Lecture Summary – Combination

Chapter 9

- **array building**
  - **two principal beamwidth shapes suitable for array building**
    - **2nd order "plateau" type that flattens out in the high frequencies ("constant directivity") – provides consistent unity splay angle → applications in both H and V planes (but in limited quantities)**
    - **highly sloped 3rd order elements useful in highly overlapped coupled array configurations (no consistent unity splay angle) – foremost application is creation of asymmetrical arrays → leader in vertical applications**
    - **(1st order speakers best suited for "standalone" applications → best for horizontal coverage applications**

- **role of overlap as a "shaping tool"**
  - **can range from half as wide to twice as wide**
  - **decisive factor: percentage overlap**
  - **control of overlap**
    - **angular (point in different directions)**
    - **displacement (moving elements apart)**
  - **low overlap: elements retain much of their individual character (yet merge to create "sculpted shapes" unique to arrays)**
  - **high overlap: individual elements disappear and merge into combined shape of "new and different" single speaker**
  - **overlap is the "shaping tool"**

- **limitations of combined shapes**
  - **will use aspect ratio icons to visualize individual contributions**
  - ***beam concentration and ripple variance aspect of combined response are not apparent in simple icon representation***

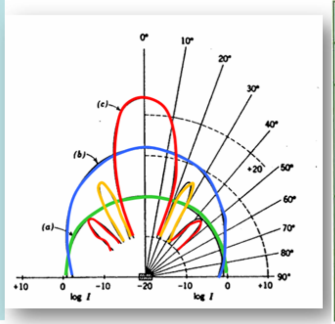
- **role of asymmetry as a "shaping tool"**
  - **what asymmetries are available to the array designer**
  - **why are asymmetries necessary**
  - **which asymmetries are static and which are dynamic**

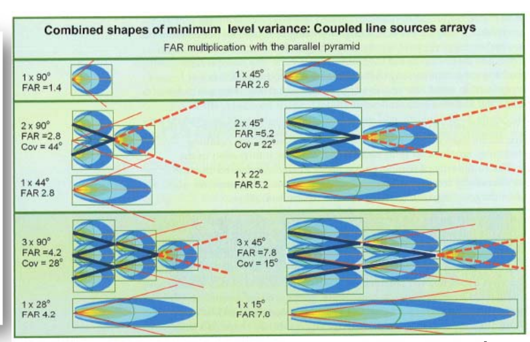
- **coupled line source arrays – basic idea**
  - **stack "aspect ratio icons" end-to-end (for side-by-side speakers)**
  - **combined shape of coupled line source visualized as forward extension by means of simple additions of aspect ratio shapes**

Recall: Beamwidth of a single speaker approaches 90° when the transmitted λ equals the radiating cone size (blue line in figure). Beamwidth is wider if λ > cone size (green line) and narrower if λ < cone size (red line).

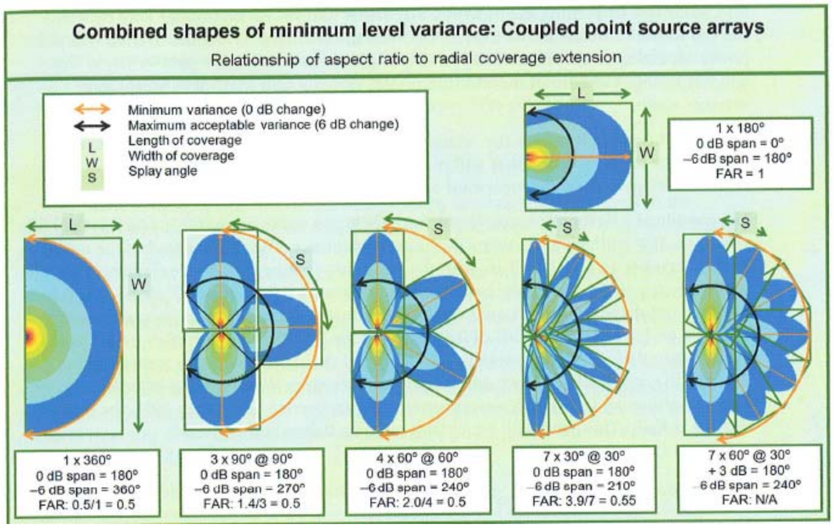
For a coupled line source, vertical coverage is 72° when the transmitted λ equals the line length (e.g. beamwidth for a 2m long array will be 72° at 170 Hz).

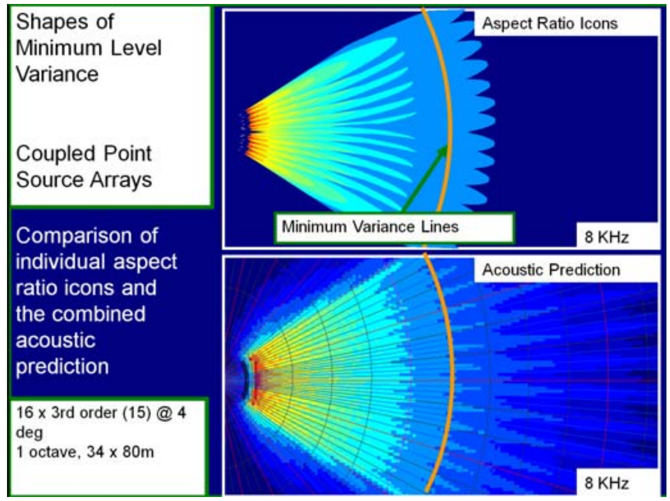
Note that equations relating line length to beamwidth assume omnidirectional ("point") sources.



