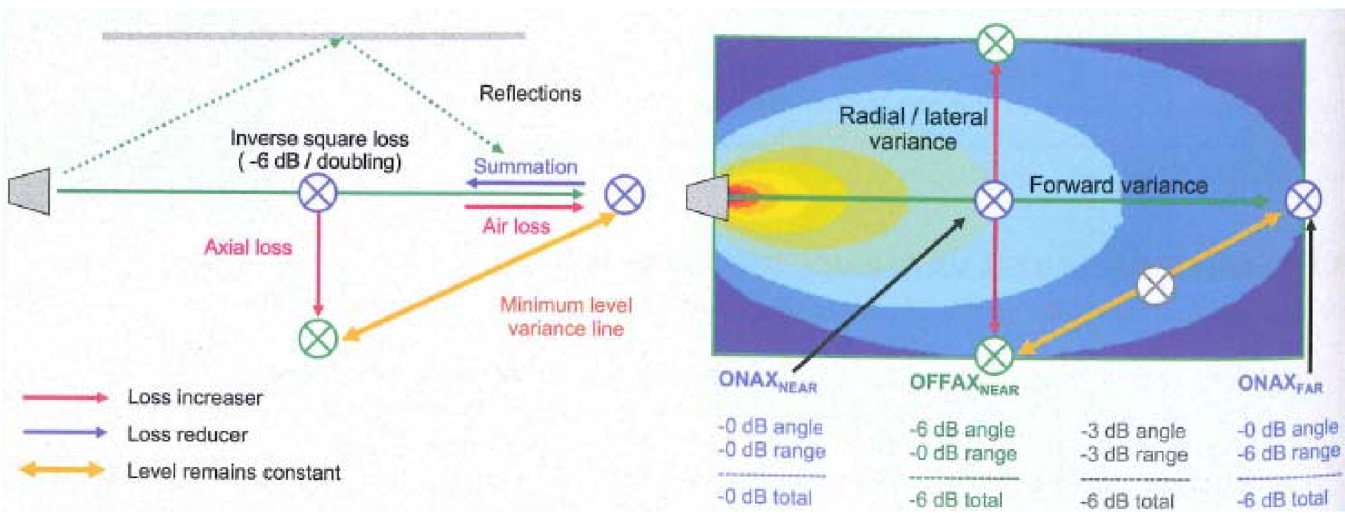
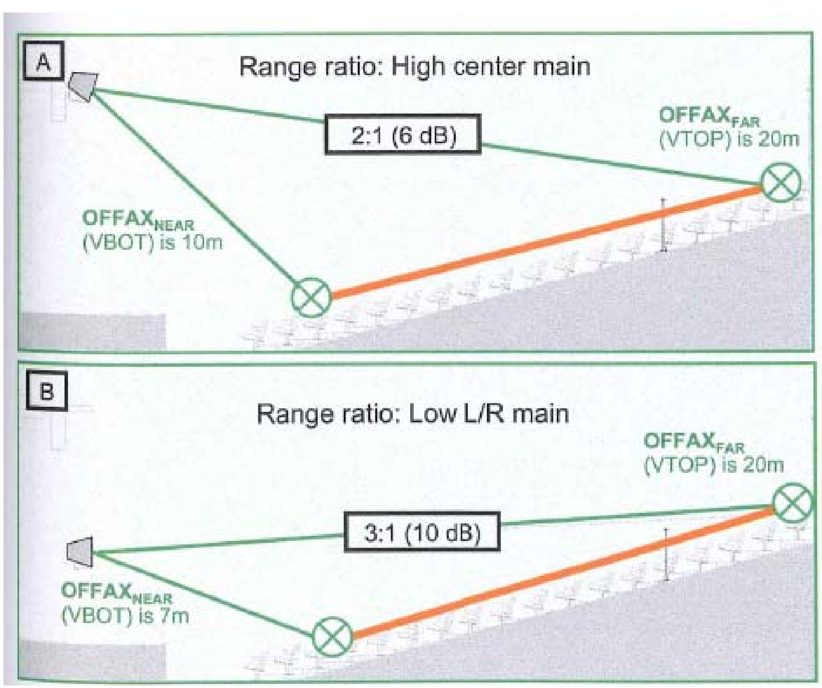
Lecture Summary – Variation
Chapter 8

