Property Sound levels

- Sound levels set by local code
- Usually use dBA system
- Inspector will check to make sure building conforms with local bylaw
- Pay close attention to schools and hospitals built in residential neighborhoods!

Type of District	Max Level (dBA)	
	7am – 7pm	7pm – 7am
Single Family Residential	50	45
Multi Family Residential	55	50
Commercial	60	55
Industrial	70	70

Typical HVAC Equipment Sound



Testing Equipment

- Trade associations agree on test standards for most HVAC equipment
 - AHRI
 - AMCA
 - ISO
- They are all different!
- Most equipment will not fit and cannot be run in a sound lab
 - Tests have to be done outdoors or in a factory
 - Not well controlled – low accuracy

Equipment Sound Data Formats

- Air Distribution products
 - NC most common
 - Some manufacturers provide sound power by octave band
- VAV and fan assisted boxes
 - Sound power by octave band
 - Sometimes NC

Equipment Sound Data Formats

- Cooling towers
 - dBA most common
- Pumps
 - Sound power by octave band

Equipment Sound Data Formats

- Air handling units and rooftop units
 - Sound power by octave band
 - Often separate supply, outdoor and return air sound power levels
 - Radiated sound power

Equipment Sound Data Formats

- Air cooled chillers
 - Sound power and/or sound pressure by octave band
 - dBA
- Water cooled chillers
 - Sound pressure as per AHRI 575

Equipment Sound Data Formats

- Ductless terminal products
 - Fan coils, WSHPs, PTACs etc
 - AHRI 350
 - Sound power by octave band
- Ducted terminal products
 - Fan coils, WSHPs, PTACs etc
 - AHRI 260
 - Sound power by octave band
 - Typically radiated, discharge and return sound power levels

Calculating Sound Power From Sound Pressure

- Comparing sound power levels between two pieces of equipment will tell you which will be louder and in what frequencies
 - It will not tell you how it will sound in a given space or at the property line
- To do this, we need to convert sound power into sound pressure
 - To do this, we need to know the properties of the space
- Prepare yourself – this is going to hurt!

SOURCE – PATH - RECEIVER

Point Source Sound Levels

- As soon as the sound energy interact with the space, it creates sound pressure
 - The pressure will radiate out from the source like ripples in a pond but in 3D
 - The sound pressure will decrease by the square root based on the distance

Point Source Sound Level

$$L_p = L_w + 10\text{Log}(Q/4\pi d^2) + k$$

Where:

L_p = Sound pressure, Pa

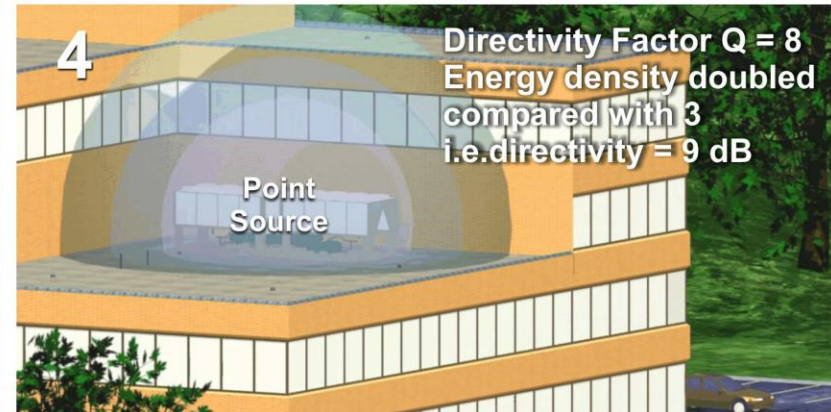
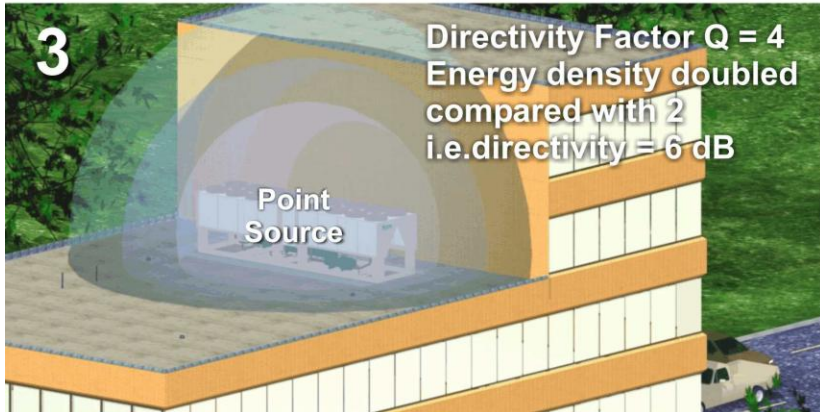
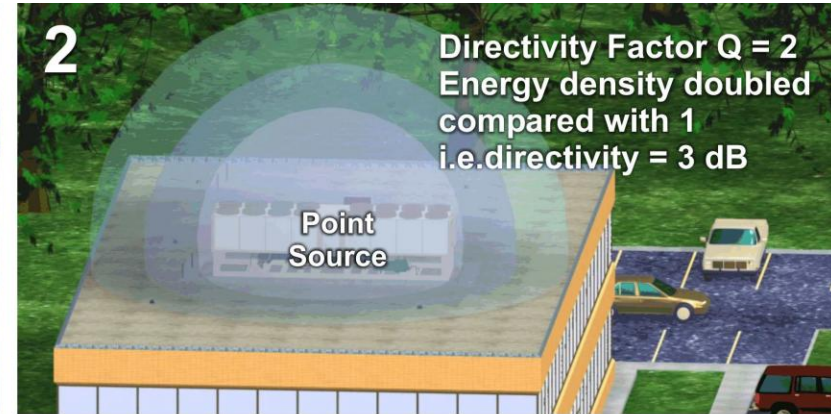
L_w = Sound power, W