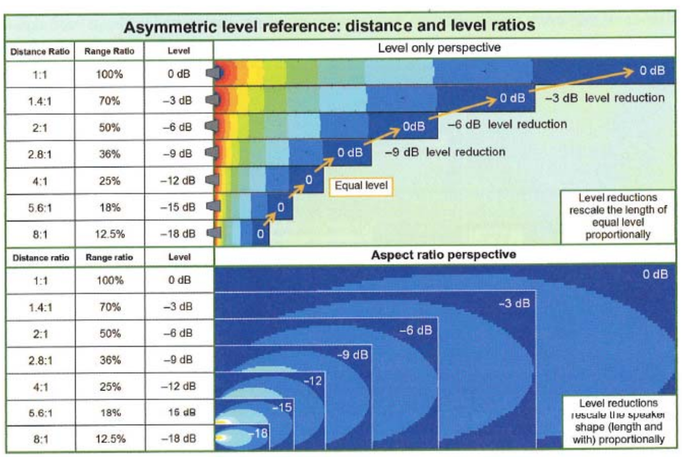


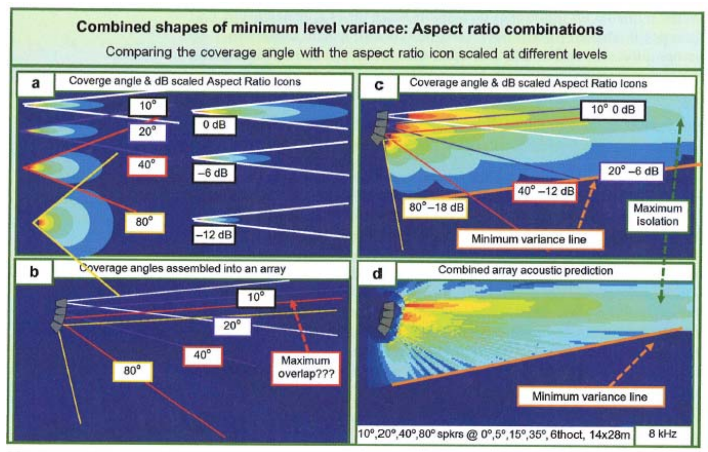
- **coupled point source arrays – basic idea**
  - **arrange aspect ratio icons side-by-side around a virtual point source (unity splay angle)**
  - **combined shape will strongly resemble radial spread of individual FAR patterns**

