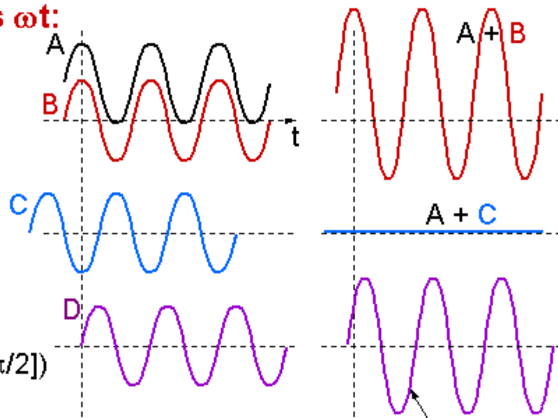
SUPERPOSITION OF PHASORS-MULTIPATH

Transmitters radiate E cos ωt:

$\cos\omega t + \cos(\omega t + \phi) =$
$2\cos(\omega t + \phi/2)\cos(\phi/2)$

{Since $\cos\alpha + \cos\beta =$
$2\cos([\alpha+\beta]/2)\cos([\alpha-\beta]/2)$}

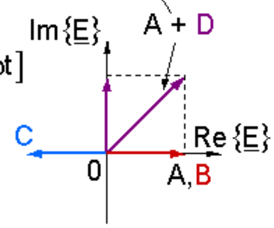
			A + B/C/D =
B	$\phi = 0$	⇨	$2\cos\omega t$
C	$\phi = \pi$	⇨	0
D	$\phi = \pi/2$	⇨	$2^{0.5}\cos(\omega t + [\pi/2])$



Phasors:

$$E(t) = \mathrm{Re}\{\underline{E}e^{j\omega t}\} = \mathrm{Re}[\mathrm{Re}\{\underline{E}\} + j\mathrm{Im}\{\underline{E}\}][\cos\omega t + j\sin\omega t]$$

A,B	E	0
C	-E	0
D	0	E



L6-1

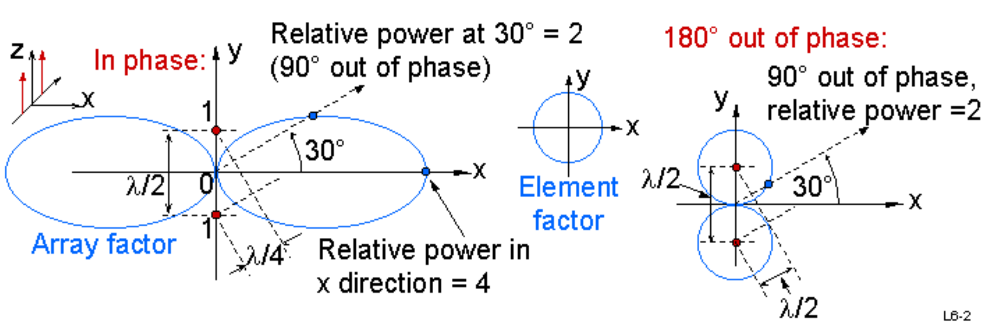
ANTENNA ARRAYS

Radiation:

$$\overline{E}(r,\theta,\phi) = \sum_i \underline{a}_i \overline{E}_i e^{-jkr_i}$$
$$= \overline{E}\left(\sum_i \underline{a}_i e^{-jkr_i}\right) = (\text{element factor } \overline{E})(\text{array factor})$$