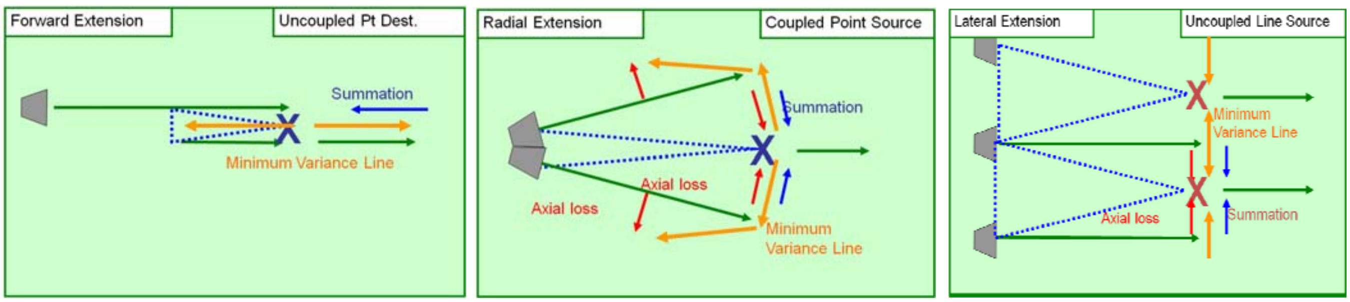
- **minimum variance principles**
  - **level variance – differences in overall level over space**
  - **spectral variance – difference in relative level over frequency among different locations**
  - **ripple variance – differences in the extent of summation-related peaks and dips**
- **single speaker**
  - **function of proximity and axial orientation**
  - **off-axis response will be a combination of level and spectral variance**
  - **loss rate off-axis will not be uniform over frequency**
  - **primary option for management of level variance is tilt**
  - **aiming speaker at the most distant coverage point offsets the two level variance factors (distance and axial)**



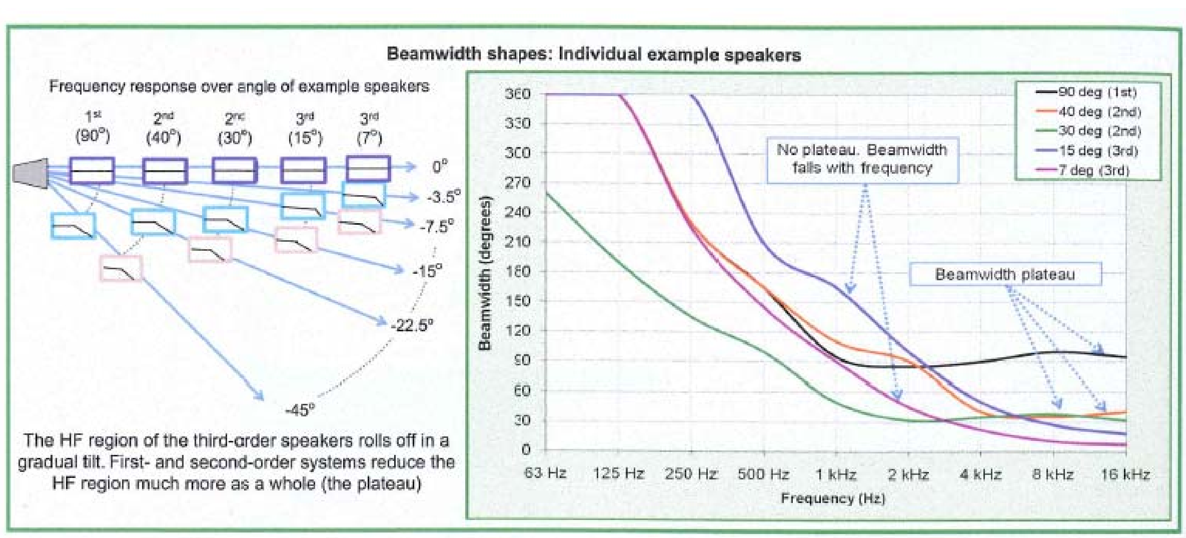
- **range ratio – difference in range between farthest and nearest listener**