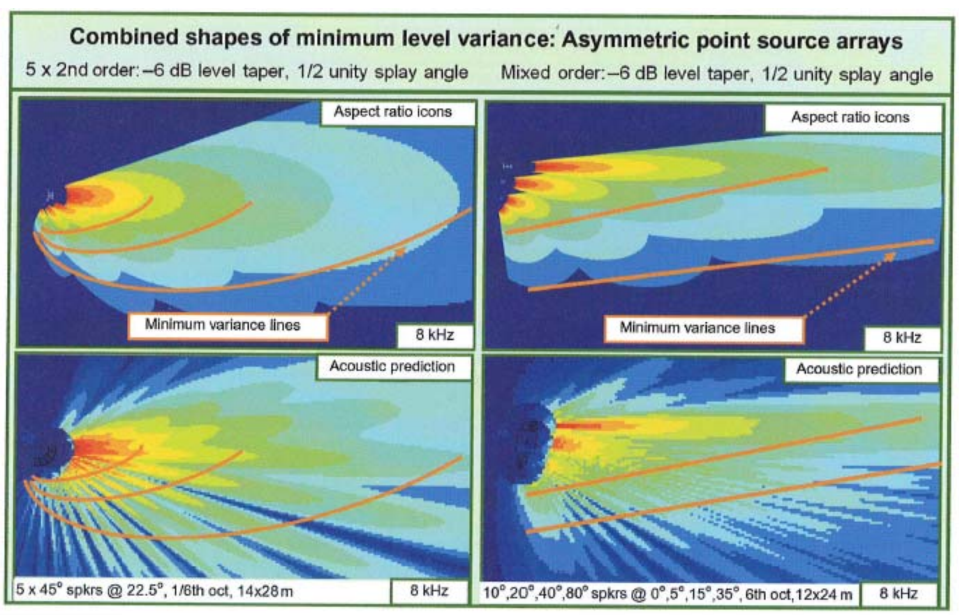




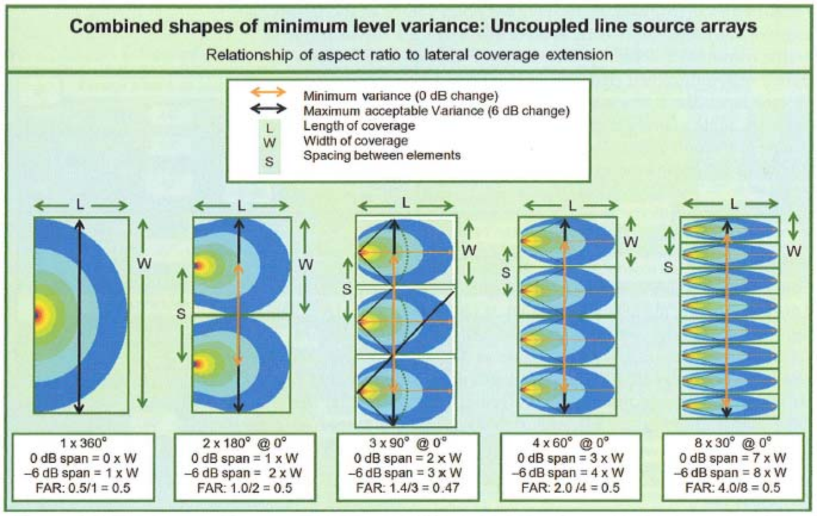
- **asymmetric level scaling – size of icon reduced 50% for each reduction in level by 6 dB**

