Antennas for mobile systems

Electromagnetics
and
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Outline

What they are

Mobile terminal

- Cellular phones.
- Walkie-talkies for PMR.
- Laptops.
- ...

What they are

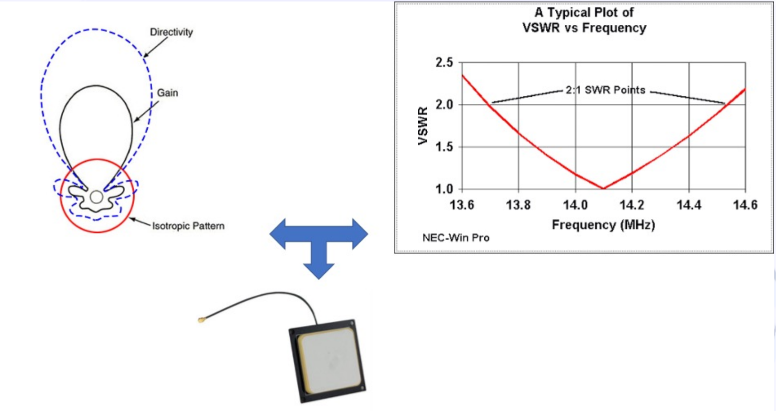
Mobile terminal

Mobile communication requires small, low-cost, low-profile antennas.
In some mobile handsets, semiconductor based diodes or detectors are used as antennas. They are much like p-n diode photo-detectors but work at microwave frequency.
Many times omnidirectional or horn antenna is used in mobile phones.
Also antennas like planar inverted-F antenna, folded inverted antenna and mono pole antenna (scanned radar) are also used widely .

Performance requirements

- Radiation patter: The large degree of multipath and the disturbance given by the close proximity with the user make the precise pattern being usually uncritical.
- Input impedance: Stable and well-matched to the source over the whole bandwidth. Multi-band operation using several resonances.
- Efficiency: High capacity to radiate the FR power at the input terminals.
- Manifacturability: Large-scale without tuning the individual element. Robust against mechanical and environmental hazards.
- Size: As small as possible to fit into casing.

Performance requirements



Bandwidth

Antenna bandwidth

It refers to the range of frequencies over which the antenna satisfies a particular parameter specification.
The parameters generally specified are gain, radiation pattern, the VSWR etc. Most commonly, the VSWR is chosen and this bandwidth is called the impedance bandwidth.
The lower and upper frequencies conforming to the desired VSWR set the frequency band over which the antenna meets the VSWR specification.

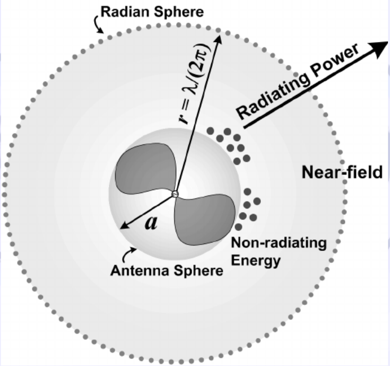
A VSWR specification commonly adopted is a 2:1 VSWR, which means that the range of frequencies over which the VSWR is less than 2 is chosen as the bandwidth of operation.

Outline

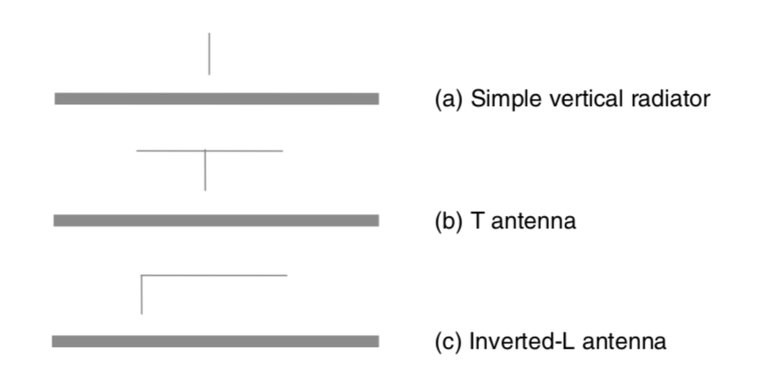
Electrically small antennas

Small wrt the wavelength

An electrically small antenna is such that its radiating structure is contained within a sphere of radius r such that $\beta r < 1$. Approximately $r \leq \frac{\lambda}{6}$.