- **three directions for extending minimum level variance in multiple speaker configurations**
  - **forward extension – accomplished by adding (delayed) speakers in the on-axis plane of the original source**
  - **radial extension – additional sources are aimed to intersect at the coverage edges and "fused" together to create a wider angle**
  - **lateral extension – uncoupled secondary sources added to the side of the original, creating a line of equal level (at the unity class crossover point)**

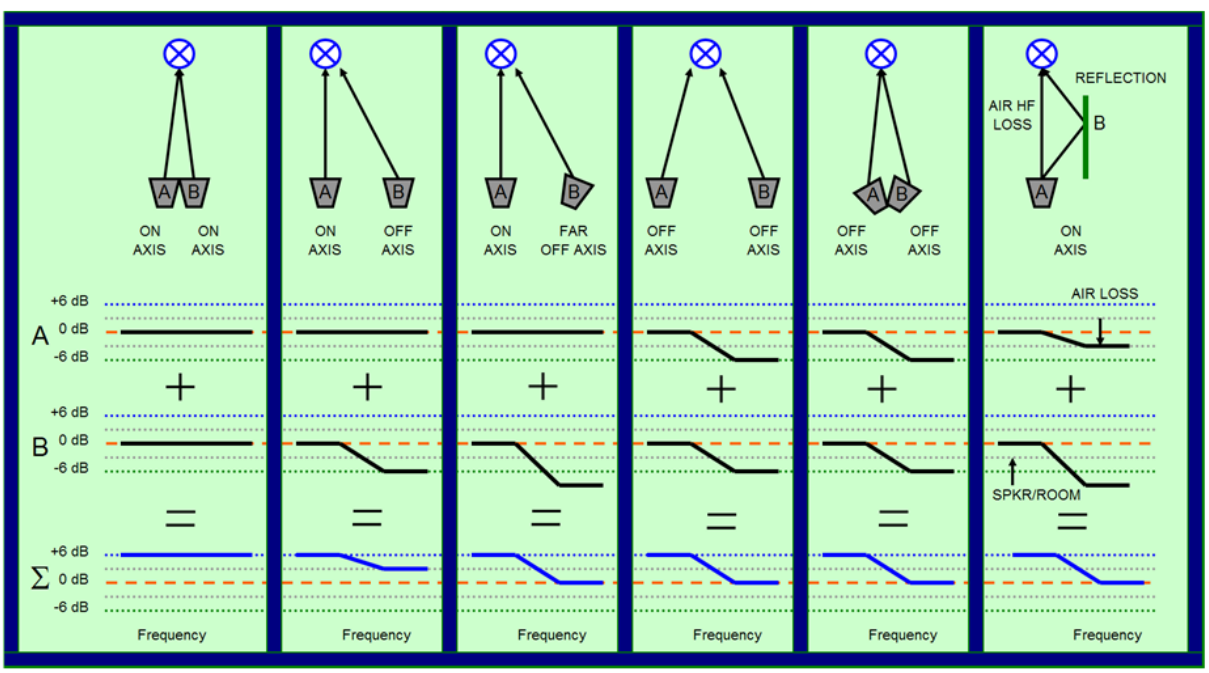


- **spectral variance**
  - **two views:**
    - **changes in coverage pattern shape over frequency ("spatial over spectrum")**
    - **changes in frequency response over coverage area ("spectral over space")**
  - **for single loudspeaker, directly related to speaker order**
    - **high-order speakers have the highest spectral variance, and therefore are least well-suited for single-speaker applications**
    - **low-order speakers have the lowest spectral variance, and therefore are best suited for single-speaker applications**