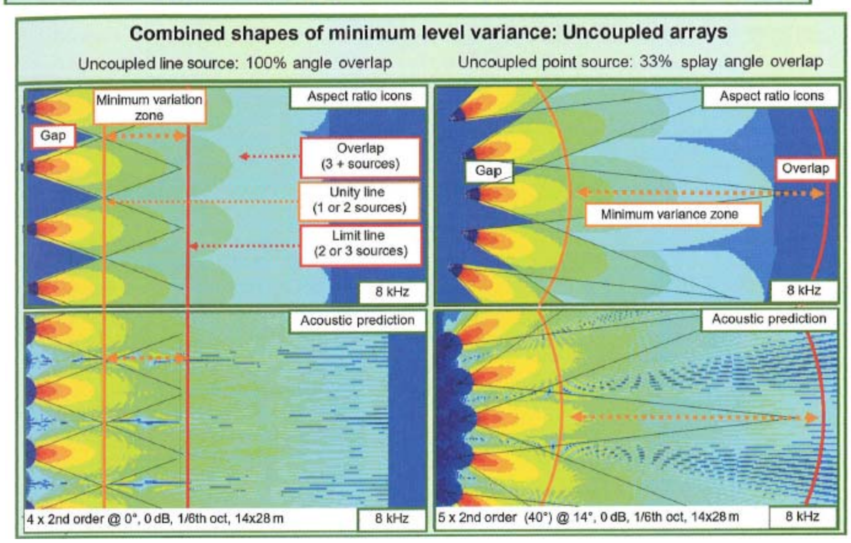


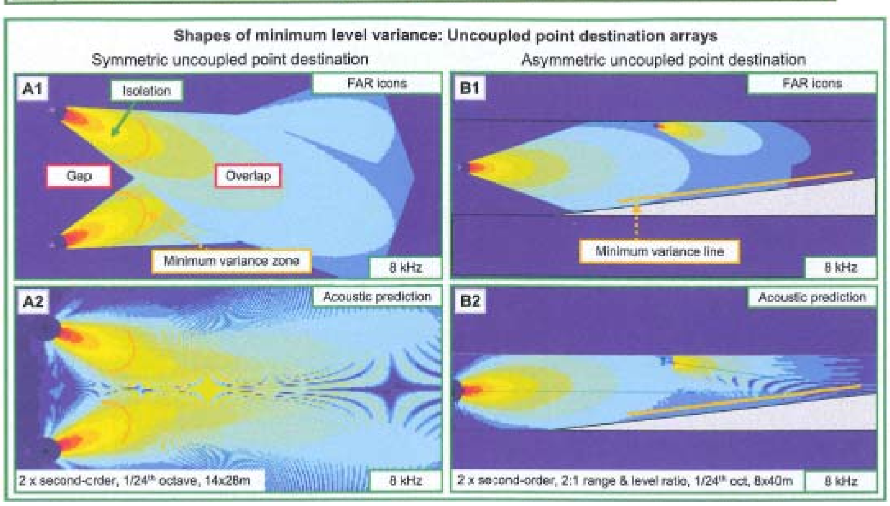




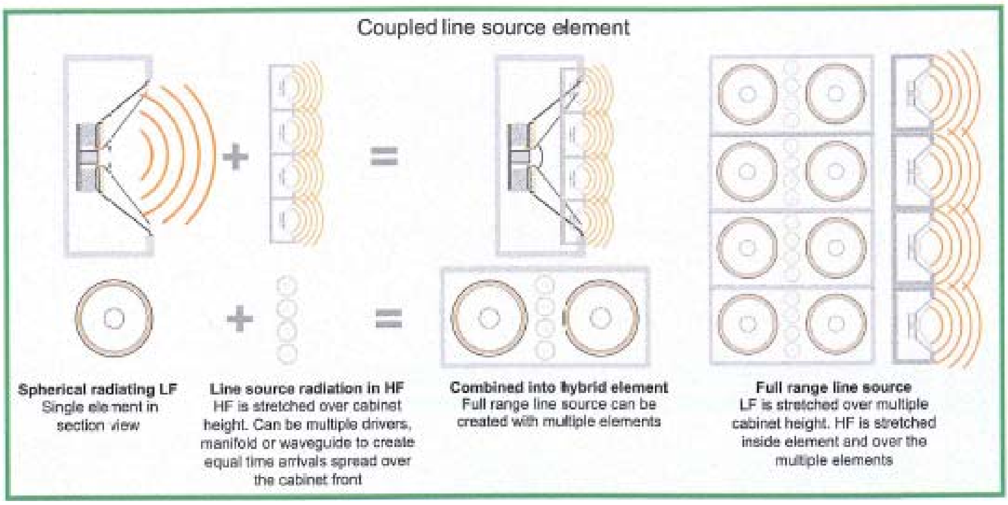
- **uncoupled arrays – basic idea**
  - **best way to deal with overly wide coverage shapes**
  - **combined shape can be seen as lateral extension by means of simple stacking of aspect ratio shapes**
  - **combined aspect ratio becomes wider (while not becoming longer) and therefore lower in number**
  - **FAR found by dividing the single element FAR by the number of elements**



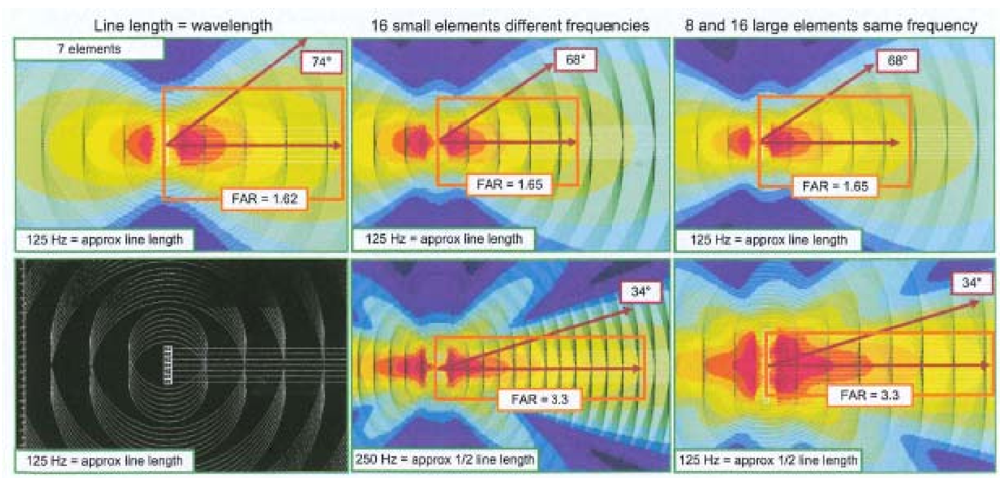




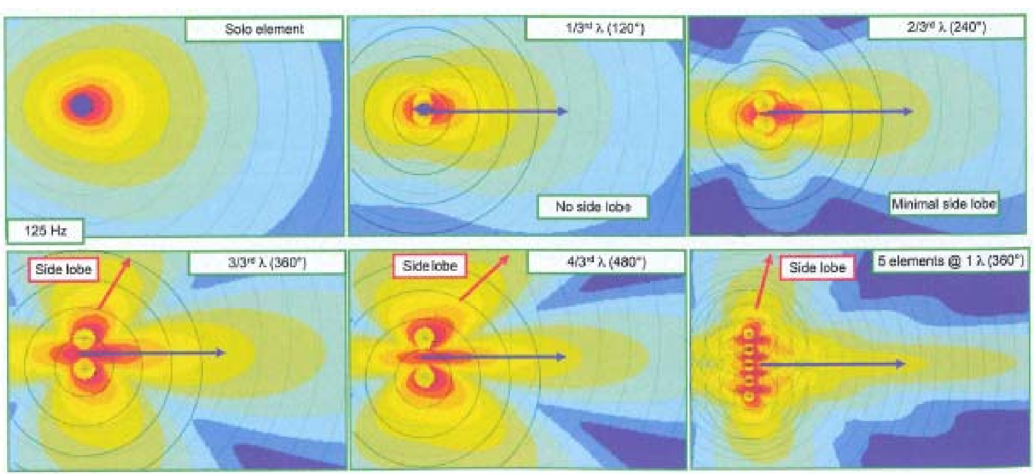
- **spectral variance of coupled arrays**
  - **possible outcomes of beam combinations**
    - **concentration/power addition (coupling zone)**
    - **spreading (isolation zone)**
    - **"passing through each other" (combing zone)**
- **spectral variance of coupled line source arrays**
  - **representative line source element**