Q = Directivity ($Q=1$ for a spherical radiation)

d = Distance in feet

k = Constant = 10.5

Directivity

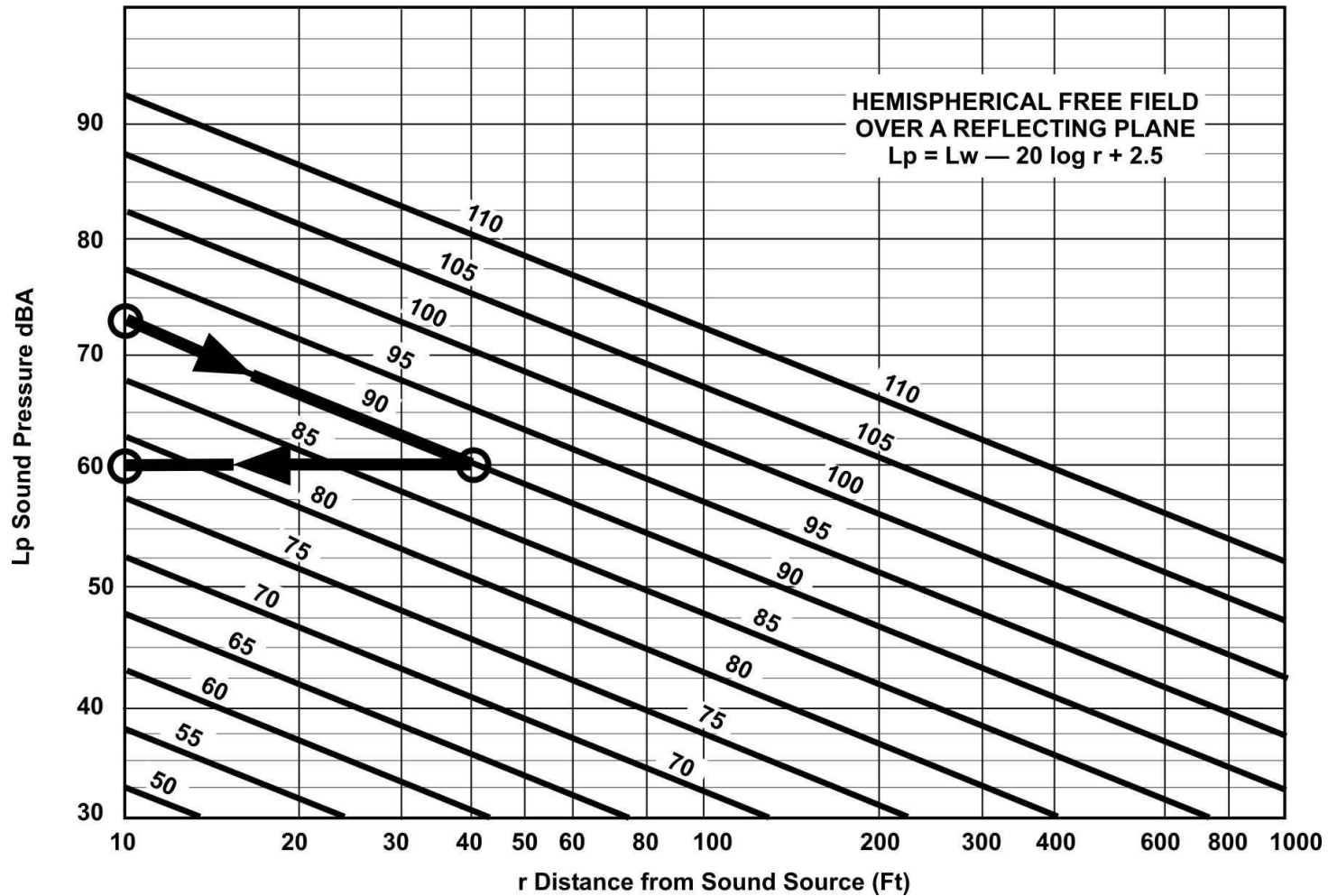


Ground Level Point Source

$$L_p = L_w + 10\text{Log}(1/2\pi d^2) + 10.5$$

- $Q = 2$
- This is typical of a unit on grade or on top of a roof.

