適用於5G之波束成形的基本原理含系統架構

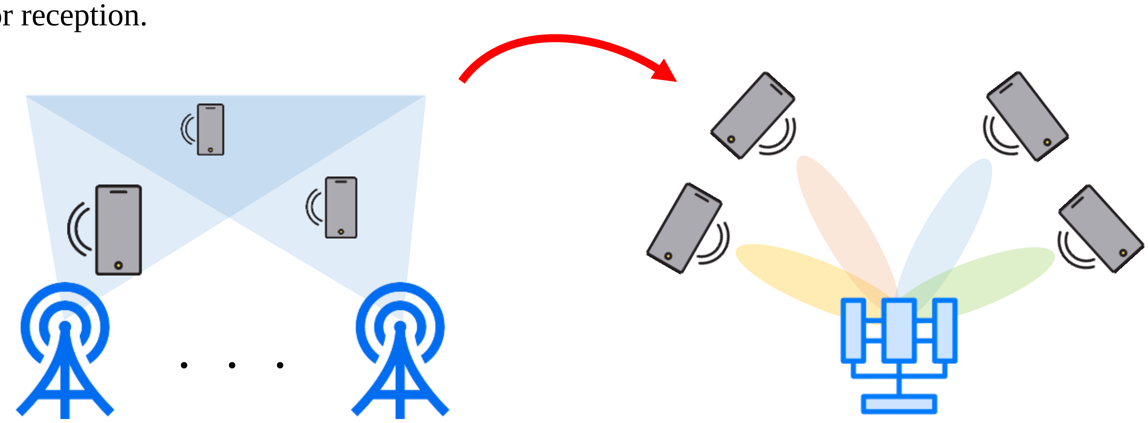
Outline

➢ Beamforming theory background
  －What is beamforming ?
  －Why we need beamforming
➢ Beamforming in application and MIMO systems
  －Applications of beamforming technology
  －What is the relation between beamforming and MIMO and smart antenna ?
➢ Antenna synthesis
  －Discrete and Continuous distribution
  －Fourier transform method
  －Schelkunoff Polynomial Method
  －Woodward-Lawson Method
  －Dolph-Chebyshev distribution
  －Taylor $\bar{n}$ line distribution
➢ Conclusion

Beamforming theory background

- What is beamforming ?

Beamforming is a method used in sensor arrays for directional signal transmission or reception.

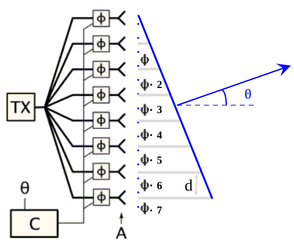


- Why we need beamforming ?

➢ Minimize interference (increases due to that antenna serving multiple UE)

➢ Maximize transmission efficiency

It is similar to spatial filtering which achieved by combining elements in a phased array in such a way that signal at particular angles .



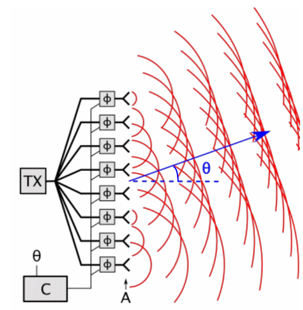
$+$

$$\mathrm{AF} = \sum_{n=0}^{N-1} a_n e^{jn\Psi}$$

$$\Psi = kd\sin\theta$$

$$a_n = e^{-jnkd\sin\theta_0}$$

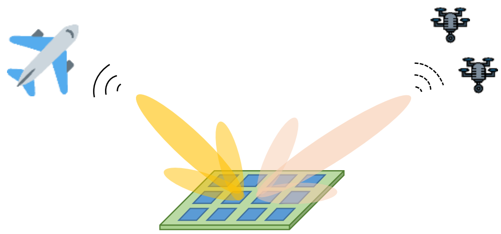
$=$

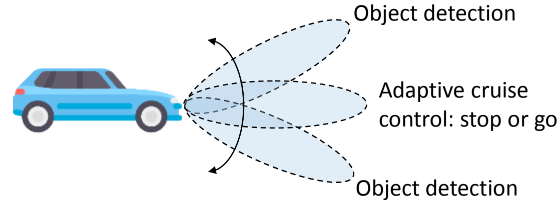


Beamforming in application and MIMO systems

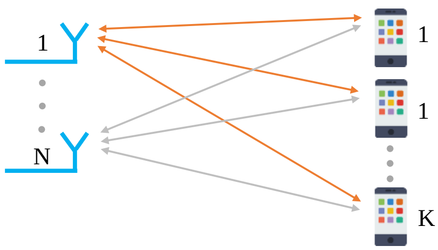
- Applications of beamforming technology