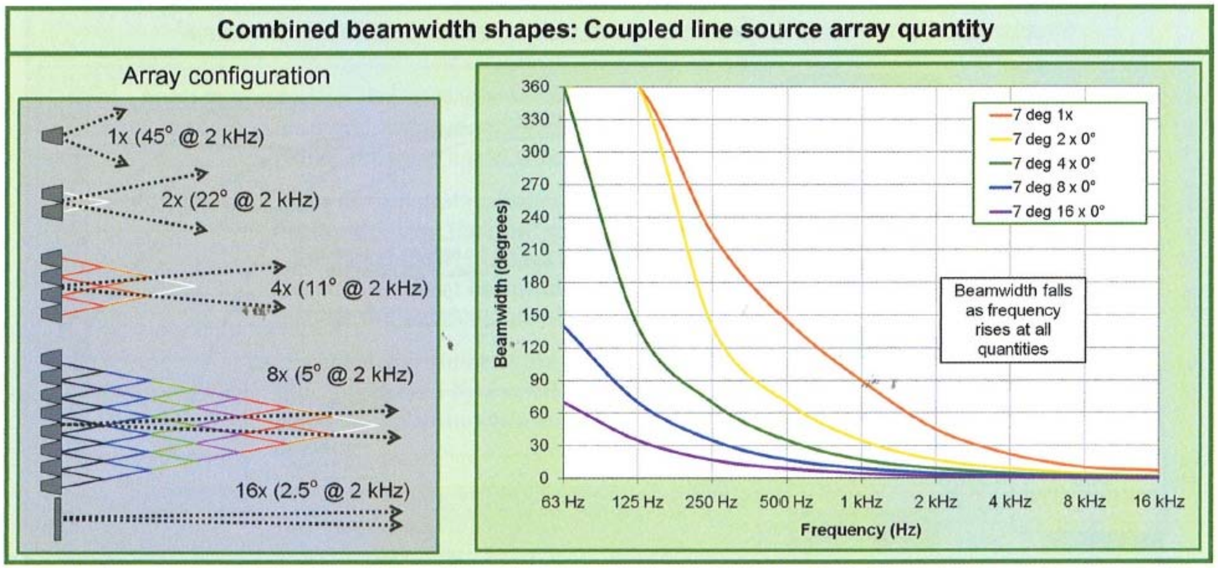
  - **coupled line source length effects**



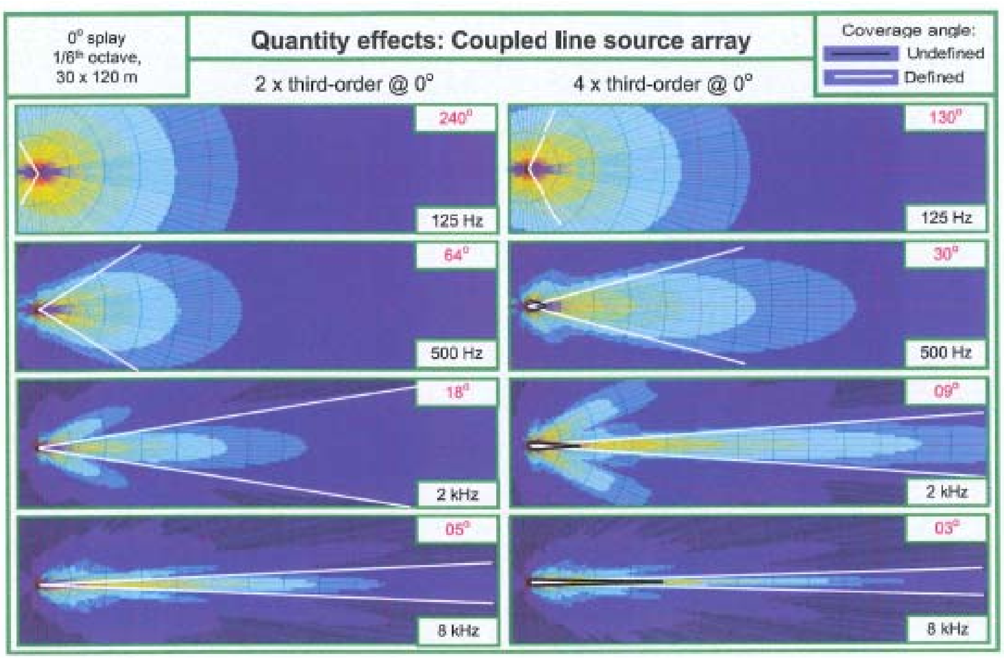
  - **coupled line source element spacing effects**