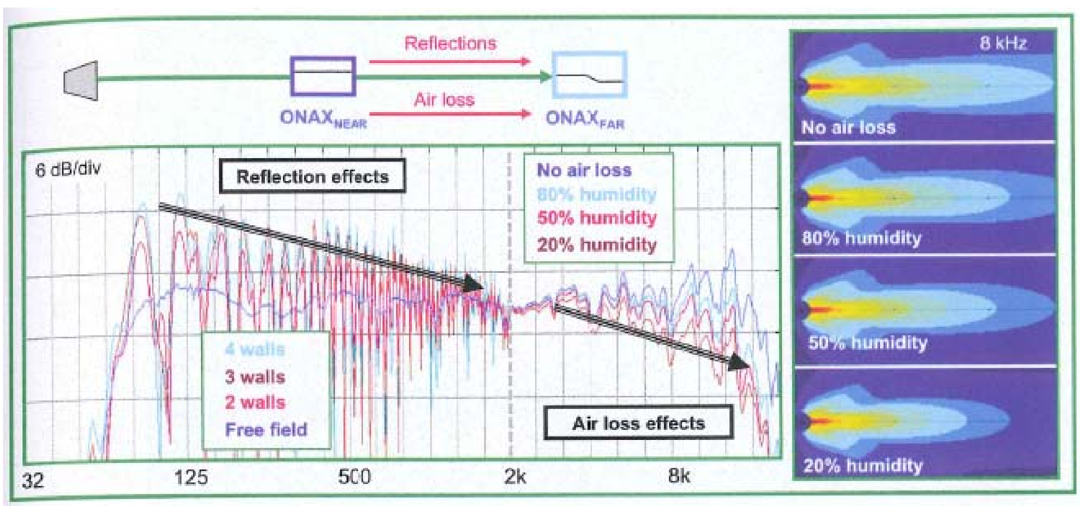
  - **note that arrays can be constructed with combined coverage shapes that differ from the individual components**
  - **coupled point source array comprised of high-order speakers**
    - **high frequencies spread (due to isolation)**
    - **low frequencies narrowed (due to coupling)**

- **spectral tilt**
  - **summation addition at low frequencies not matched by a comparable addition at high frequencies**
  - **affects overall shape of frequency response**
  - **difference between on- and off-axis response of a single speaker is not just level: only the higher frequencies have been significantly reduced by the axial loss (also a source of spectral tilt)**
  - ***the difference in spectral tilt among listening locations is the spectral variance***
- **spectral tilt vs. spectral variation**
  - **points with matched flat responses: no spectral tilt or spectral variance**
  - **points with matched HF/LF rolloffs/boosts: spectral tilt but no spectral variance**
  - **one point has HF/LF rolloff/boost (spectral tilt) and another has flat response (no tilt): spectral variance**
  - ***spectral variance is therefore a measure of the change in spectral tilt across a listening area***
  - **goal is to minimize spectral variance, but not necessarily spectral tilt (many clients actually prefer large amounts of spectral tilt!)**
  - **want to ensure that same amount of tilt is found in all areas of listening space**
- **spectral tilt causes**
  - **transmission-related effects**
    - **axial loss (as move off-axis, higher frequencies attenuate faster than lower frequencies)**
    - **air loss (even on-axis, have high-frequency loss due to absorption effects of air)**
    - **spectral tilt caused by transmission-related effects favors lower frequencies**
  - **summation-related effects**
    - **reflections (room reflections tend to reduce loss rate at lower frequencies)**
    - **combinations with other speakers (typically have more power coupling at lower frequencies than higher ones)**
    - **spectral tilt caused by summation-related effects also favors lower frequencies**

