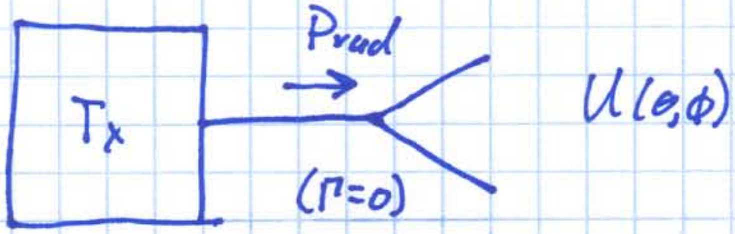
Antenna Directivity

Recall the intensity of the E.M. wave produced by an isotropic radiator (i.e., an antenna that radiates equally in all directions) is:

$$U_o = \frac{P_{rad}}{4\pi}$$

Remember, an isotropic radiator is actually a physical <u>impossibility</u> — real antennas propagate E.M. energy unequally as a function of direction, a fact represented by the radiation intensity function $U(\theta, \phi)$.

Note that $U(\theta, \phi)$ is dependent on both the antenna <u>and</u> the transmitter power. Increasing the transmitter power will of course increase $U(\theta,\phi)$ in all directions.



Of course, this is evident when we consider that the radiated power can be determined from $U(\theta,\phi)$:

$$P_{rad} = \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi) \sin\theta \, d\theta \, d\phi$$

Q: Isn't there some way to characterize the directional behaviour of the <u>antenna only</u>, independent of transmitter power??

A: Yes! We call it the antenna <u>directivity pattern</u> $D(\theta,\phi)$.

To find a function that describes the antenna behaviour <u>only</u>, we need to somehow <u>normalize</u> $\mathcal{U}(\theta,\phi)$ with respect to Prad.

We do this by comparing the radiation intensity $\mathcal{U}(\theta,\phi)$ of the antenna to the radiation intensity produced by an <u>isotropic</u> radiator connected to the same transmitter! I.E.:

$$\boxed{\begin{aligned} D(\theta,\phi) &\doteq \frac{\text{intensity of antenna}}{\text{intensity of an isotropic antenna}} \\ &= \frac{\mathcal{U}(\theta,\phi)}{\mathcal{U}_o} \\ &= \frac{4\pi\,\mathcal{U}(\theta,\phi)}{P_{rad}} \end{aligned}}$$

Note $D(\theta,\phi)$ is a <u>unitless</u> value.

We can show that $D(\theta,\phi)$ is independent of Prad by integrating $D(\theta,\phi)$ over all directions θ, and ϕ

$$\int_0^{2\pi}\int_0^{\pi} D(\theta,\phi)\sin\theta\, d\theta\, d\phi$$

$$= \int_0^{2\pi}\int_0^{\pi} \frac{4\pi\, U(\theta,\phi)}{P_{rad}} \sin\theta\, d\theta\, d\phi$$

$$= \frac{4\pi}{P_{rad}} \int_0^{2\pi}\int_0^{\pi} U(\theta,\phi) \sin\theta\, d\theta\, d\phi$$

$$= \frac{4\pi}{P_{rad}} \left(P_{rad}\right)$$

$$= \underline{\underline{4\pi}}$$

$$\therefore \quad \boxed{\int_0^{2\pi}\int_0^{\pi} D(\theta,\phi)\sin\theta\, d\theta\, d\phi = 4\pi}$$

Furthermore, we find that the average value of $D(\theta,\phi)$ across 4π steradians (i.e., across all directions θ, ϕ) is:

$$\boxed{\begin{aligned} D_{ave} &= \frac{1}{4\pi} \int_0^{2\pi}\!\!\int_0^{\pi} D(\theta,\phi) \sin\theta \, d\theta \, d\phi \\ &= \frac{1}{4\pi}(4\pi) = \underline{\underline{1}} \end{aligned}}$$

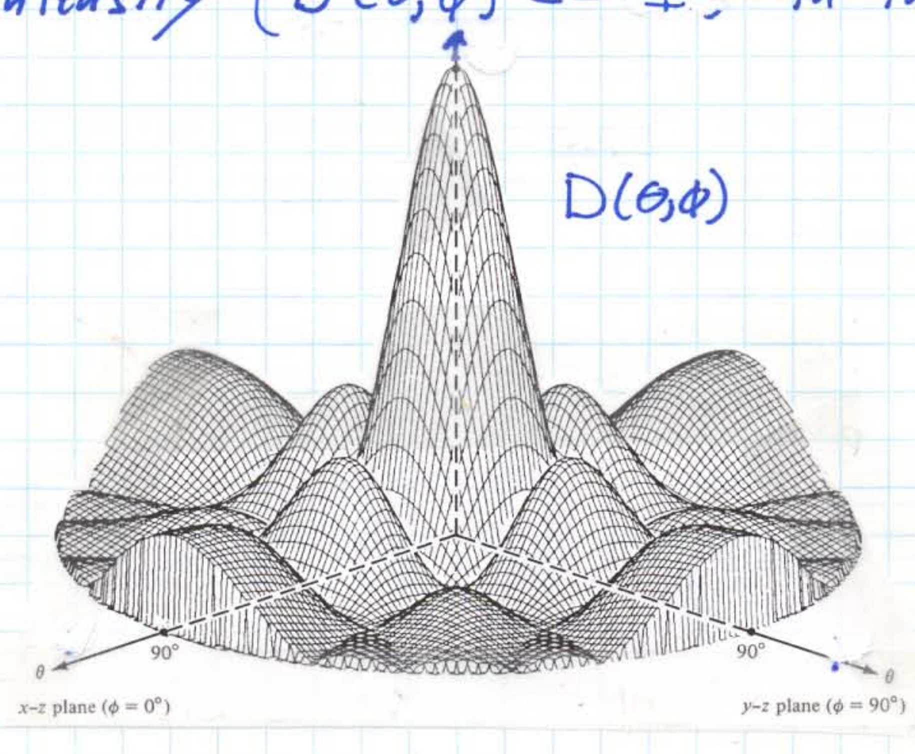
In other words, the average value of $D(\theta,\phi)$, across all directions θ, ϕ, of any and all antennas is $\underline{\underline{1}}$!

What this means is that an antenna may produce an intensity larger than that of an isotropic radiator (U_0) in some directions, but then it must produce an intensity less than an isotropic radiator in other directions.

Likewise, if the intensity is much, much larger than U_0 in a specific direction, then the intensity must be very small in many other directions.

$\Rightarrow$ In other words, the antenna cannot produce above average intensity in all directions!!

Typically an antenna will produce very large intensity (i.e., $D(\theta,\phi) >> 1$) in one general direction, and very small intensity ($D(\theta,\phi) << 1$) in the rest.



Note that there will typically be one direction where the function $D(\theta,\phi)$ is its <u>maximum</u> value.

This maximum value is defined as the antennas <u>directivity</u>:

$$\boxed{\text{Directivity} \doteq D_0 = D(\theta,\phi)\Big|_{max}}$$

Note D_0 is a <u>number</u> (often expressed in dB) while directivity pattern $D(\theta,\phi)$ is a <u>function</u> of θ and ϕ.