Free Field Sound Pressure



Line Source Sound Level

- Sound radiates in a cylindrical pattern from a source
 - Ductwork
 - Highway

Line Source Sound Level

$$L_p = L_w + 10\text{Log}(Q/\pi dL) + k$$

Where:

L_p = Sound Pressure

L_w = Sound Power

Q = Directivity ($Q=1$ for a spherical radiation)

d = Distance in feet

L = Length of sound source

k = Constant = 10.5

Plane Source Sound Levels

- Sound radiates from a flat surface such as a wall
- Will depend on how close you are to wall
- In close, sound level does not change with distance
- Medium distance, sound level has a fixed and variable component
- Long distance, sound pressure varies with distance only

Plane Source Sound Level

When $d < b/\pi$

$$L_p = L_w + 10\log(\pi/(4bc)) + k$$

When $b/\pi < d < c/\pi$

$$L_p = L_w - 10 \log(d) - 10\log(4c) + k$$

When $d > c/\pi$

$$L_p = L_w - 20 \log(d) - 11 + k$$

Where:

d = distance in feet

c = larger dimension of sound source in feet

B = lesser dimension of sound source in feet

k = constant = 10.5

Lp From Lw In Open Field

- Point Source

$$L_p = L_w + 10\log(Q/4\pi d^2) + k$$

Ideally 6 dB drop for every doubling of distance

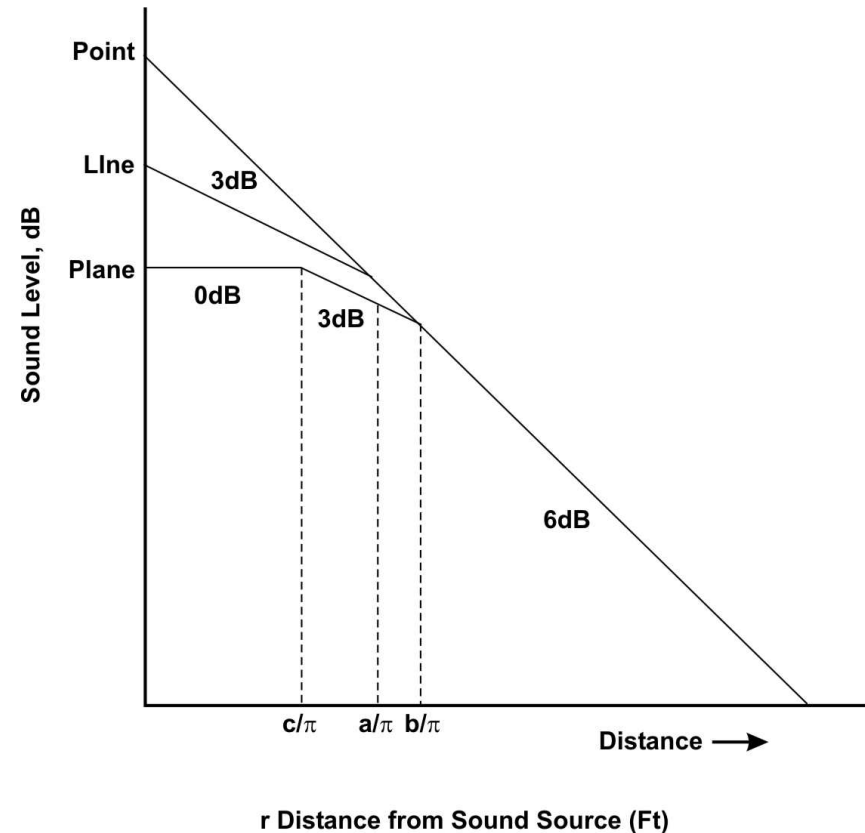
- Line Source

$$L_p = L_w + 10\log(Q/\pi d L) + k$$

- Plane Source

$$L_p = L_w - 10\log(d) - 10\log(4c) + k$$

Q = directivity factor (sphere = 1)
k = 10.5 for I-P and 0.5 for SI



Sound Pressure in Confined Space

- When sound source is released in a confined space (room) the sound energy
 - Radiates out in the ***near*** field
 - Reflects off surfaces back to receiver in ***reverberant*** field
 - Some sound is absorbed by surfaces
 - Some sound transmits through surfaces