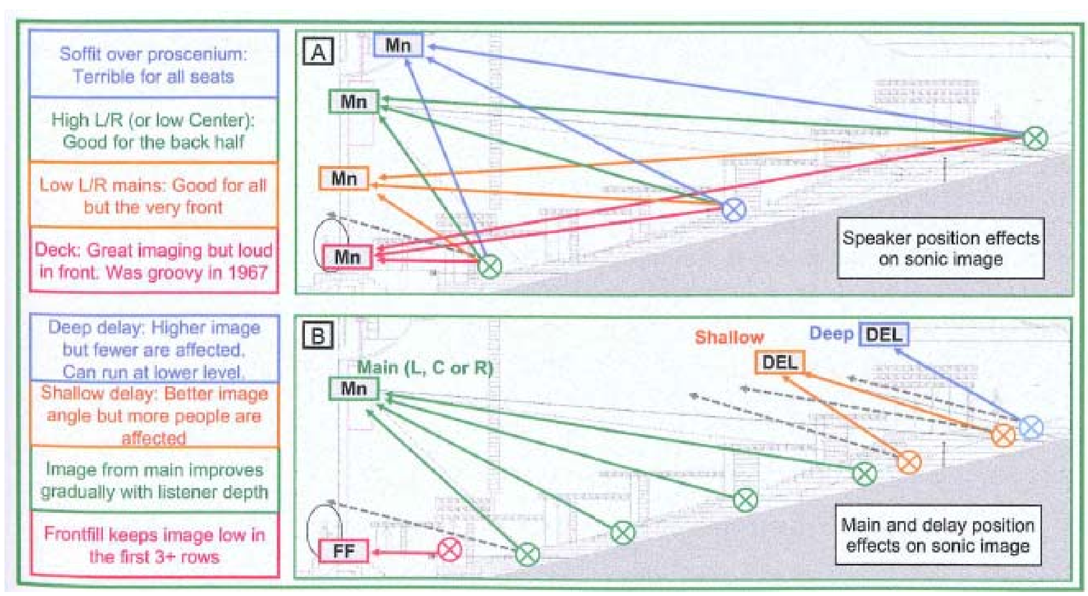


- **spectral tilt progression summary**
  - **since all the progressions lead to tilting, the spectral variance can be reduced by matching the tilts rather than trying to stop the progression**
  - **tilt can be "leveled" by equalization to the extent desired**
  - **note that a frequency response need not be flat to be considered to possess minimum spectral variance**
- **pink shift**
  - **based on perceptions of distance to the sound source**
  - **analogous to pink noise: filtered white noise (equal energy per frequency band) with steady 3 dB reduction per octave, which creates equal energy per octave balanced for our logarithmic hearing**
  - **frequency response progressions previously described can be viewed as pink shift added to response**
  - **in natural acoustic transmission, pink shift is directly related to sonic source distance: the farther away we are from a source, the greater the degree of tilting due to air absorption effects (HF loss) and room summation effects (LF boost)**
  - **our internal ear-brain processing estimates source distance by factoring in expectations of pink shift**