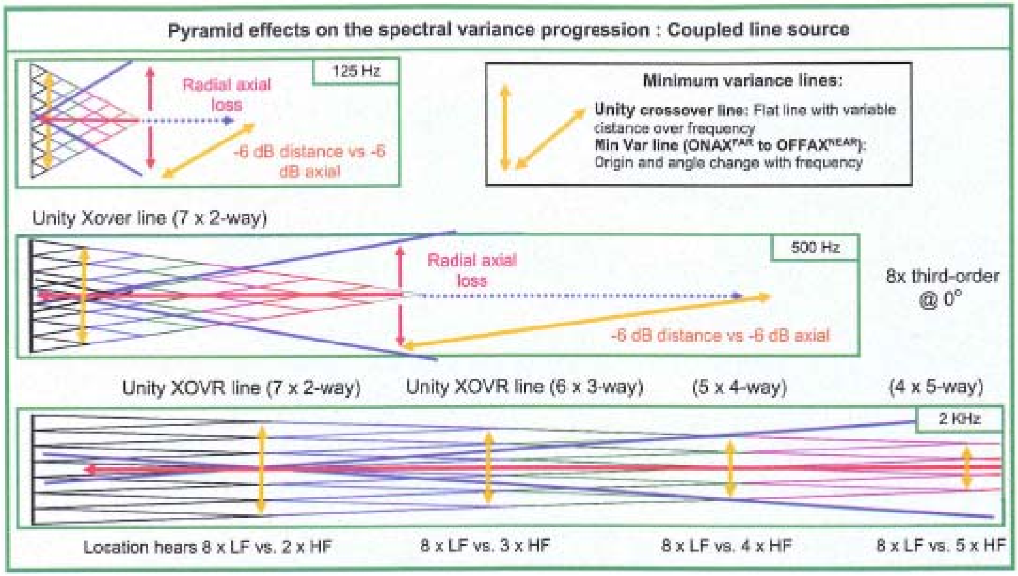
- **coupled line source element beamwidth shapes**



- **coupled line source element quantity effects**
  - **coverage pattern narrows as quantity rises**
  - **ratio of spectral variance unchanged by quantity**
  - **beam concentration is primary driving force**
  - **larger quantities give appearance of reduced spectral variance if range of viewing does not extend far enough for coupling to occur over the full frequency range**



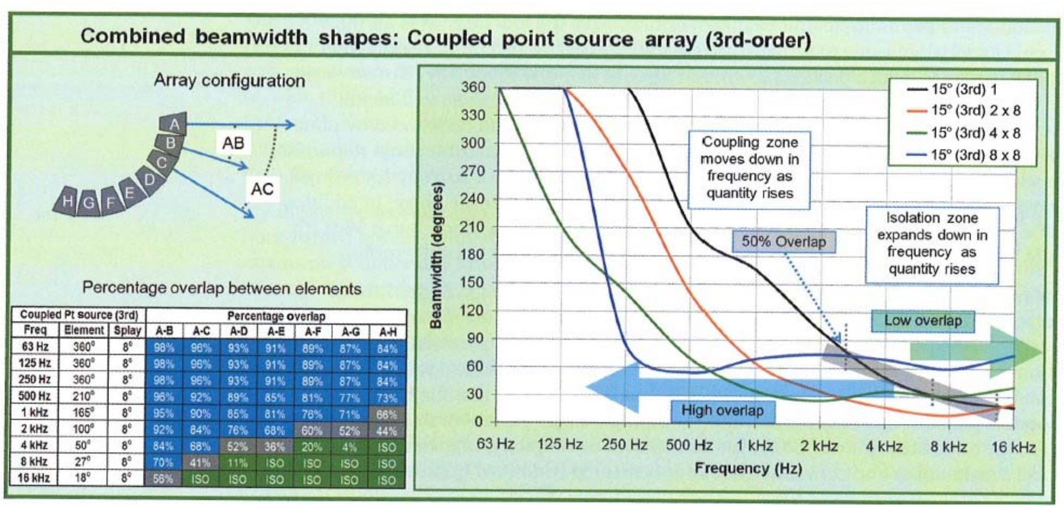
- **coupled line source pyramid effects**



- **coupled line source speaker order effects**
  - **line length is dominate force at lower frequencies (where line length ≥ λ/2)**
  - **side lobes vary with speaker order but main lobes are still matched at mid frequencies**
  - **at high frequencies, low-order array coverage degenerates into ripple, while high-order array maintains focus**

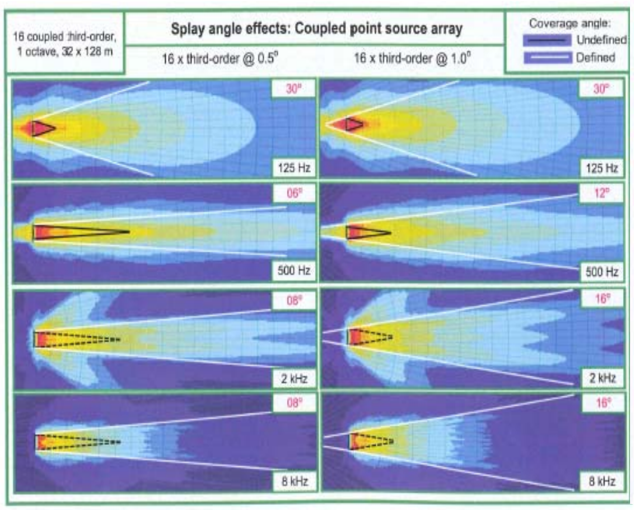
- **coupled line source level tapering effect**
  - **effectively reduces number of elements contributing to the "pyramid"**
  - **behavior mimics an array of shorter length**
  - **(aside – *frequency dependent* amplitude tapering not considered in text, nor is delay tapering – accomplished using DSP)**