Short radiators over the ground



Short radiators over the ground

- The short monopole fed against the ground looks capacitive up to $\lambda/4$.
- The bandwidth is ruled d by the $Q = X/R$ factor, with $Z_{in} = R + jX$. Since R is small a large current must be excited and large losses (that limit the efficiency) apply.
- Both the efficiency and the bandwidth are small.

Increasing bandwidth and radiated power

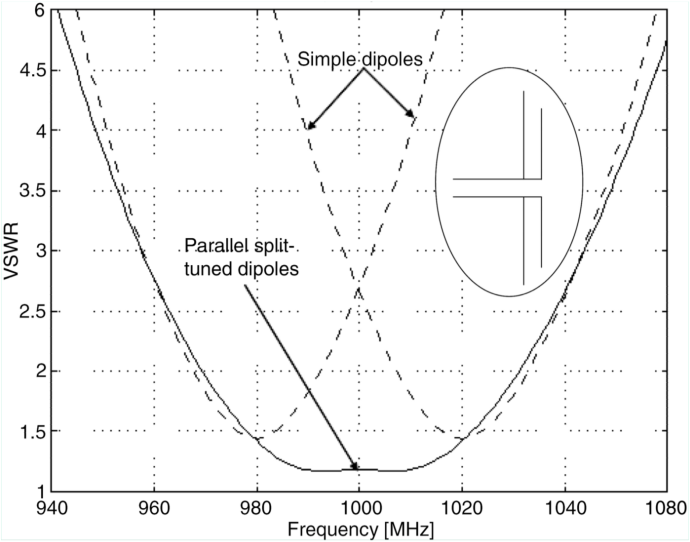
- The horizontal conductor increases the radiation resistance (a constant and larger current will flow on the vertical conductor) and reduces the reactance X at the feedpoint.
- An alternative configuration is the inverted L-antenna.
- Note that in both the cases, the horizontal conductor contributes little to the radiation according to the image theory.

Folded dipole

Main features

- The folding increases the bandwidth wrt the dipole.
- It is ok for home FM/VHF radio.
- It is not convenient for portable devices: 16.5 cm @900 MHz.

Folded dipole

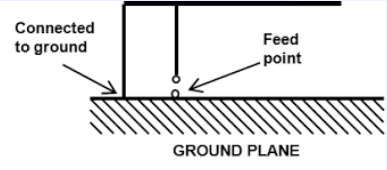


Sleeve dipole

Main features

- It acts as an asymmetrically-feed half-wave dipole with a dipole-like radiation pattern.
- The metal sleeve that surrounds the outer conductor of the coax makes the antenna fairly robust against the user's hand.
- It is used in private mobile radio applications.

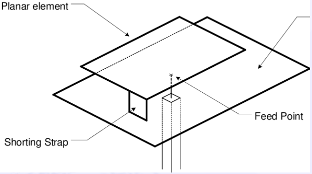
Inverted-F Antenna (IFA)



Main features

- It consists of tapping an inverted-L antenna.
- The ground plane can be one side of the case.
- According to image theory, it appears as a two-wire balance T-line with a short circuit at one hand.
- The direction of maximum radiation is normal to the ground plane.

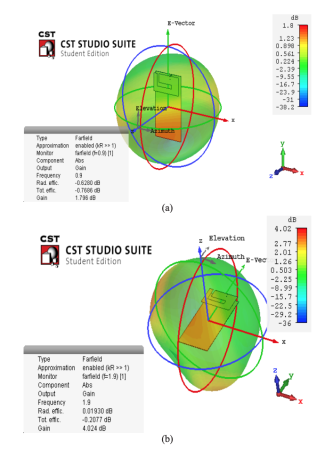
Planar Inverted-F Antenna (PIFA)



Main features

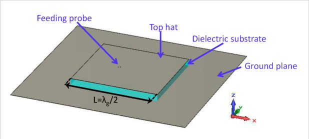
- It is aka Open Microstrip Antenna.
- The wires of the IFA are replaced by metal plates that yield a parallel-plate waveguide between the ground plane and the patch.
- It is typically dielectric-loaded to reduce size.
- The radiation pattern is similar to a uniform current dipole above the ground plane.