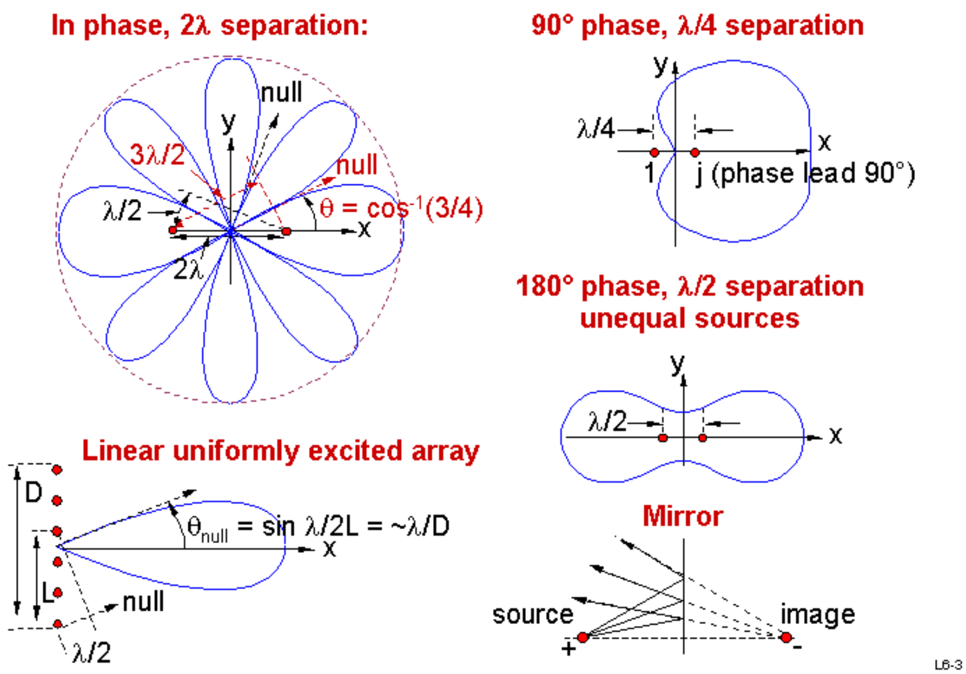
if elements have the same orientation and pattern (so $\overline{E}_i = \overline{E}$), but different locations $\overline{r}_i$, and amplitudes and phases $\underline{a}_i$, where $\underline{a}_i$ characterizes the currents driving each radiating element

Example, horizontal arrays of vertical dipoles:



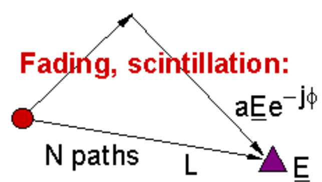
L6-2

MULTI-ELEMENT ANTENNA ARRAYS



L6-3

MULTIPATH EFFECTS



Causes of fading:

- Moving reflectors (trucks, trees) vary ϕ
- Moving sources and receivers
- Variations in c due to temperature, humidity
- Polarization rotation or variation

Examples:

FM radios in moving cars click during nulls below FM threshold
Snowy TV broadcast stations waiver as planes fly overhead or trucks pass
Strength of radio stations varies with the weather (also due to refraction)
Ionosphere faraday rotates linear polarization $\lesssim$3 GHz, causing fades

Doppler shift Δf:

If the path L to the source increases at $v = \partial L/\partial t$, we lose
$\Delta f_D = (\partial L/\partial t)/\lambda$ cycles per second $= v/\lambda = f_o v/c$ Hz, so $f_D = f_o(1 - v/c)$ Hz

Remedies:

Doppler shift – retune receiver
Fading – error-correction codes; space, frequency, polarization diversity

L6-4

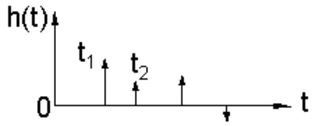
FREQUENCY RESPONSE OF MULTIPATH CHANNELS

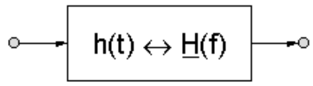
Two-path fading:

Sinusoidal fading with frequency, new null as Δ(path difference) = λ
Null goes to zero if the two strengths are equal

Multipath fading:

Frequency response is square of Fourier transform of multipath impulse response h(t)





Example: $H(f) = \int_{-\infty}^{+\infty} [\delta(t - t_1) + \delta(t - t_2)] e^{-j\omega t} dt = e^{-j\omega t_1} + e^{-j\omega t_2}$

$$= e^{-j\omega(t_1+t_2)/2}\left[e^{j\omega(t_1-t_2)/2} + e^{-j\omega(t_1-t_2)}\right]$$

$$|\underline{H}(f)|^2 = \left[2\cos(\omega[t_1 - t_2]/2)\right]^2 = 0 \text{ when } \omega_n[t_1 - t_2]/2 = (2n+1)\pi/2$$

Therefore null frequencies $f_n = \omega_n/2\pi = (n + 1/2)/(t_1 - t_2)$, and therefore