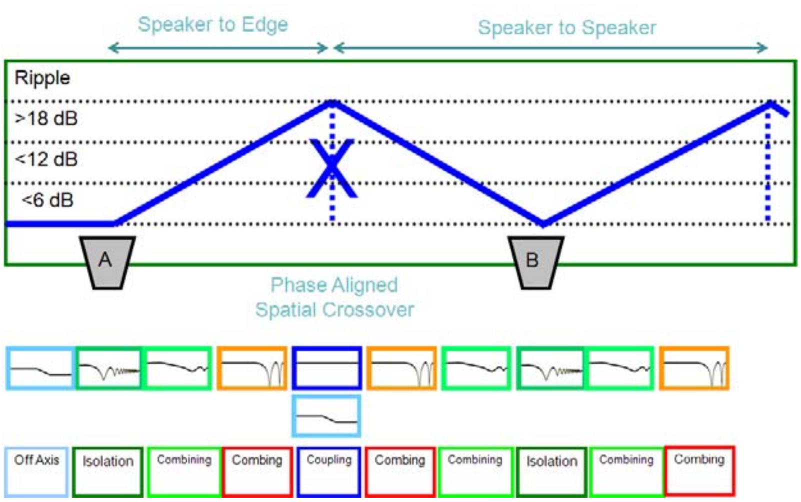
- **pink shift progressions**

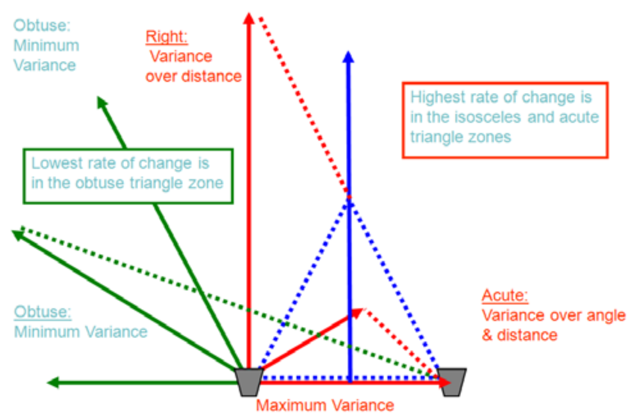


- **vertical location variance**



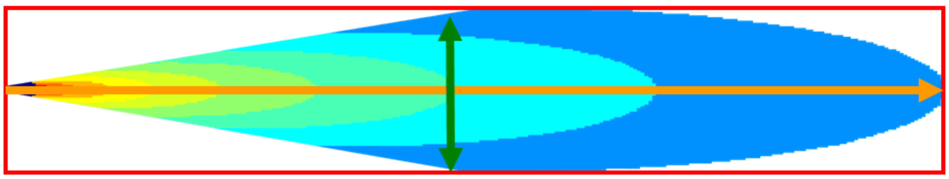
- **ripple variance**
  - **defined as differences in the extent of the summation-related peaks and dips in the response**
  - **center point is phase-aligned spatial crossover (point of lowest variance)…but center of area where highest rate of change in ripple variance occurs (like "eye of hurricane")**
  - **can be found in all forms of speaker arrays**
  - **focus will be on full-range spatial crossover transitions**
  - **primary factors are source displacement and pattern overlap**
- **ripple variance progression**
  - **frequency response ripple: as the spatial crossover is approached, the ripple variance increases; as overlap increases, the ripple variance increases**
  - **from the spatial crossover point: coupling zone → combing zone → combining zone → isolation zone**
  - **from the isolation zone: to coverage pattern edge, or to combining zone → combing zone → coupling zone → next crossover point**
  - **cycle repeats for each speaker transition until coverage edge is reached**
  - **all spatial crossovers must be phase-aligned (phase- aligned crossovers cannot eliminate ripple variance over the space, but are the best means to control it)**





- **ripple variance geometry**
  - **triangle types indicate ripple variance behavior**
    - **isosceles – zero variance on-axis**
    - **acute – highest rate of change (over angle and distance)**
    - **right – variance over distance**
    - **obtuse – lowest rate of change**
  - **compromise between minimum variance and maximum SPL capability**
    - **maximum overlap (100%) will yield maximum power (+6 dB) but with maximum risk of ripple variance**
    - **minimum overlap reduces risk of ripple variance, but significantly limits the amount of power addition possible**

- **forward aspect ratio (FAR)**
  - **defined as a single level contour's length from the speaker (forward) compared to its width (street term: "throw")**
  - **determined by creating a rectangle that encloses the following:**
    - **the speaker**
    - **the on-axis point at distance X**
    - **the off-axis points at distance X/2**



FAR=5.8 (20 deg)

- **proximity ratio**
  - **defined as the difference between the closest and farthest seats in the coverage area of the speaker(s) – a measure of the asymmetry of the coverage shape**
  - **can be expressed as a number or in dB (20 x $\log_{10}$ of ratio)**
  - **creates an asymmetry level requirement for which the source (speaker) must compensate**
  - **compensation can be achieved by:**
    - **orienting the speaker coverage pattern to compensate for the asymmetry**
    - **using multiple loudspeakers to create an asymmetric shape in proportion to the listeners**
  - **has implications for control of spectral variance (excessive pink shift) – coverage areas with proximity ratios $\geq$ 2 can benefit from the addition of a "fill" subsystem**
- **minimum level variance**
  - **aspect ratio rectangle is most basic shape of minimum level variance**
  - **as coverage angle narrows, rectangle elongates**
  - **minimum variance area can be found as a solid shape and a line**
    - **solid shape standard for symmetric applications often found in horizontal plane – front half of rectangle highly variable, back half experiences nominal variation**
    - **line of minimum variance is most representative for asymmetrical applications, such as vertical coverage – extends from on-axis rear to off-axis mid-point**