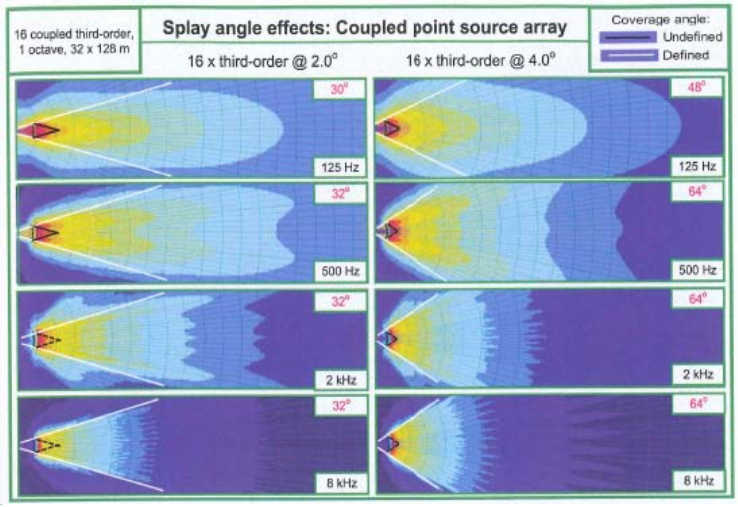
- **spectral variance of coupled point source arrays**
  - **beamwidth shapes**



Coupled Pt source (3rd)			Percentage overlap						
Freq	Element	Splay	A-B	A-C	A-D	A-E	A-F	A-G	A-H
63 Hz	360°	8°	98%	96%	93%	91%	89%	87%	84%
125 Hz	360°	8°	98%	96%	93%	91%	89%	87%	84%
250 Hz	360°	8°	98%	96%	93%	91%	89%	87%	84%
500 Hz	210°	8°	96%	92%	89%	85%	81%	77%	73%
1 kHz	165°	8°	95%	90%	85%	81%	76%	71%	66%
2 kHz	100°	8°	92%	84%	76%	68%	60%	52%	44%
4 kHz	50°	8°	84%	68%	52%	36%	20%	4%	ISO
8 kHz	27°	8°	70%	41%	11%	ISO	ISO	ISO	ISO
16 kHz	18°	8°	56%	ISO	ISO	ISO	ISO	ISO	ISO

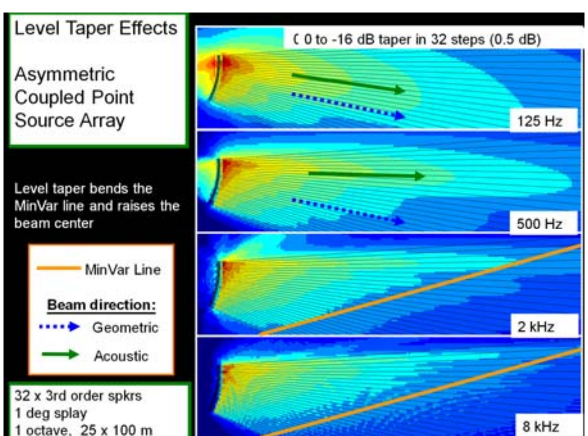
- **splay angle effects**
  - **even a small splay angle creates an opportunity for reduced spectral variance (that cannot be found in a coupled line source…*unless DSP techniques are used*)**
  - **isolation (even in small measure) will counteract pattern narrowing**