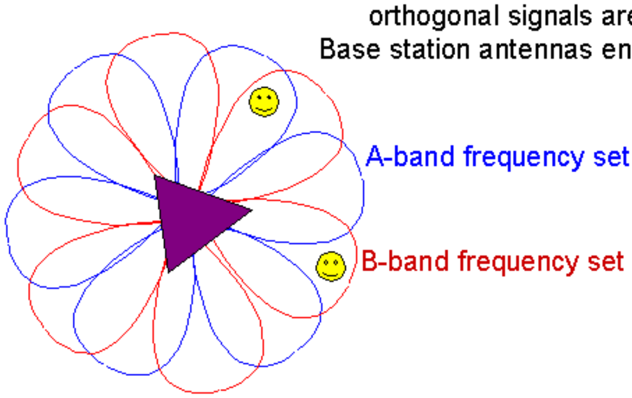
For two paths at t_1,t_2, Δf between nulls is $1/(t_2 - t_1)$ Hz (1 MHz ↔ 300 m)

L6-5

FREQUENCY REUSE

Cell phones:

Frequency allocations are limited
Therefore narrowband signals or otherwise orthogonal signals are used
Base station antennas enable frequency reuse

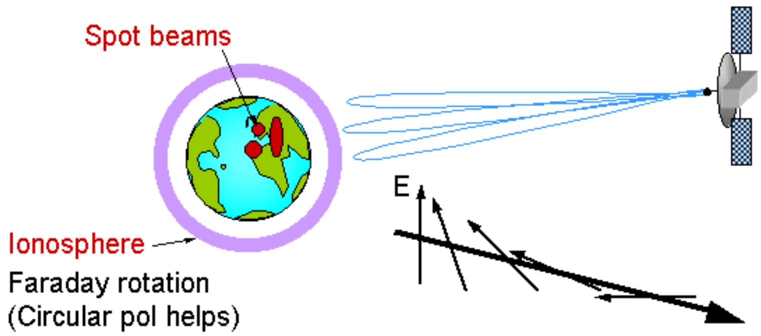


Typical 4-antenna face

Most clients can use non-faded frequencies

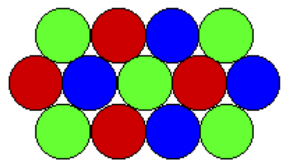
L6-6

SATELLITE COMMUNICATIONS SYSTEMS



Faraday rotation
(Circular pol helps)

Overlapping beams
Three independent arrays
(R,G,B); avoids nulls

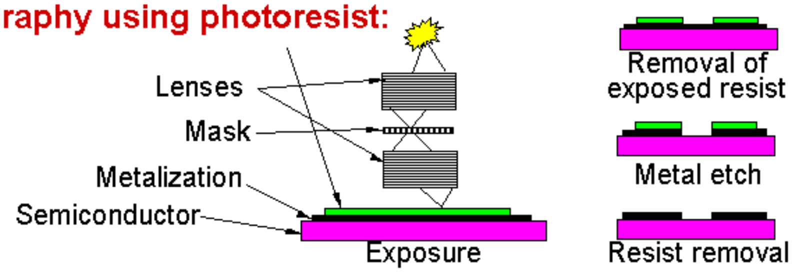


Rain is an increasingly serious problem at frequencies above 2-4 GHz,
99.99% availability ⇨ 99.9% ⇨ 99% ⇨ 90% with increasing frequency
("4 nines", "3 nines", 2 nines", etc.)

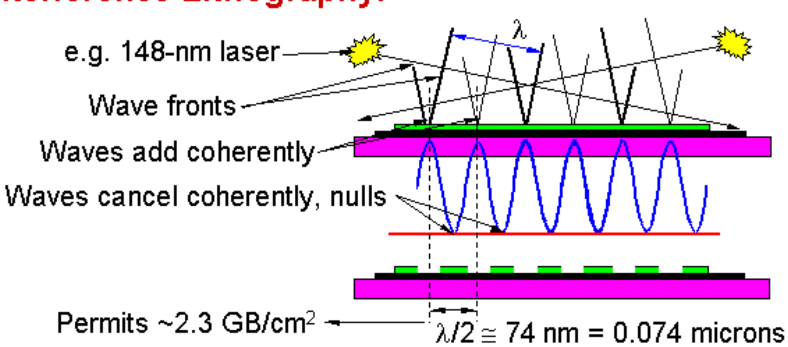
L6-7

WAVE INTERFERENCE X-RAY LITHOGRAPHY

Lithography using photoresist:



Wave Interference Lithography:



L6-8