PIFA simulated pattern - GSM use



The antenna is a modification of traditional design of PIFA by creating an L-slot that covers GSM bands. The radiation patterns were almost omnidirectional in the two planes.

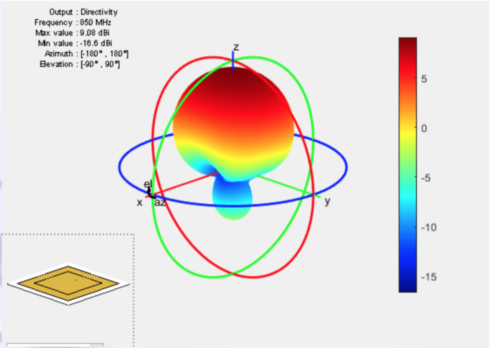
Patch antenna



Main features

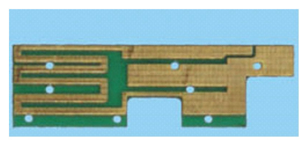
- They are commonly a half-wavelength square.
- It is vertically compact
- It avoids the vertical short circuit that applies in the PIFA while providing a similar radiation pattern.
- It can be miniaturized by dielectrical-loading.

Patch antenna simulated pattern



Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated.

Meander patch antenna



Main features

- In meander line antennas, the wire is continuously folded to reduce the resonant length.
- The advantage is that this antenna is planar and thus easy to integrate inside a mobile phone.
- It can be printed on circuit board.
- It is used in mobile phones.

Coupled antenna-chassis

- It consists of taking benefit of the effect of the conducting mobile terminal chassis.
- The chassis is what has been referred to as the ground plane and it comprises all those parts of the handset that are connected to the ground plane, including the battery, display, case metallization and screening cans.
- The bandwidth of an antenna-chassis combination can be improved by enhancing the coupling from the antenna element to the dominating characteristic wavemode of the chassis.

Outline

How many antennas in cell phone?

Mobile terminal

Smartphone antenna design is reasonably complicated. There are carrier requirements (from the cell plan carriers) and regulatory requirements. In addition, there are multiple antennas on each phone:

- Primary Cellular Antenna (Transmit and Receive)
- Diversity Cellular Antenna (Receive Only)
- GPS Antenna (Receive Only)
- WIFI Antenna (Transmit and Receive)
- NFC Antenna

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How they look like: cell phones

Why we do care

Primary antenna

The primary cellular antenna is the primary communication antenna on the smartphone, and hence is extremely important. It has many specifications and requirements to meet:

- Specific Absorption Rate (SAR) which measures the amount of energy absorbed by the human body when the phone is transmitting at the maximum power.
- The spec on the minimum Total Radiated Power (TRP) is set by the carriers for every frequency band the phone will support.
- The cellular carriers set minimum specifications for the amount of Total Isotropic Sensitivity (TIS) for every frequency band the phone will operate in.

Why so many antennas?

Why so many antennas?

One or two antennas for Wi-Fi, one for Bluetooth, one for GPS, NFC, and two or four for 4G LTE.

Why so many antennas?

Signal's dropout

This multiplicity of LTE antennas avoids dropouts, including those that occur when your hand obscures one antenna, which can be particularly frustrating during a conversation.

High data rates

Having multiple antennas for the same communications link also allows cellphone carriers to combine multiple streams for improved data transfer rates.

Why so many antennas?

The iPhone 4 debacle: The cellular signal dropped merely changing the position of the hands.

The iPhone 4 debacle

That episode in part triggered the use of multiple antennas at the same frequency, typically paired at the bottom and top of the phone and the top left and bottom right corners.