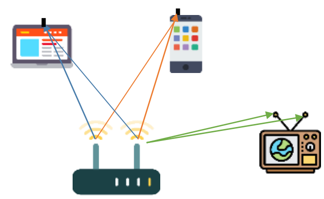
Radar : Air traffic control 、Vehicle radar





Communications : MIMO 、WIFI





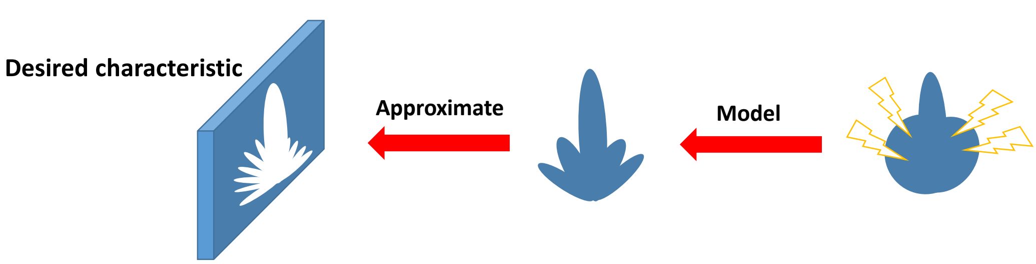
- What is the relation between beamforming and MIMO and smart antenna ?

<u>Antenna synthesis</u>

- Antenna synthesis

Analysis of antenna synthesis is done by choosing a particular antenna model and radiation characteristics such as pattern, directivity, gain, polarization, beamwidth, impedance, bandwidth, and efficiency, they are usually analysed by specifying its current distribution.

The goal is to find not only the antenna configuration but also its geometrical dimensions and excitation distribution.

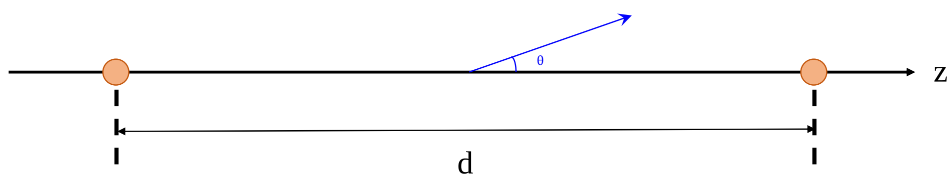


- Discrete and Continuous distribution

Recall the array factor

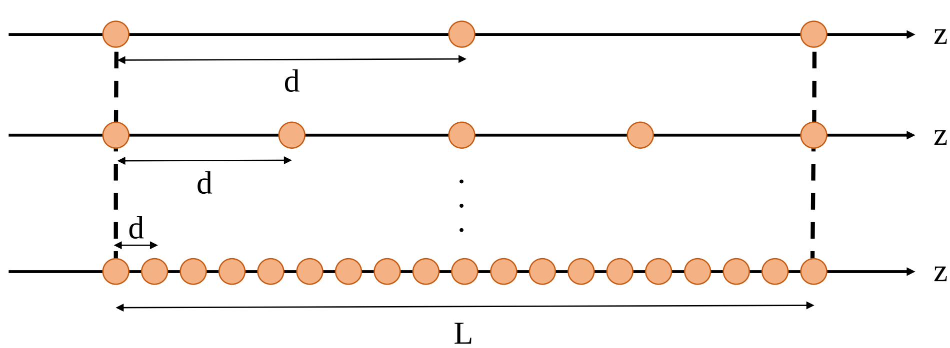
$$AF = \sum_{n=0}^{N-1} a_n e^{jn\Psi} \; ;\Psi = kdcos\theta, a_n = e^{-jnkd\cos\theta_0} \qquad \textit{(discrete)}$$

Consider the 2-element array where each element is driven by the same signal (a uniform excited array), where the overall array length is L and the elements are separated by d.



