The Acoustics of Sound Systems for Baseball

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http://audiosystemsgroup.com

System Uses and Needs

- Basic Public Address
- Sing the anthem
- Public safety
  - Crowd control
  - Emergency announcements
- Fire up the crowd (and the team)
  - Loud music
  - Enthusiastic announcer

System Uses and Needs

- Special events
  - Presentation of awards
  - A band plays before the game
  - Major productions
- Production communication
  - Support for special events
- Support for hearing impaired

System Uses and Needs

- Some facilities used for other sports
  - Football
  - Soccer
- Some facilities have non-sports uses
  - Public assembly
  - Exhibitions
  - Concerts
  - Tractor pulls

System Uses and Needs

- Main sound system
  - Covers all spectator seating
  - Public address functions
  - Sound reinforcement - small band, anthem, bigger programs
  - Very good uniformity of direct sound, frequency response, intelligibility, wide dynamic range

System Uses and Needs

- Hearing Impaired system
  - FM radio
- Private boxes and suites
  - Public address functions
  - Crowd ambience
- Press box
  - Official scorer announcements

System Uses and Needs

- Electronic feeds to broadcast media
  - Main sound system
  - Umpire or referee (especially football)
  - Crowd ambience mics
- Concourses and concession areas
  - Main sound system
  - Play-by-play from radio or TV

System Uses and Needs

- Security office access to all systems
  - Crowd control
  - Emergency announcements
  - Take over system if necessary
- Tie lines
  - Microphones, line level, intercom, loudspeakers
  - Playing field, press areas, grandstands
- Production Intercom system

Performance Requirements

- All sound within 15 dB within 30 ms
- Direct sound equal ±3 dB
- Frequency response uniform ±3 dB
  - 250 Hz to 5 KHz most critical
  - 100 Hz to 8 KHz if possible
  - Integrate over 30 ms for mids and highs
  - Longer integration time below 400 Hz
- Loud enough to keep up with crowd

Performance Requirements

- Be a good neighbor
  - Control program dynamics
  - Overall loudness
  - Compression and peak limiting
  - Something special for main park announcer
- Automatic level control
  - Keep announcer under control
  - Adjust to loudness of crowd

Two Basic Approaches

- Point source covers most or all of park
  - A lot of large loudspeakers
  - Typically on scoreboard
- Advantages
  - Usually cheaper --it's all in one place
  - No loudspeakers near fans - sight lines
- Disadvantages
  - High variability due to weather effects
  - Spill to Neighborhood

Two Basic Approaches

- Lots of much smaller loudspeakers
  - Well distributed around all seating
- Advantages
  - No weather variability
  - No big cluster on scoreboard
  - Very little spill to neighborhood
- Disadvantages
  - Sight lines
  - Cost

Wrigley Field - The Ballpark

- Intimate
- Low Key
- Traditional
- You can hear the crack of the bat.
- You can hear the players.
- And yell at them!

Wrigley Field Sound System

- Distributed Loudspeaker System
- Intimate
- Low Key
- It doesn’t overpower you.
- You can still hear the players.
- And the crack of the bat.
- Baseball (and Wrigley Field) is the star.

Weather Effects

- Very Powerful
- Highly Variable
  - Short Term (seconds)
  - Medium Term (minutes)
  - Long Term (hours, days)

“Sound waves travel from source to receiver outdoors through an atmosphere that is in constant motion. Turbulence, temperature and wind gradients, viscous and molecular absorption, and reflections from the earth’ surface all affect the amplitude and create fluctuations in the sound received. The longer the the transmission path through the atmosphere, the less certain the average amplitude and the greater the fluctuations in the received sound.”

Leo Beranek

Excess Attenuation

- (i.e., beyond inverse square law)
  - Varies with Frequency
  - Varies with Humidity
  - Varies with Temperature
  - Mechanisms are VERY complex
    - Mostly empirical data
    - Inconsistent data (hard to measure)

Excess Attenuation

"Energy is extracted from a sound wave by rotational and vibrational relaxation of the oxygen molecules of the air. The vapor content determines the time constant of the vibration, which is more important than rotational relaxation."

(Leo Beranek)

Excess Attenuation

"Energy is lost as oxygen molecules hang around with water vapor molecules and have a good time and lose energy in the process."

(Peter Mapp)

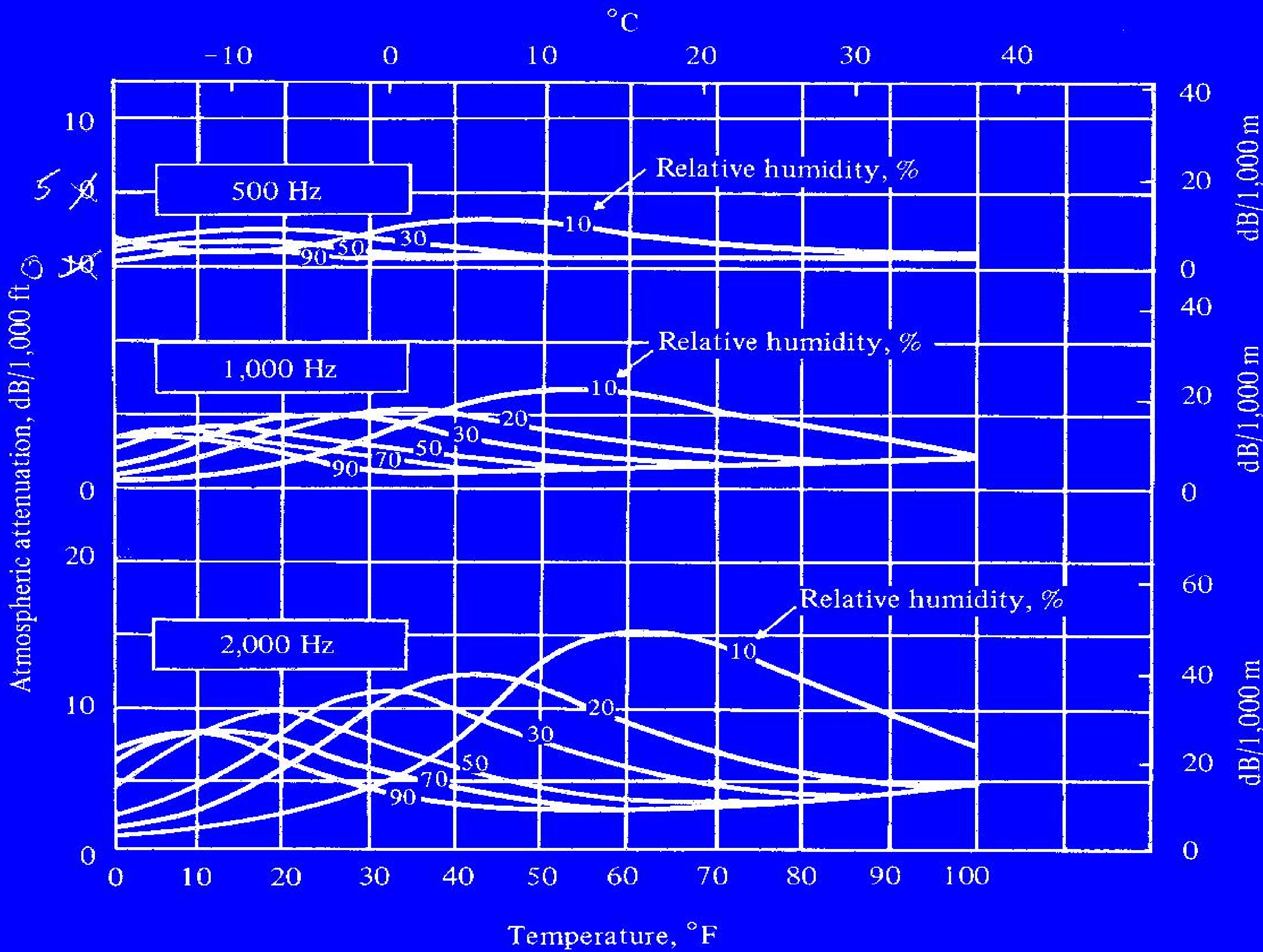


FIGURE 1.31. Atmospheric excess attenuation for aircraft to ground propagation for octave band center frequencies 500, 1,000, and 2,000 Hz.