TRP measurements

Mobile Phone	TRP (dBm)												TRP (dBm)								
	GSM900			UMTS900			GSM1800			UMTS2100			LTE800			LTE1800			LTE2600		
	FS	BHHR	BHHL	FS	BHHR	BHHL	FS	BHHR	BHHL	FS	BHHR	BHHL	FS	BHHR	BHHL	FS	BHHR	BHHL	FS	BHHR	BHHL
Doro 7070	28.7	23.5	23.6	20.7	14.5	14.8	27.6	25.2	26.0	18.9	17.4	17.2	18.5	12.9	13.1	18.9	16.3	17.4	17.5	15.0	15.6
Samsung Galaxy S9	27.2	20.7	20.7	17.0	10.5	10.9	26.1	21.6	23.5	18.4	13.4	16.2	16.4	10.7	9.3	18.1	14.2	16.3	16.9	14.4	14.8
Samsung Galaxy S9+	27.6	20.5	20.3	18.1	11.5	10.0	26.0	18.8	21.7	18.6	11.8	15.8	17.8	10.1	10.0	18.7	14.2	15.6	17.8	15.3	14.9
Samsung Galaxy S8	27.4	19.9	20.9	16.9	10.4	10.9	25.8	21.3	22.7	19.7	13.8	17.1	17.3	9.5	8.8	18.5	11.7	14.5	17.8	13.4	9.9
Huawei P20 Pro	26.7	18.5	19.7	17.5	7.2	9.5	23.6	19.0	17.8	18.8	11.0	9.7	16.3	8.7	0.1	16.5	4.7	11.4	15.7	13.7	5.6
Nokia 7 Plus	24.7	17.8	15.0	15.6	9.8	6.0	24.6	20.7	19.9	19.5	14.7	15.3	16.5	8.7	6.6	16.0	10.3	11.6	16.5	13.5	8.3
iPhone 7	27.4	17.5	14.0	18.2	9.2	3.3	25.3	11.0	20.4	18.5	7.3	14.5	16.2	8.3	3.0	18.0	4.1	13.4	18.1	14.7	13.0
iPhone 8	26.8	17.4	10.5	17.9	9.1	-0.7	23.7	18.1	18.8	18.1	7.5	12.3	17.6	7.7	5.0	17.4	10.4	10.7	16.9	12.0	9.6
iPhone X	25.4	17.4	16.2	16.3	9.0	6.4	22.7	16.9	18.1	17.0	11.7	14.1	14.5	7.4	4.5	17.3	13.5	12.4	15.0	10.7	10.9
iPhone 8 Plus	26.2	17.3	7.7	17.7	8.3	-1.4	24.6	17.5	18.8	18.8	10.6	13.7	17.0	7.3	-4.9	17.5	10.5	11.9	17.1	12.4	6.6
Sony Xperia XA2	27.8	17.3	18.0	18.9	8.1	9.6	22.5	19.9	16.8	18.0	14.9	9.8	16.0	6.5	7.9	16.1	10.8	9.5	15.1	10.3	6.2
OnePlus 6	25.6	16.3	12.8	16.1	6.8	2.9	24.1	20.6	16.6	16.5	12.9	9.4	16.5	6.4	7.4	16.2	14.0	9.4	14.6	10.1	12.6
Huawei P10 lite	29.7	15.8	15.1	20.2	7.9	6.7	25.9	19.0	19.3	19.6	11.9	12.9	17.6	6.0	6.2	16.4	13.5	10.4	16.8	11.0	13.3
Huawei P9 lite mini	27.0	14.6	16.2	18.8	5.1	7.3	26.3	23.1	20.5	16.4	13.2	14.0	18.3	5.8	6.9	19.5	6.8	13.2	16.3	8.7	6.0
iPhone Xs Max	20.5	14.4	15.2	15.9	-1.3	6.2	22.6	14.2	18.3	16.9	9.9	14.0	15.9	5.4	1.9	16.3	12.9	6.7	17.0	14.1	13.9
Huawei P10	28.0	12.0	18.2	18.7	3.5	9.3	25.9	11.5	19.6	18.8	13.6	10.8	16.1	0.3	5.8	16.7	7.6	12.4	16.3	5.8	12.9

- BHHR - beside head hand right;
- BHHL - beside head hand right;
- FS - free space

PIFA bandwidth and radiation pattern in case of phantom

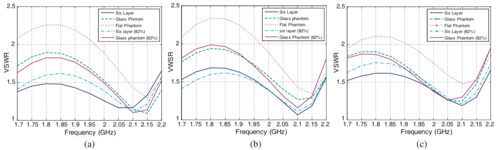


Figure 3: Computed VSWR. (a) 5 mm, (b) 15 mm, (c) 25 mm.