If the number of elements increases in a fixed-length array, the source approaches a continuous array when the number of points goes to infinity.

So the current distribution of the array becomes continuous rather than an excitation at discrete points.



In the limit, the array factor becomes the space factor

$$AF = \sum_{n=0}^{N-1} a_n e^{jkz\cos\theta}$$

where $z = nd$. We replace summation with integral, then the array factor for the continuous array has been called the *space factor SF*

$$SF = \int_0^L a(z) e^{jkz\cos\theta}\, dz$$

$$\boxed{SF = \int_0^L a(z) e^{j2\pi\frac{z}{\lambda}\cos\theta}\, dz} \qquad \textit{(continuous)}$$

Fourier Transform

where $a(z) = 1$ over the interval $0 \leq z \leq L$.

- Fourier Transform Method

According space factor of continuous array we derived last section, it can be rewritten as

$$SF = \int_{-\infty}^{\infty} a(z) e^{j2\pi\frac{z}{\lambda}\cos\theta}\, dz$$

since $a(z) = 0$ outside of $0 \leq z \leq L$ interval. It is Fourier Transform of $a\left(\frac{z}{\lambda}\right)$. We can think of $\frac{z}{\lambda}$ as the "spatial frequency" and $\cos\theta$ as the "time variable".

(Fourier transform)

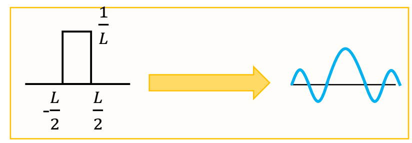
$$f(t) = \int_{-\infty}^{\infty} F(f) e^{j2\pi ft}\, df \quad \longleftrightarrow \quad SF = \int_{-\infty}^{\infty} a(z) e^{j2\pi\frac{z}{\lambda}\cos\theta}\, dz$$

$a\left(\frac{z}{\lambda}\right)$ defines a pulse that is $\frac{L}{\lambda}$ in extent, which if centred at the origin is expressed as

$$a\left(\frac{z}{\lambda}\right) = rect\left(\frac{\frac{z}{\lambda}}{L}\right)$$

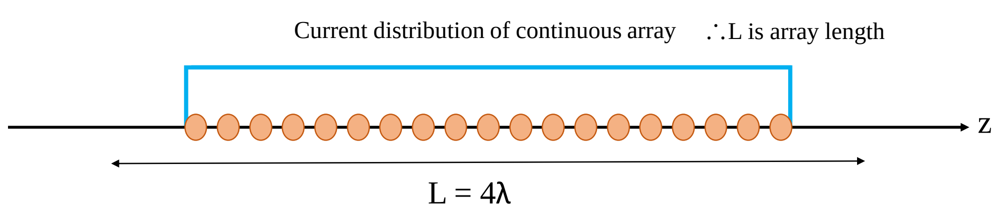
We know the Fourier Transform of a pulse is sin$c$ function, therefore the space factor is

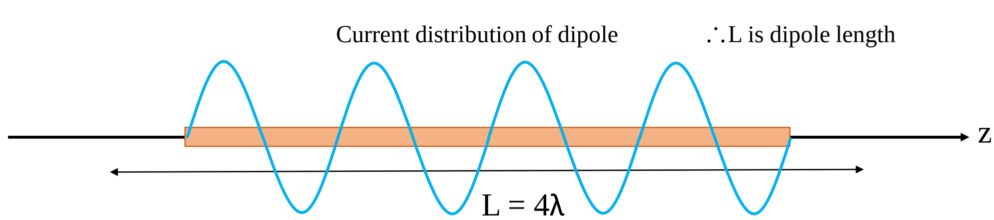
$$SF = sinc(\frac{L}{\lambda}\cos\theta)$$