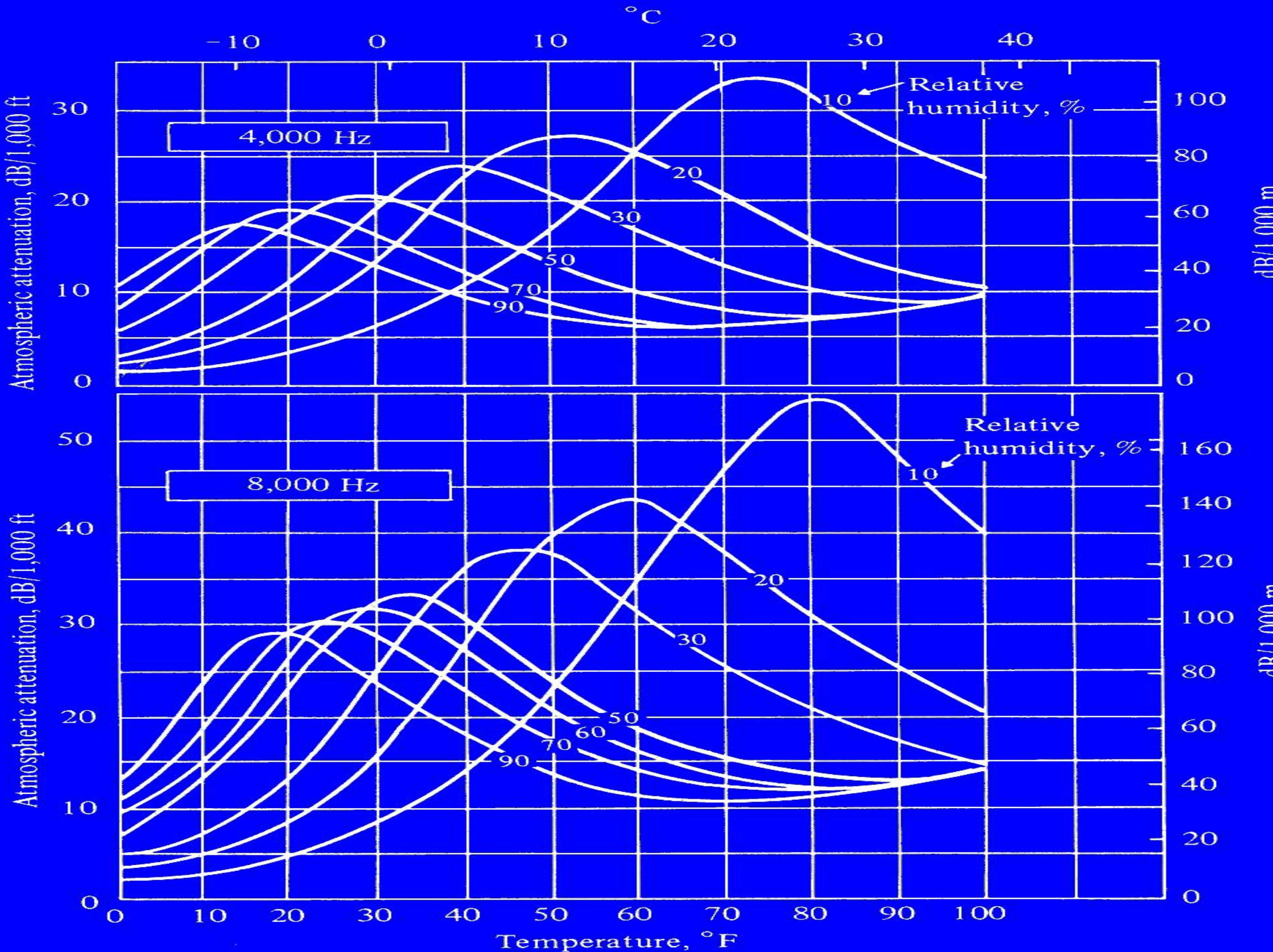


FIGURE 1.32. Atmospheric excess atenuation for aircraft to ground propagation for octave band center frequencies 4,000 and 8,000 Hz.

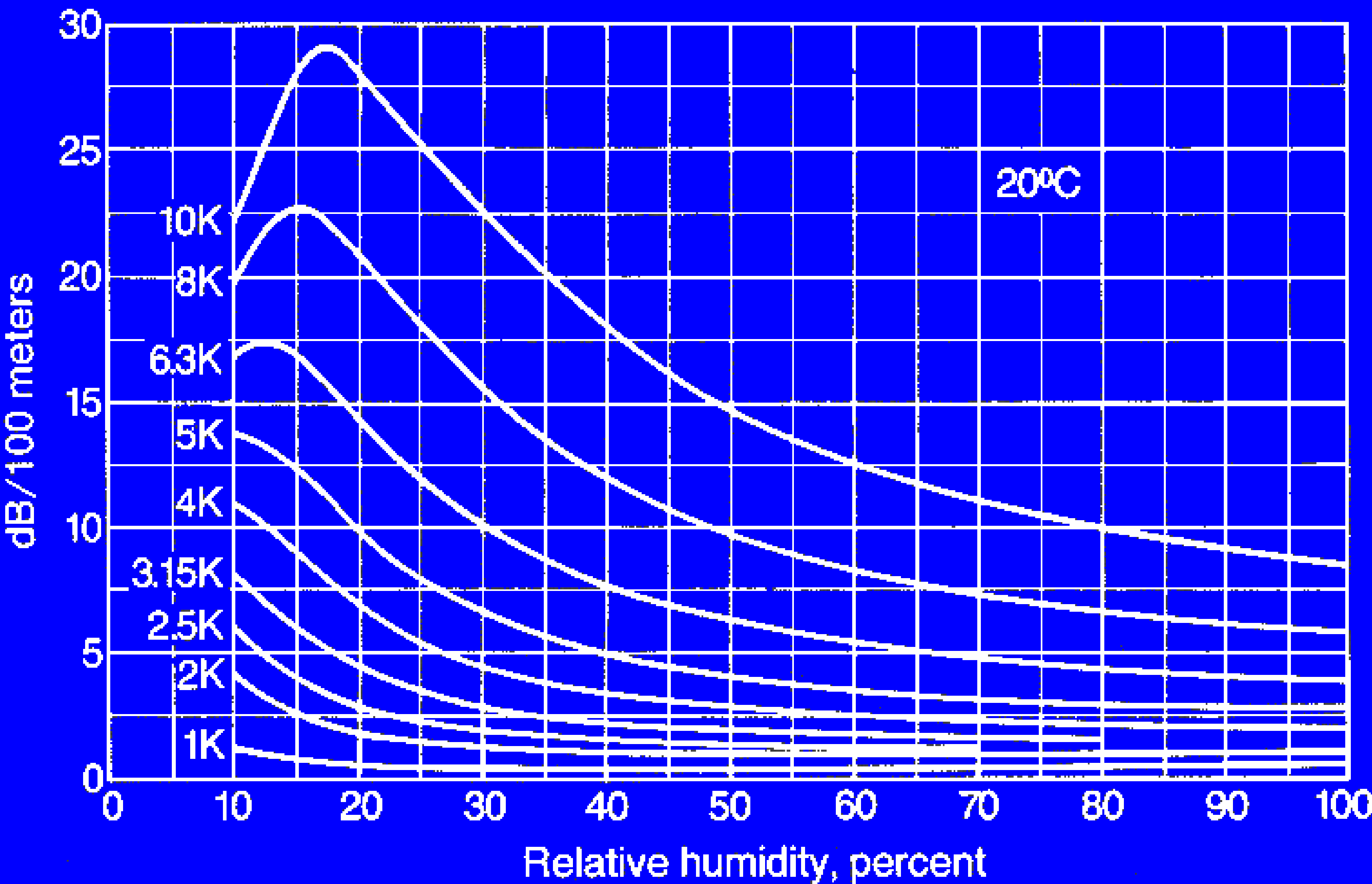


FIG. 2·17 Total attenuation coefficient m for sound in air at 20 °C, versus relative humidity with frequency as parameter, between 1 and 12.5 kHz in $\frac{1}{3}$ octave bands.