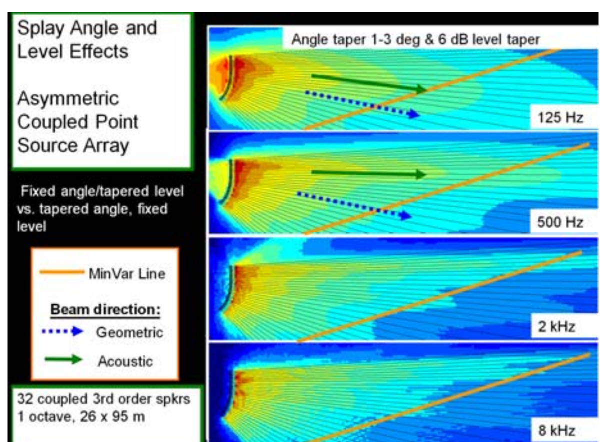


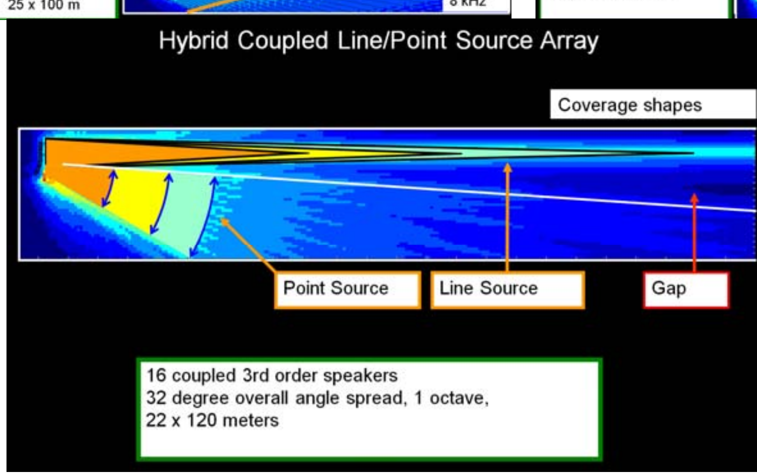


- **asymmetry (symmetry percentage) – ratio of angular coverage above and below center**
  - **level taper**
  - **splay (angle) taper**
  - **mixed loudspeaker orders**
  - **lateral spacing/level offsets**
  - **forward spacing/level offsets**
  - **hybrid coupled line/point source arrays**

Level tapering bends the minimum variance line and raises the beam center



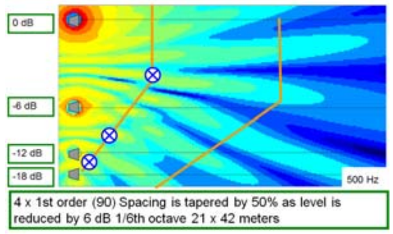


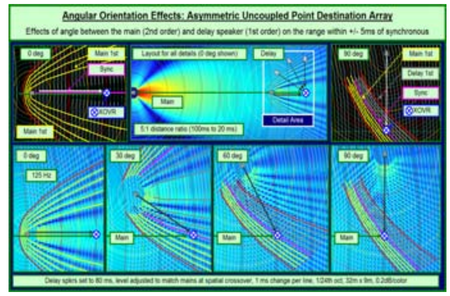


Where would a "gap" in the coverage shape be useful?

- **uncoupled arrays**
  - **line source**
  - **point source**
  - **point destination**

Lateral Spacing and Level Effects





- **conclusions**
  - **1st order speakers**
    - **most suitable for single-element applications with a low proximity ratio**
    - **least suitable for angular overlap**
    - **least suitable for combination (power addition)**
    - **beamwidth must not widen as frequency rises (once plateau reached must remain constant)**
    - **should be arrayed at or near unity splay angle based on beamwidth plateau**
  - **2nd order speakers**
    - **most suitable for single-element applications with a medium proximity ratio**
    - **suitable for combination (power addition) on a limited basis**
    - **no beamwidth reversal (widening as frequency increases)**
    - **should be arrayed at or near unity splay angle based on beamwidth plateau**
  - **3rd order speakers**
    - **least suitable for single-element applications**
    - **most suitable for angular overlap**
    - **suitable for combination (power addition)**
    - **constant downward beamwidth slope (with no reversals) as frequency increases**
    - **should be arrayed at an angle greater than 0º (relative)**
  - **power capability**
    - **coupled arrays can increase concentrated power capability beyond a single element while maintaining minimum variance over long distances**
    - **the coupled point source has the highest ratio of increased power to variance over the widest frequency span and spatial area**
    - **the coupled line source can provided "unlimited" power but is incapable of minimum spectral variance over the space**
    - **asymmetric level tapering will decrease the overall power capability at the geometric center of the array but provide the opportunity for minimum variance over an asymmetric space**
    - **uncoupled arrays can increase distributed power capability beyond a single element while maintaining minimum variance, but only over a very limited distance**
  - **minimum variance coverage shapes**
    - **rectangle: individual speaker**
    - **arc: symmetric point source**
    - **right triangle: asymmetric coupled point source**
  - **minimum variance principles**
    - **single speakers**
      - **position the speakers with the lowest possible proximity ratio to the audience in at least one plane**
      - **use speakers that have minimum beamwidth ratio over frequency (1st or 2nd order)**

- **match the properties of symmetry (symmetric orientation for symmetric shapes, asymmetric orientation for asymmetric shapes)**
- **match speaker aspect ratio to audience coverage shape**
- **if speaker coverage pattern overlap on to room surfaces is too strong, use an array instead**

- **minimum variance principles, continued…**
  - **symmetric point source coupled arrays**
    - **fill the arc angle required to fit the shape of the audience area (number of elements required will depend on speaker order)**
      - **low-order speakers must have minimal overlap**
      - **high-order speakers can be overlapped for power addition**
    - **beam spreading will shape (widen) the HF coverage**
    - **beam concentration will shape (narrow) the LF coverage**
    - **apply these principles to make shapes meet in the mid-range**
  - **uncoupled arrays**
    - **achieve isolation by angular offset and/or displacement**
    - **as angular offset falls, the usable depth range falls as well**
    - **uncoupled array depth is initiated by overlap**
      - **before overlap, response is as a single element**
      - **after overlap begins, array behavior and ripple variance begin**
    - **uncoupled array depth is limited by overlap – multiple overlap provides the ending limit for depth**
    - **uncoupled arrays can be scaled by relative level to appropriate depth**