Confined Space Sound Level

$$L_p = L_w + 10\log(Q/\pi d^2) + 4/R + k$$

Where:

L_p = Sound Pressure

L_w = Sound Power

Q = Directivity ($Q=1$ for a spherical radiation)

d = Distance in feet

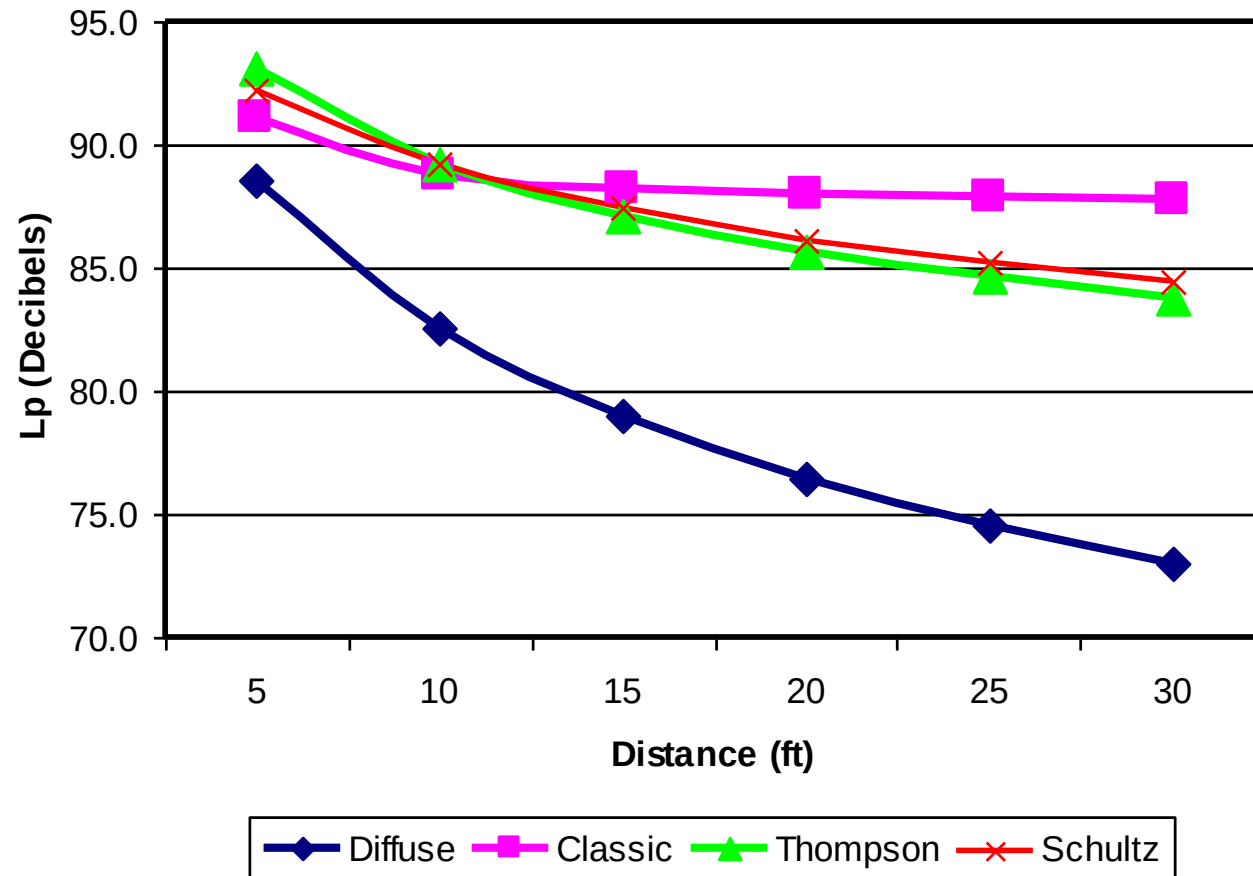
R = Room constant

k = Constant = 10.5

Sound Pressure in Confined Space

- If receiver is close to source, near field is dominant
 - $10\text{Log}(Q/\pi d^2)$
- As receiver moves away from source, reverberant source comes into play
 - $4/R$
- Room Constant is acoustic property of wall
 - If $R = \infty$, then room behaves like a free field (Anechoic Chamber)

Sound Level vs. Distance in Confined Space



Sound Transmission Through Wall

- Some sound energy will transmit through walls
 - Reduces sound level in source room
 - Increases sound level in adjoining room

Sound Transmission Through Wall

$$NR = TL - 10\log(S_w/R)$$

Where:

- NR = noise reduction, dB
- TL = Transmission Loss of wall, dB
- S_w = is common wall area, ft²
- R = Room Constant of receiving room

End of Lesson

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