A simplified equation for Excess Attenuation at 68° F

$$A_e = \frac{24.3 \; f^2 \, r}{\phi} \quad dB$$

f = Frequency in KHz

r = Distance in 100 feet

ϕ = Relative Humidity, %

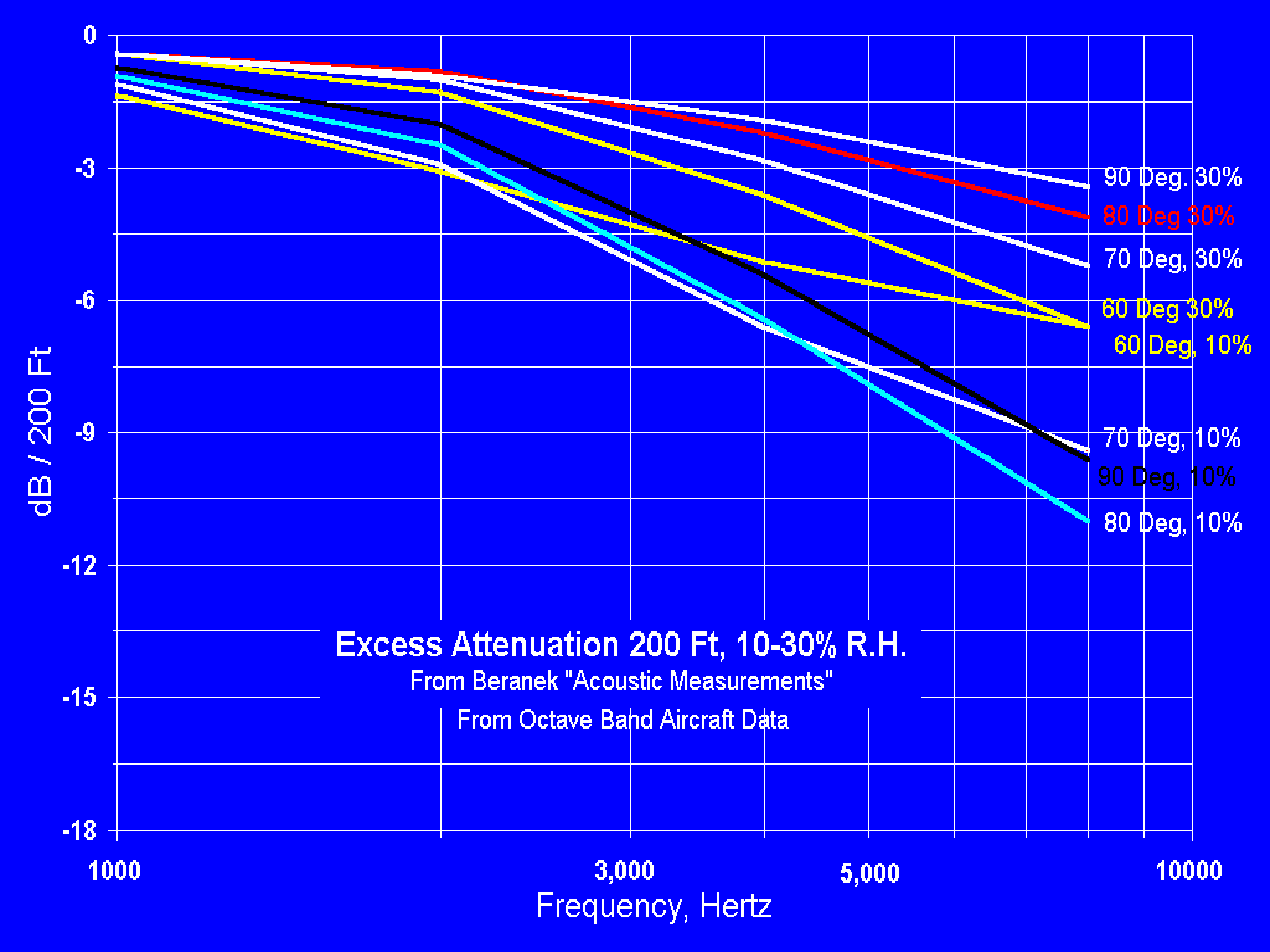
Excess Attenuation, Variable Temperature @ 50% RH

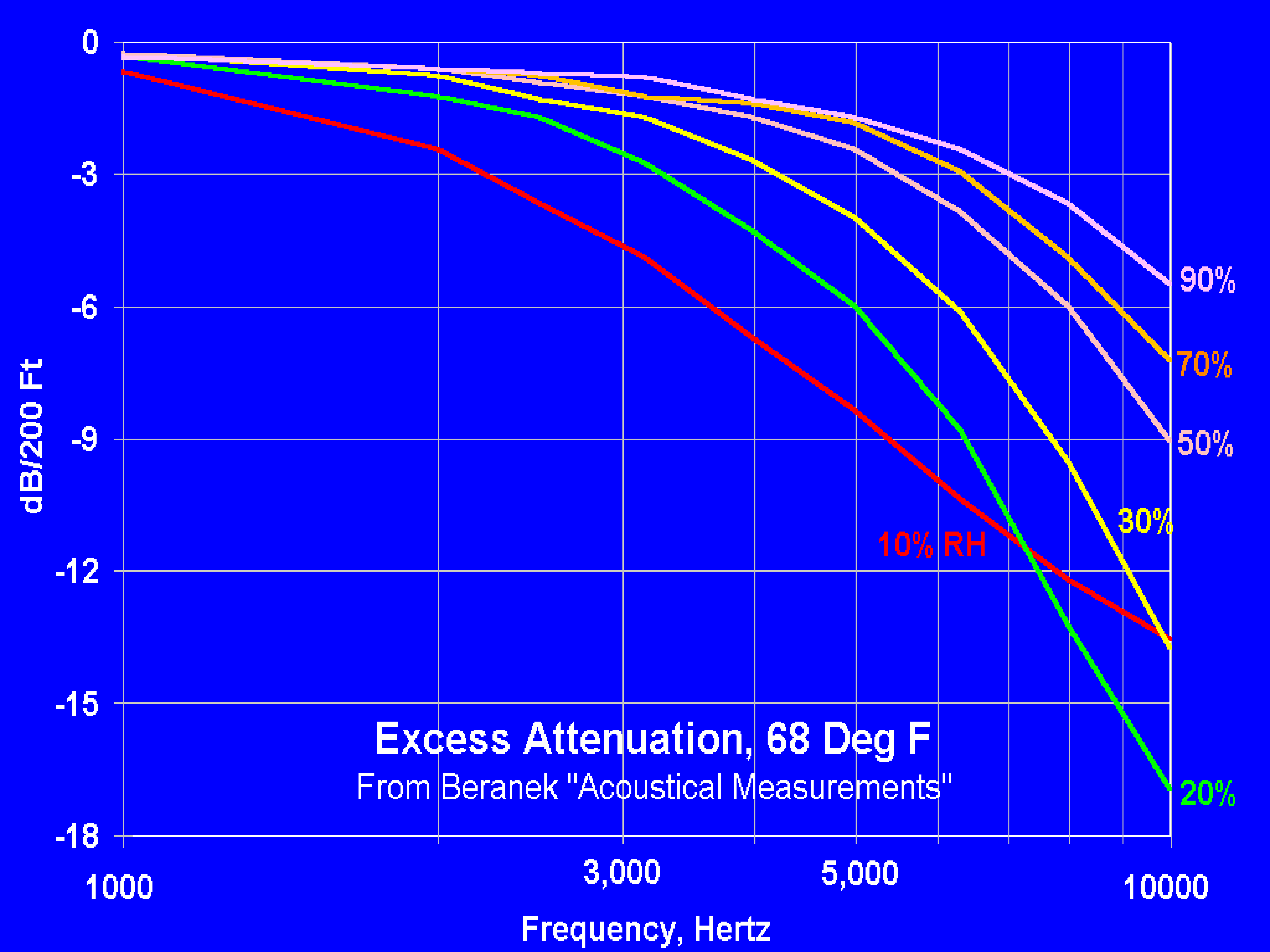
$$A_e(T) = \frac{A_e(68^\circ F, 50\%\ \mathrm{RH})}{1 + 2 \times 10^{-3}\, \Delta T\, f}\ \mathrm{dB}$$