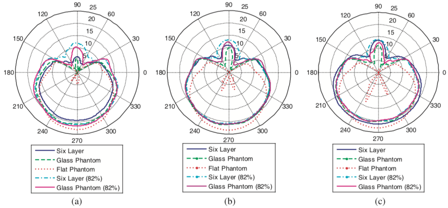


Figure 4: Radiation patterns of the PIFA antenna ($\theta = 90°$). (a) 5 mm, (b) 15 mm, (c) 25 mm.

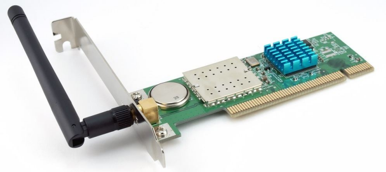
Measurements are made using different phantom models and different distances from the phantom.

Outline

Antennas for laptops

From PC cards to integrated implementations

The initial implementations integrated these systems into portable platforms such as laptops using PC cards inserted into the PC card slot. However, laptop manufacturers have moved away from PC cards in favor of integrated implementations since wireless technologies have become more prevalent and lower cost.



Antennas for laptops

Integrated WLAN antennas

For cellphones being a radiating device, the system and industrial designers know that the antenna is a very important part of the cellphone design, so antenna space is allocated at the beginning of the design process. Laptops started as non-radiating devices. As a result, the location of the antenna is often very bad.

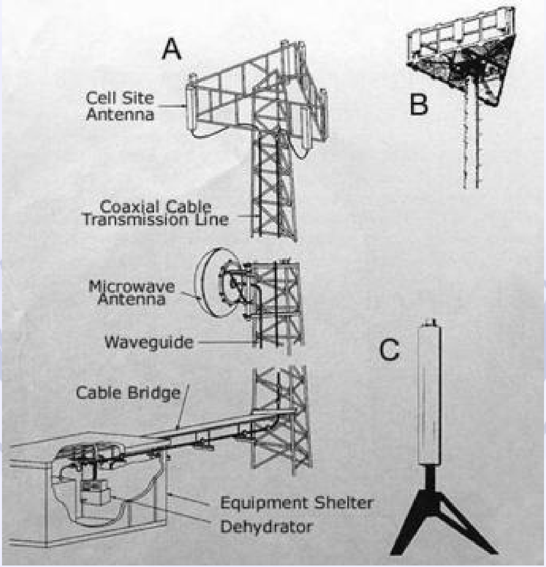
Where they are?

- Rear panel.
- Keyboard.
- Display bezel.
- Bottom bezel.

A crawded environment

Nowadays, laptops are full of metal and carbon fiber. Strong and attractive as they may be, these materials are conductive or absorptive, so they block radio signals. As a result, the antennas generally end up in the hinge or in plastic screen bezels.