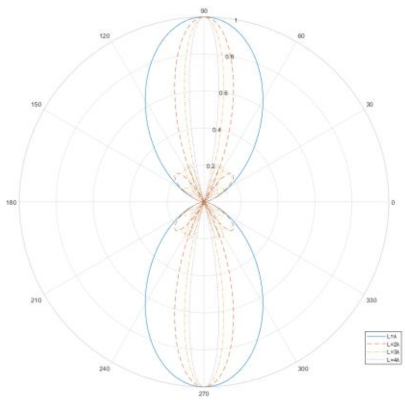


As above formula shown, the array factor is plotted in below for various array lengths, and we compare it to a line source (dipole) with same various

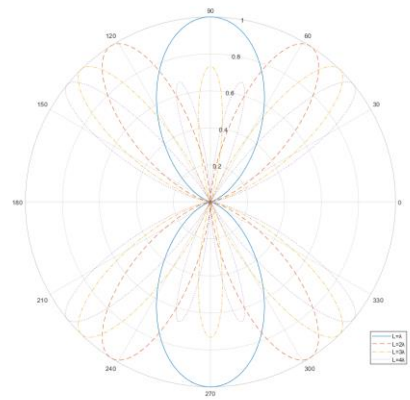
You may recall that a dipole must to maintain a sinusoidal current distribution alone the wire in order to meet the boundary conditions at the end of the wire. Because of the sinusoidal current distribution, it is impossible to generate the pattern like array.







Pattern from continuous array of various lengths



Pattern from dipole antennas of various lengths

- Schelkunoff Polynomial method

The array factor for an N-element, equal spacing, nonuniform amplitude, and additional phase excitation is given by

$$AF = \sum_{n=1}^{N} a_n e^{j(n-1)\Psi} \;\; ;\Psi = kdcos\theta + \alpha$$

Let $\quad z = x + jy = e^{j\Psi} \;\; = e^{jkdcos\theta+\alpha}$

$$AF = \sum_{n=1}^{N} a_n z^{n-1} = a_1 + a_2 z^1 + a_3 z^2 + \cdots + a_N z^{N-1}$$

which is a polynomial of degree (N-1).

Thus,

$$AF = a_N(z - z_1)(z - z_2)\cdots(z - z_{N-1})$$

where $z_1, z_2, \cdots\cdots z_{N-1}$ are the roots. The magnitude then becomes

$$|AF| = |a_N||z - z_1||z - z_2|\cdots|z - z_{N-1}|$$

Note that

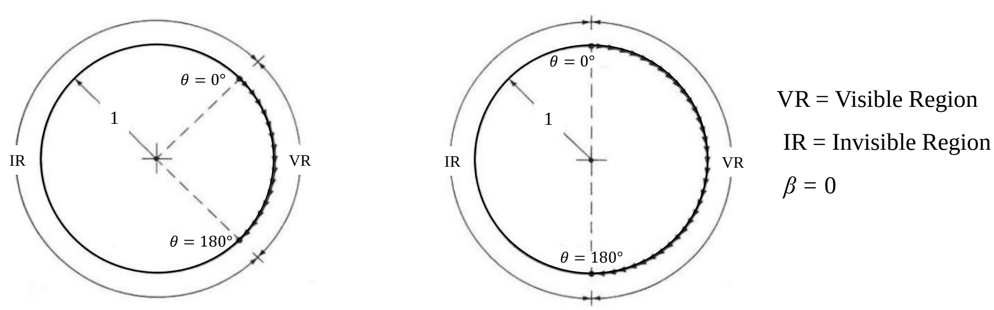
$$|z| = |z|e^{j\Psi} = |z|\angle\Psi = 1\angle\Psi$$

$$|z_n| = |z|e^{j\Psi_n}$$

$$\Psi = kd\cos\theta + \alpha$$

z is on a unit circle.

Schelkunoff's design idea was to place all N − 1 zeros of the array within the visible region, for example, by equally spacing them within it. The following Figure shows the visible regions for a four-element endfire array with element spacings from d = λ/8 and d = 3λ/4.



d = λ/8 , $\alpha = 0$

$$\Psi = \frac{\pi}{4}\cos\theta$$

d = λ/4 , $\alpha = 0$

$$\Psi = \frac{\pi}{2}\cos\theta$$