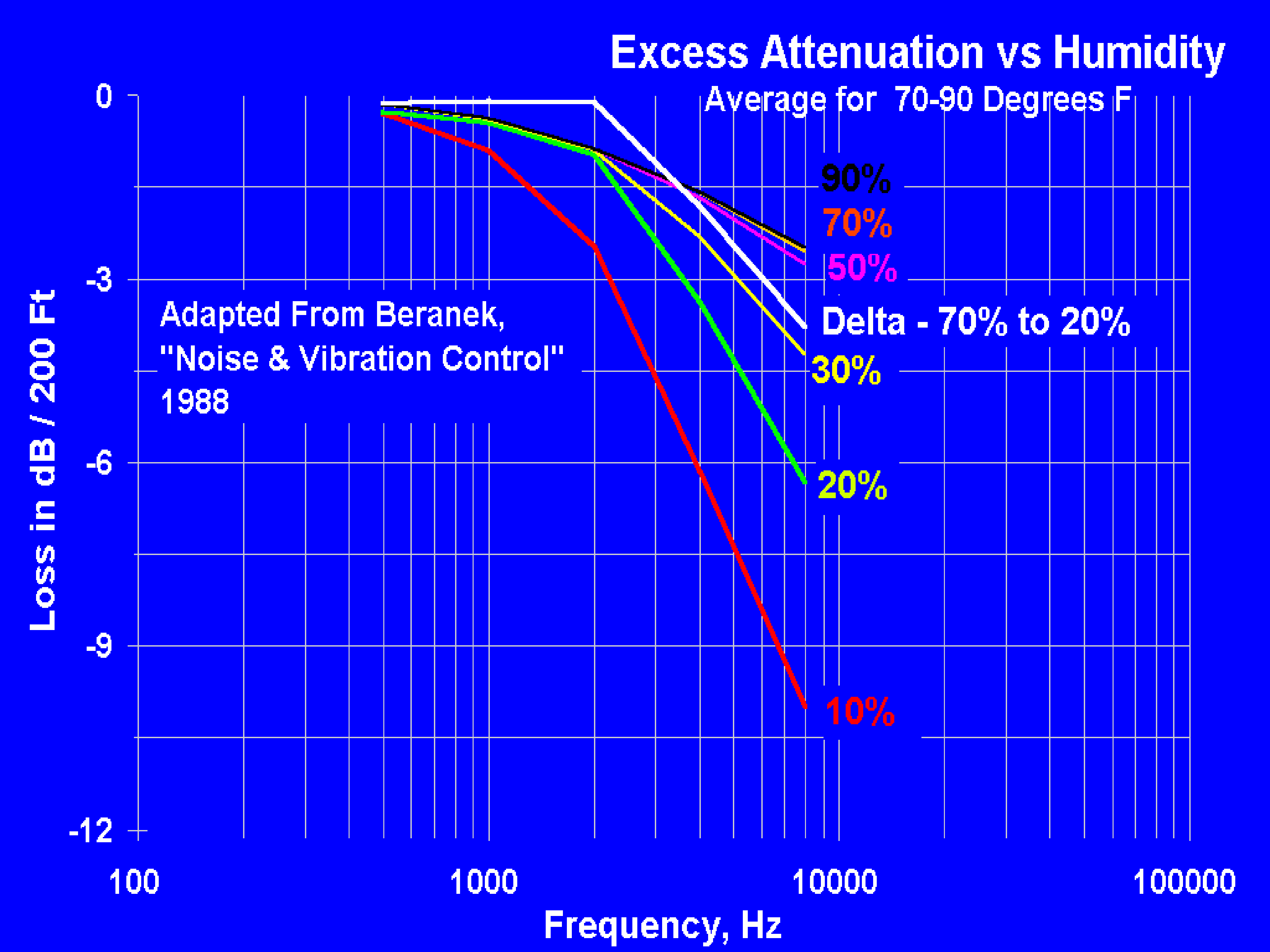
For: f = Frequency in KHz

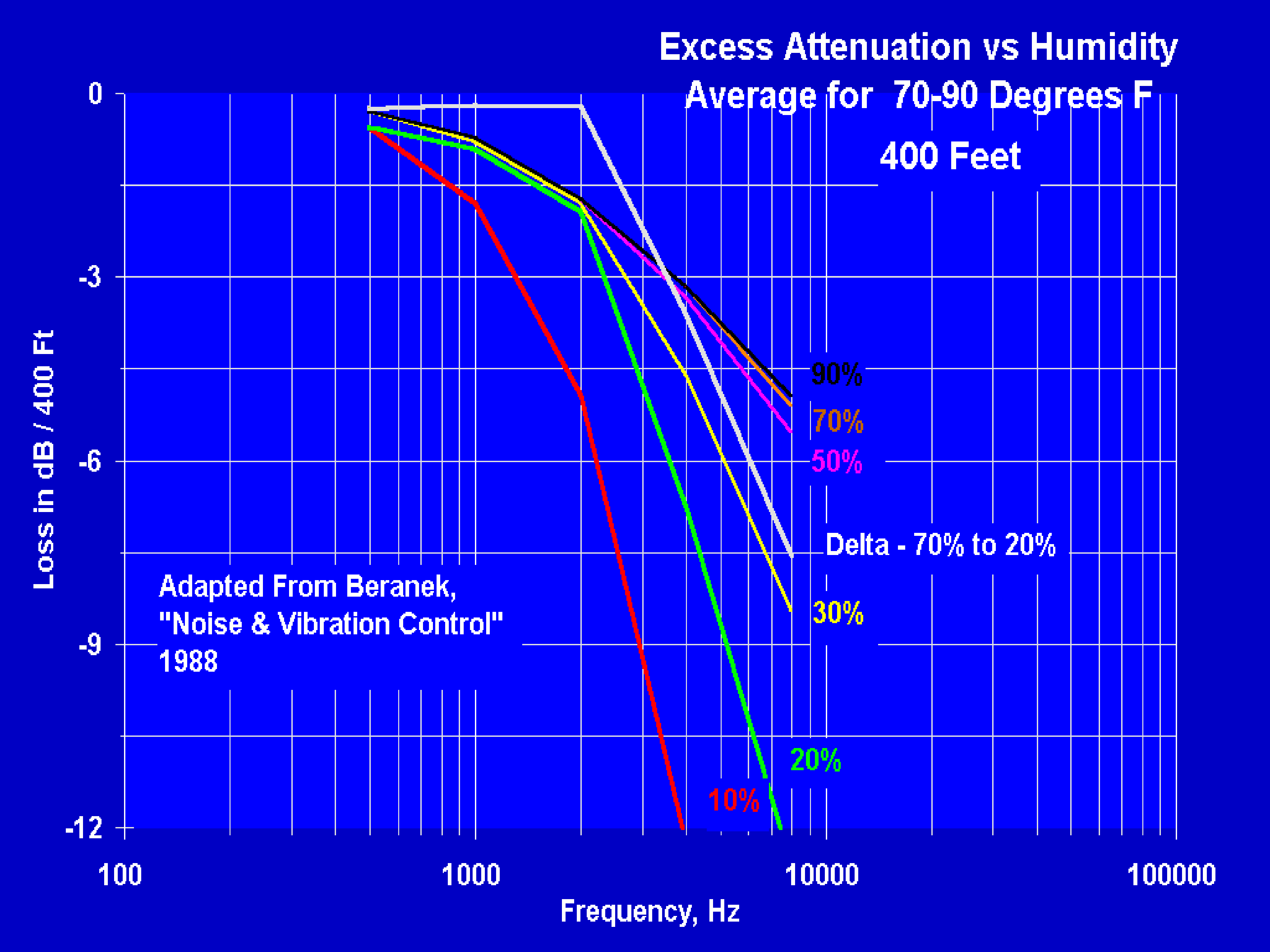
ϕ = 50% Rel Humidity

T = 50° - 86° F


0
-3
-6
-9
-12
-15
-18
dB / 200 Ft
1000
3,000
5,000
10000
Frequency, Hertz
90 Deg. 30%
80 Deg 30%
70 Deg, 30%
60 Deg 30%
60 Deg, 10%
70 Deg, 10%
90 Deg, 10%
80 Deg, 10%
Excess Attenuation 200 Ft, 10-30% R.H.
From Beranek "Acoustic Measurements"
From Octave Band Aircraft Data


0
-3
-6
-9
-12
-15
-18
dB/200 Ft
90%
70%
50%
30%
10% RH
20%
Excess Attenuation, 68 Deg F
From Beranek "Acoustical Measurements"
1000
3,000
5,000
10000
Frequency, Hertz


Excess Attenuation vs Humidity
Average for 70-90 Degrees F
0
-3
-6
-9
-12
Loss in dB / 200 Ft
Adapted From Beranek,
"Noise & Vibration Control"
1988
90%
70%
50%
Delta - 70% to 20%
30%
20%
10%
100
1000
10000
100000
Frequency, Hz



Excess Attenuation vs Humidity
Average for 70-90 Degrees F
400 Feet
0
-3
-6
-9
-12
Loss in dB / 400 Ft
90%
70%
50%
Delta - 70% to 20%
30%
20%
10%
Adapted From Beranek,
"Noise & Vibration Control"
1988
100
1000
10000
100000
Frequency, Hz

Excess Attenuation

- Cascaded single pole low pass filters
  - Turning frequency determined by:
    - Temperature
    - Humidity
  - Number of poles determined by:
    - Distance from source to listener

Excess Attenuation

- Pre-Emphasis to correct for it
  - Loss approaches a Bessell curve (Gunness)
  - Don't overdo corrections - the ear already knows about it!
  - Use about one half as much as what it takes to get "flat" (Gunness)

Excess Attenuation

- Ground Impedance Loss
  - Impedance varies with frequency
    - Grass
    - Seating
    - Audience
  - Cancellations at certain wavelengths
  - Most pronounced close to the boundary
  - Most pronounced for grazing incidence (low sources, firing parallel to boundary)

Refraction

- Change of Direction
  - Wind
  - Temperature Gradients
  - Humidity Gradients
- It all boils down to the speed of sound varying across the wavefront!

Wind

- Speed of sound in wind is vector sum of speed of wind and speed of sound.

Loudspeaker Facing Wind

- Simple case: Wind blowing lateral to earth
  - Velocity approaches zero at the boundary, so speed is unaffected by the wind there.
  - Velocity at top of wavefront is speed of sound minus wind.
  - Sound refracts (bends) upward.

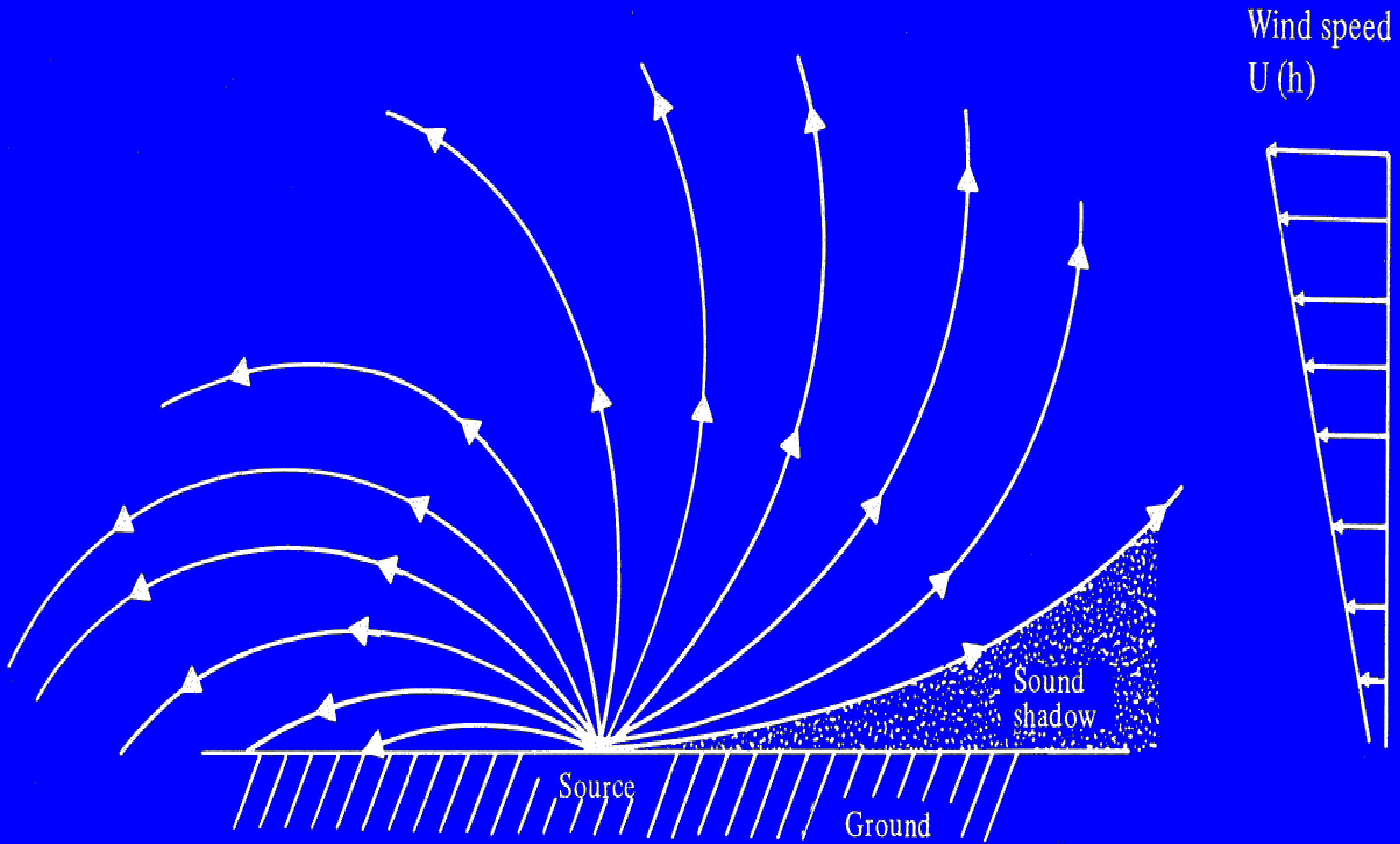


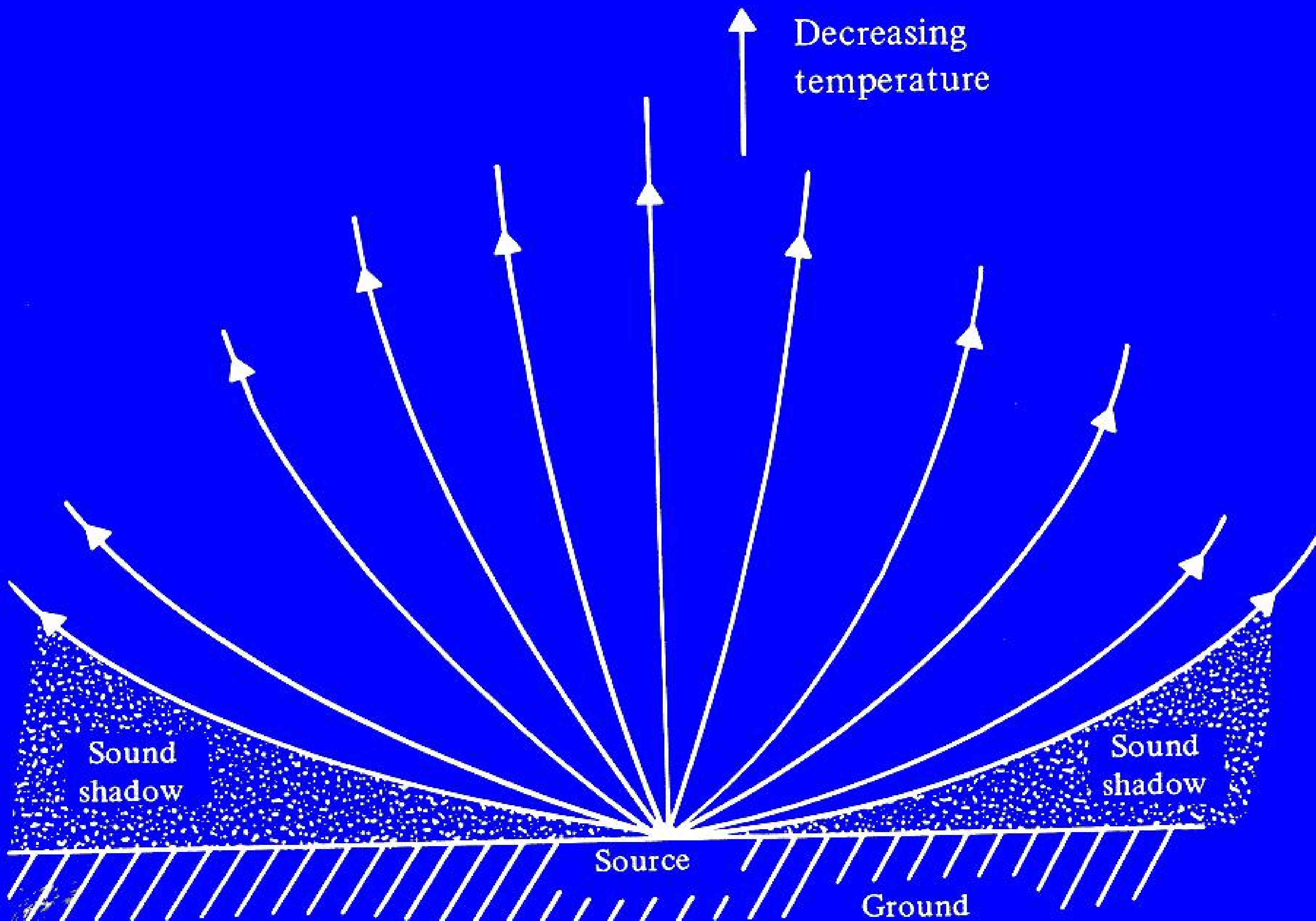
FIGURE 1.27. Refraction of sound in air with wind speed increasing with altitude.

Loudspeaker has Wind at its Back

- Velocity approaches zero at the boundary, so speed is unaffected by the wind there.
- Velocity at top of wavefront is speed of sound PLUS wind.
- Sound refracts downward.

Temperature Gradients

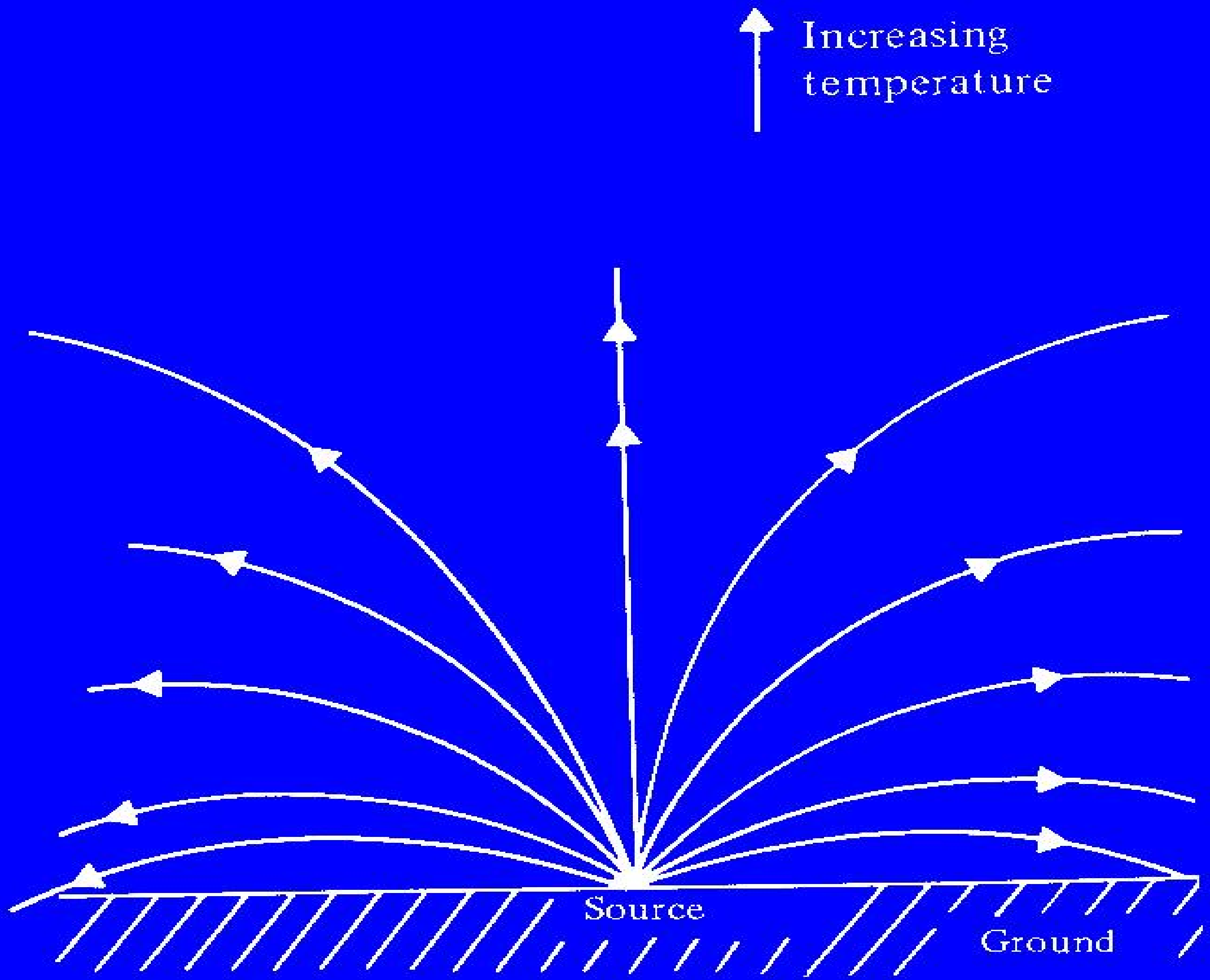
- "Normal" conditions (air cooler at higher altitude) ("Temperature Lapse"):
- Speed of sound increases with temperature.
  - Square Root of Absolute Temperature
  - Air most often warmest at earth surface, gets cooler as elevation increases.
- Aim loudspeaker parallel to the earth.
  - Top of wavefront will travel slower.
  - Wavefront will refract upward.



a) Normal temperature lapse (temperature decreases with altitude)

Temperature Inversion

- Air gets warmer at higher altitude
  - As sun rises, earth may be cooler than air
  - Weather patterns cause warm air to overlay cool air (a front comes in)
- Sound travels faster at top of wavefront, so is refracted (bent) downward.



b) Temperature inversion

FIGURE 1.30. Refraction of sound in air with normal temperature lapse and with temperature inversion.

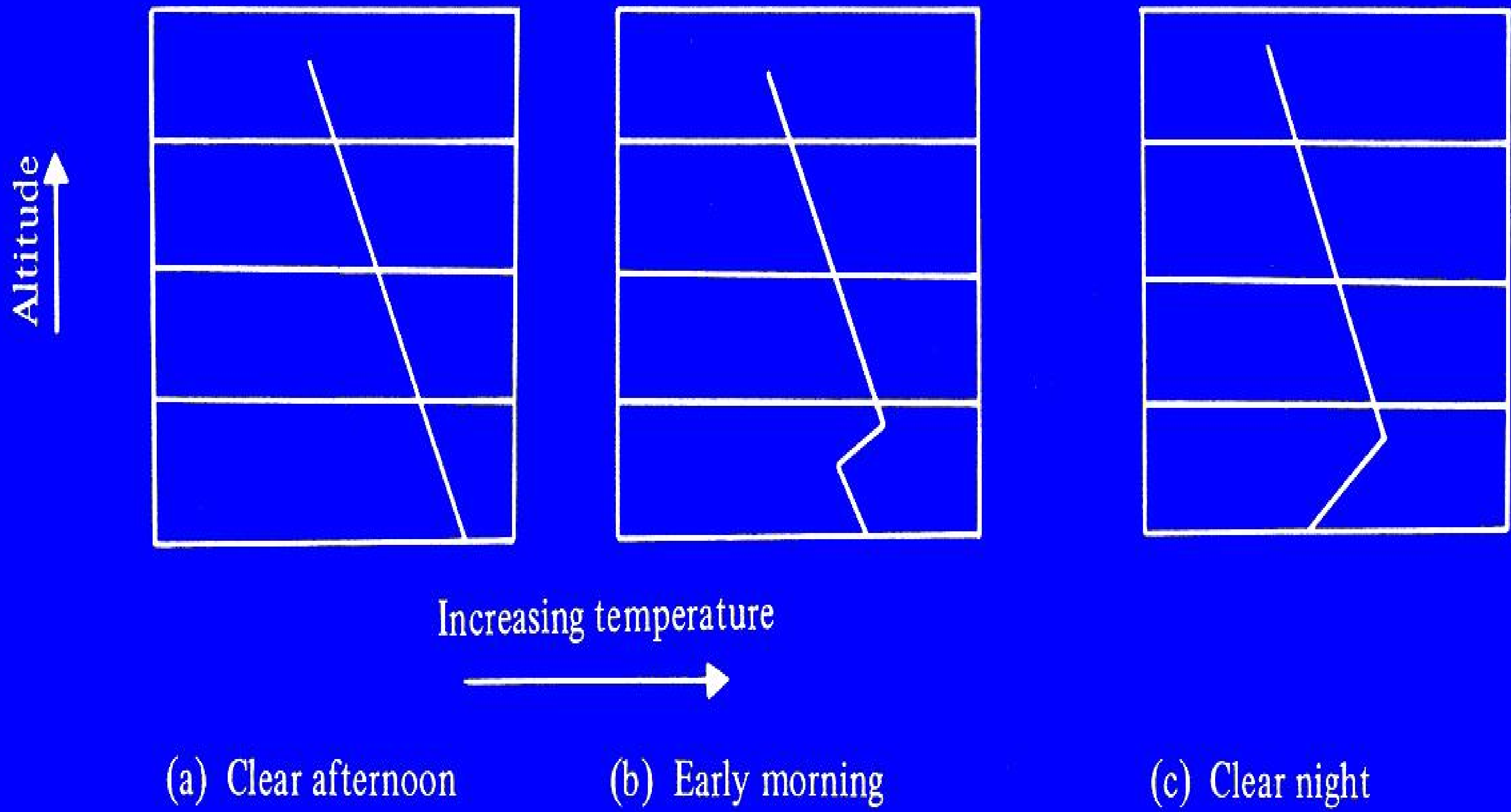
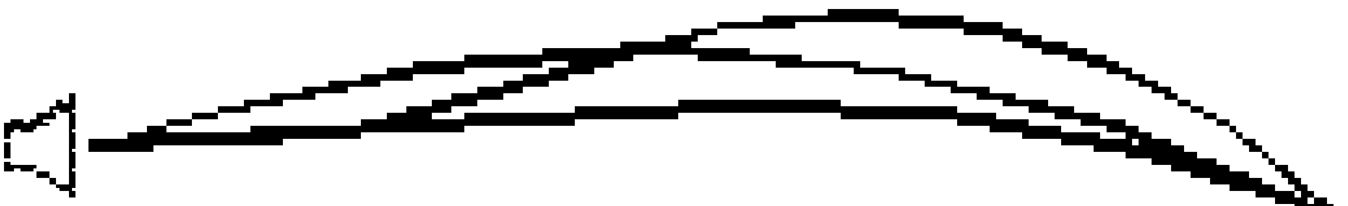


FIGURE 1.29. Typical examples of temperature variation with height.

Ducting

- Close to earth, air gets cooler, so sound refracts upward.
- Higher, there's an inversion (air gets warmer as elevation increases), so sound is refracted back down.
- When it gets back down, it's refracted back up again!
- No longer spherical wave -- begin approaching 3 dB/doubling (plus excess attenuation)

Long Distance Focusing



Distance, velocity and time

Velocity of sound $V = 20.06\sqrt{273 + °C}$

Where V is in metres per second and C is temperature in degrees Celsius.

Velocity of sound $V = 49\sqrt{459.4 + °F}$

Where V is in feet per second and F is temperature in degrees Farenheit.

$d = vt$	d = Distance in feet or metres
$v = d/t$	v = Velocity in feet per second or metres per second
$t = d/v$	t = Time in second

At room temperature:

Speed of sound increases ≈ 0.1% / ^{o}F,

1% for 10% change in Rel Humidity

A 10 mph wind is ≈ 1/77 the speed of sound.

A 10 mph wind, OR a 7.5^{o} F temperature gradient, can refract sound by 15 ft in 200 ft!

None of these effects are constant.

All can occur together,

Each can be positive or negative!

Turbulence

- Temperature variations (5♣ common)
- Wind gusts
- Both make sound transmission very unstable
- 6-12 dB quite common over as little as 200 ft
- Windowed measurements

Long Throw "Gotchas"

- It takes a lot more high frequency power
  - Forget about > 8 KHz
- Much brighter sound at 100 ft than 200 ft or 300 ft -- how do you equalize it?
- Synchronizing long delays when speed of sound changes due to temperature
- Increased travel time due to curved path
- It's hard to tune with <u>ordinary</u> turbulence

Long Throw "Gotchas"

- The system isn't aimed where you thought
  - Bent up and carried over the audience
  - Loud and clear at the high rises across town

Timing

- Listener hears multiple loudspeakers
- Reflections (rear walls, roof structures, etc.)
- Brain has trouble understanding if it hears two copies of the same sound, but delayed
  - 30 ms (35 ft)
- Echoes (reflections more than 30 ms late)
- Watch out for focusing -- concave surfaces!

Timing

- Where does sound go after it hits listeners?
- Upper deck loudspeakers spill to ground level
- Field box loudspeakers spill to bleachers or opposite side of field
- Line arrays -- double edged sword
  - 3 dB/doubling of distance increases coverage and can produce echoes

Reverberation

- Even outside -- under upper decks
  - Wrigley Field has it
- Domed stadiums
  - Long echoes
  - Air absorption limits reverberation in large open areas
  - Reverberation under balconies


NORTHWESTERN


PEPSI
10
20
30
40
50
40

University Sound®
a MARK IV company

SPECIFICATIONS

Frequency Response:
280-8,000 Hz ±5 dB
(see Figure 3)

Power Handling,
8 Hours, 6-dB Crest Factor:
60 watts (500-5,000 Hz pink noise)

Transformer Taps and Impedances:
See Table I

Sound Pressure Level, at 1 Meter,
1 Watt Input Averaged, Pink Noise
Band-Limited from 500 to 5,000 Hz:
105 dB

Horizontal Beamwidth:
150° @ 2 kHz (see Figure 2)

Vertical Beamwidth:
110° @ 2 kHz (see Figure 2)

Directivity Factor R_θ (Q):
5.2 @ 2 kHz

Usable Low-Frequency Limit:
180 Hz

Construction:
Large fiberglass compression molding with gray finish, front horn of gray die-cast zinc and phenolic compression-molded inner horns with steel "U" bracket

Voice-Coil Diameter:
5.08 cm (2.0 in.)

Magnet Weight:
0.45 kg (1.00 lb)

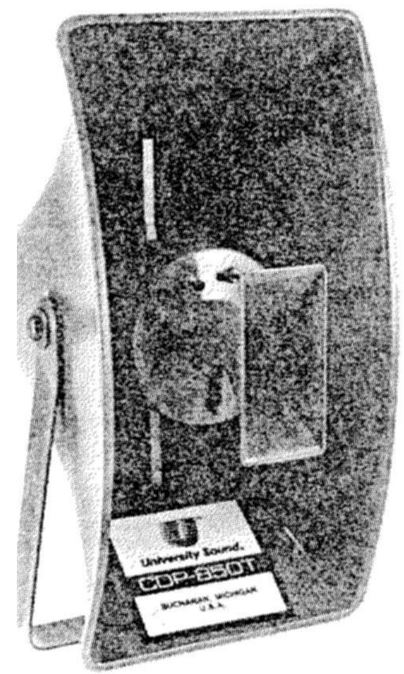
Magnet Material:
Strontium ferrite

Flux Density:
1.35 Tesla

Dimensions,
Height:
52.0 cm (20.5 in.)
Width:
26.5 cm (10.5 in.)
Length:
51.0 cm (20.0 in.)

Net Weight:
8.4 kg (19 lb)

Shipping Weight:
9.5 kg (21.0 lb)



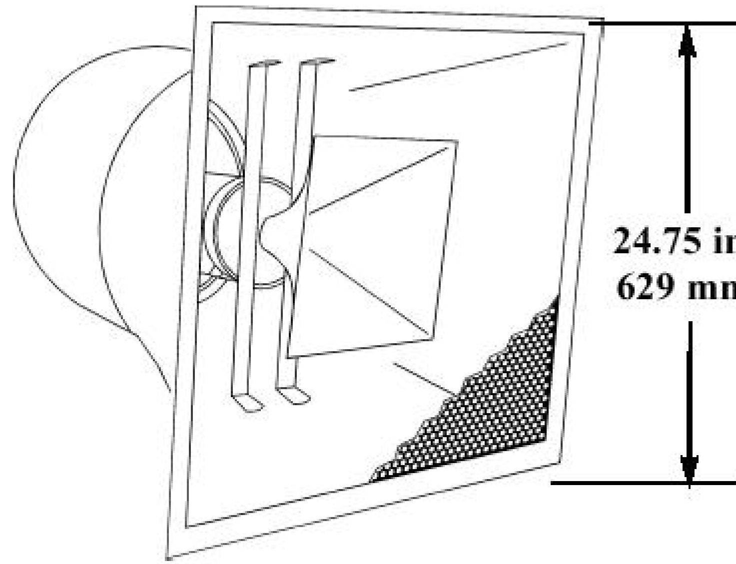
Community
PROFESSIONAL LOUDSPEAKERS

R1-94

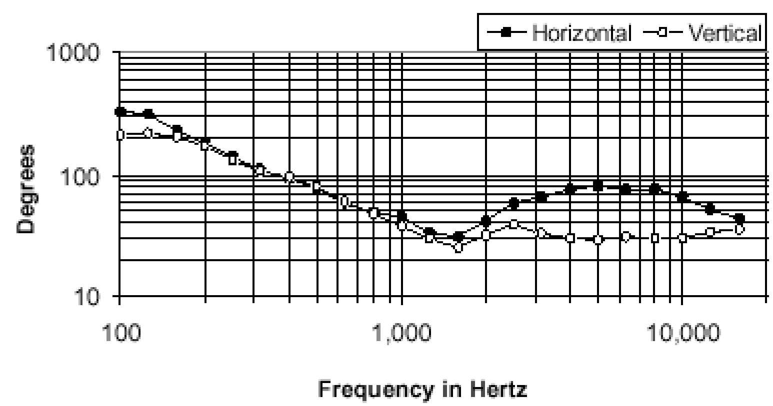
TWO-WAY HORN-LOADED WEATHER-RESISTANT FULL-RANGE LOUDSPEAKER

SPECIFICATIONS (See notes 1 and 2)

Loudspeaker Type: 2-way, Horn-loaded co-axial, weather resistant
Operating Range: 90 Hz - 16 kHz
110 Hz - 10 kHz (+/-4dB)
Max Input Ratings: 200W continuous, 500 W program
40 volts RMS, 89 volts momentary peak
Recommended Power Amplifier:
420W to 600W @ 8 Ohms
Sensitivity 1W/1m:
104 dB SPL (100 Hz - 16 kHz 1/3 octave bands)
105 dB SPL (250 Hz - 4 kHz speech range)
Maximum Output: 127 dB SPL / 134 dB SPL (peak)
Nominal Impedance: 8 Ohms
Min Impedance: 5.7 Ohms @ 230 Hz
Nominal -6dB Beamwidth:
80° H (+0° / -49°, 1 kHz - 16 kHz)
35° V (+4° / -10°, 1 kHz - 16 kHz)
100° H x 100° V (400 Hz)
Axial Q / DI: 29.7 / 14.7, 1 kHz - 16 kHz
Crossover Frequency: 1.2 kHz
Recommended Signal Processing:
90 Hz high pass filter
Drivers: LF (1) 12" weather-treated, Ferrofluid-cooled
HF (1) 1" exit, titanium diaphragm

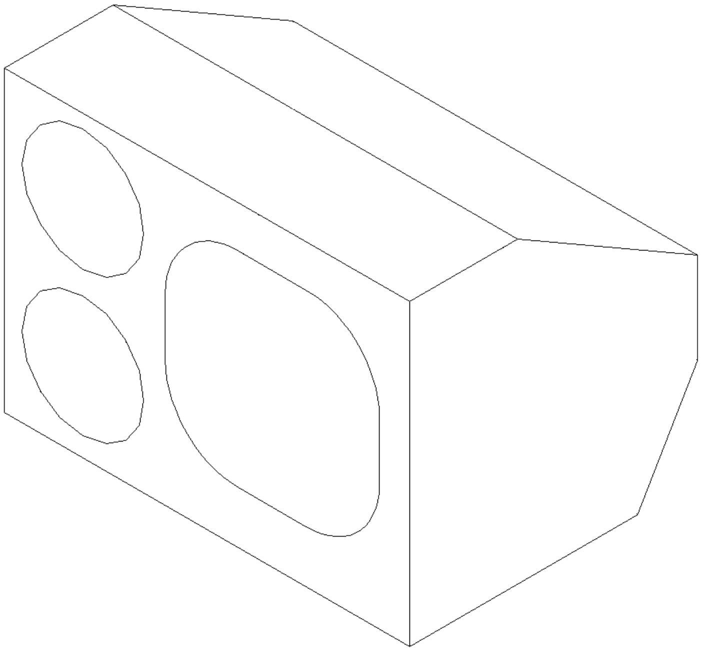


BEAMWIDTH



Custom Loudspeaker

- 96 dBSPL 1w/1m HF
- 94 dBSPL 1w/1m MF
- 90º x 40 º Horn
- 6” MF in vertical bass array
- 1 KHz Crossover
- 14.5” H x 20” W x 14” D

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20
10


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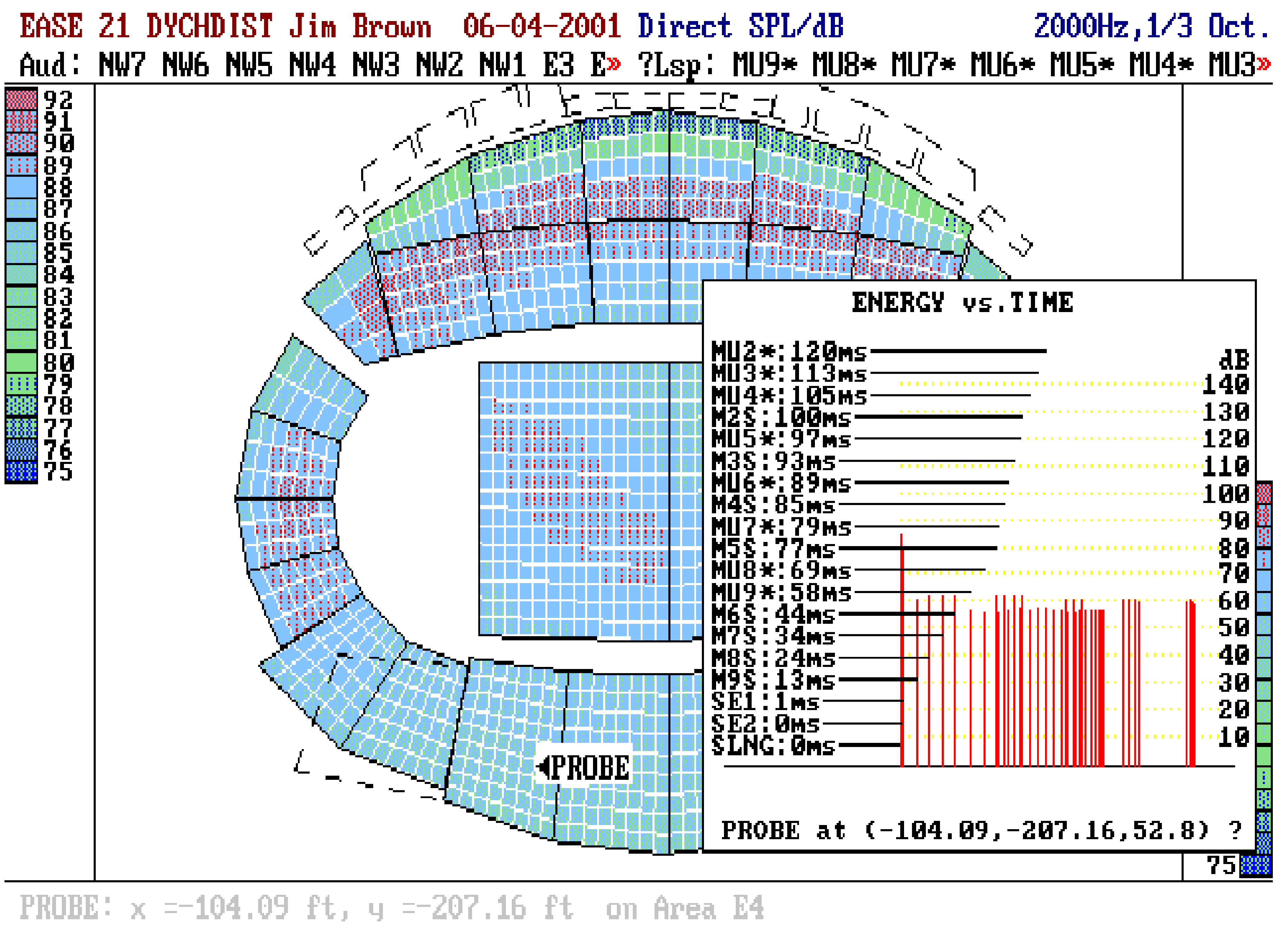
EASE 21 DYCHDIST Jim Brown 06-04-2001 Direct SPL/dB 2000Hz,1/3 Oct.
Aud: NW7 NW6 NW5 NW4 NW3 NW2 NW1 E3 E» ?Lsp: MU9* MU8* MU7* MU6* MU5* MU4* MU3»
92
91
90
89
88
87
86
85
84
83
82
81
80
79
78
77
76
75
ENERGY vs.TIME
MU2*:120ms
MU3*:113ms
MU4*:105ms
M2S:100ms
MU5*:97ms
M3S:93ms
MU6*:89ms
M4S:85ms
MU7*:79ms
M5S:77ms
MU8*:69ms
MU9*:58ms
M6S:44ms
M7S:34ms
M8S:24ms
M9S:13ms
SE1:1ms
SE2:0ms
SLNG:0ms
dB
140
130
120
110
100
90
80
70
60
50
40
30
20
10
PROBE
PROBE at (-104.09,-207.16,52.8) ?
75
PROBE: x =-104.09 ft, y =-207.16 ft on Area E4


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Selected Reading

- Beranek: “Acoustical Measurements”
- Beranek: “Noise and Vibration Control”
- Humphreys: “Physics of the Air”
- Knudsen & Harris: “Acoustical Designing in Architecture”
- Crocker & Price: “Noise and Noise Control”

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