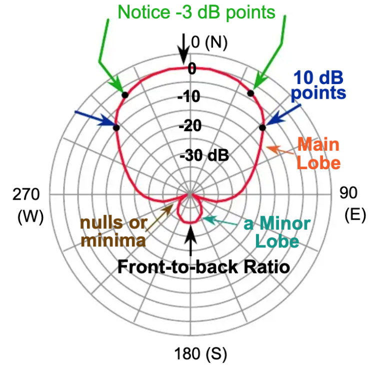
How they look like



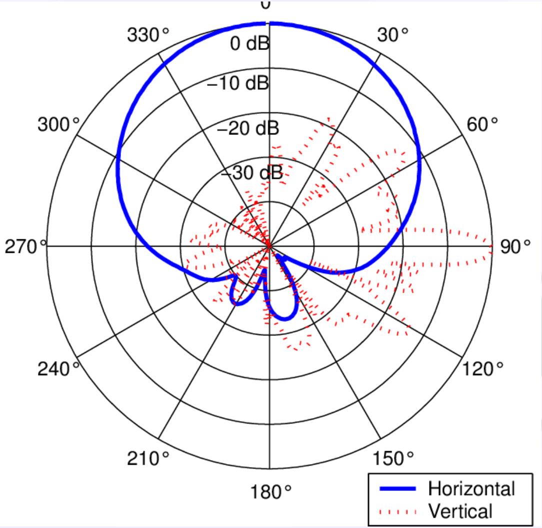
Why we do care

Antennas

The antennas should be designed to guarantee the desired coverage while minimizing co-channel interference.



Azimuth and elevation patterns



Azimuth and elevation patterns

An array of antenna elements is typically made in both the horizontal and vertical directions.

Azimuth pattern

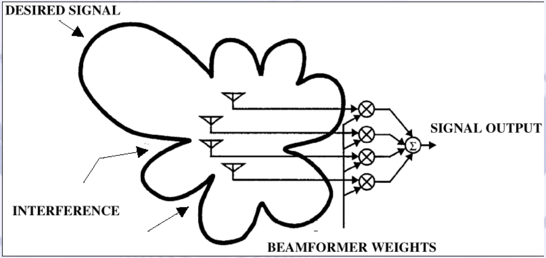
The antenna must be designed to produce almost uniform coverage in the azimuth plane. Some directivity in the azimuth plane is needed to split the area into sectors. In this case, typical half-power beamwidths are 85-90° for 120° sectors.

Elevation pattern

Directivity is needed to direct power towards the ground instead of the sky. Downtilting (typically electrical) is mandatory to limit co-channel interference.

Introduction

Adaptive antennas (also termed as smart antennas) consist of an efficient combination of received signals at multiple-antenna elements at the TX station and (potentially) at the RX station.



A key issue is estimating the channel properties

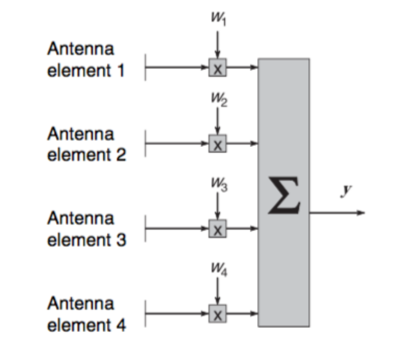
Outline

Phased arrays

In a phased array, a set of antenna elements is arranged in space, and the output of each element is multiplied by a complex weight and combined by summing.

Phased arrays

The complete array can be regarded as an antenna in its own right, with a new output



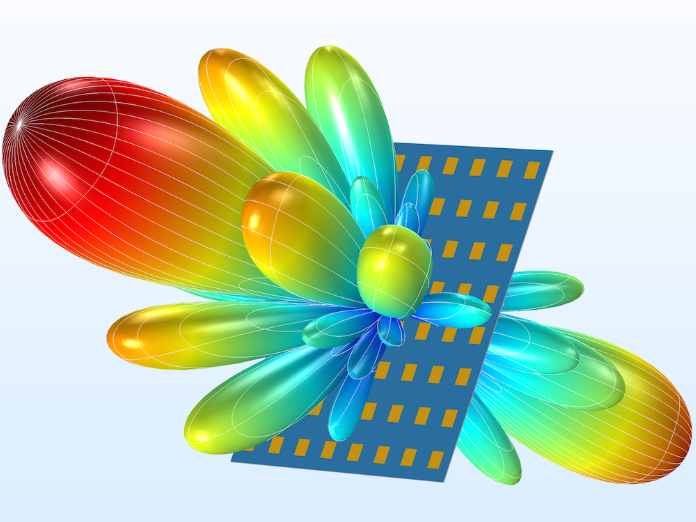
The radiation patterns of the individual elements are summed with phases and amplitudes depending on both the weights applied and their positions in space; this yields a new combined pattern

Array antenna and mobile communications

An antenna array (or array antenna) is a set of multiple connected antennas which work together as a single antenna.

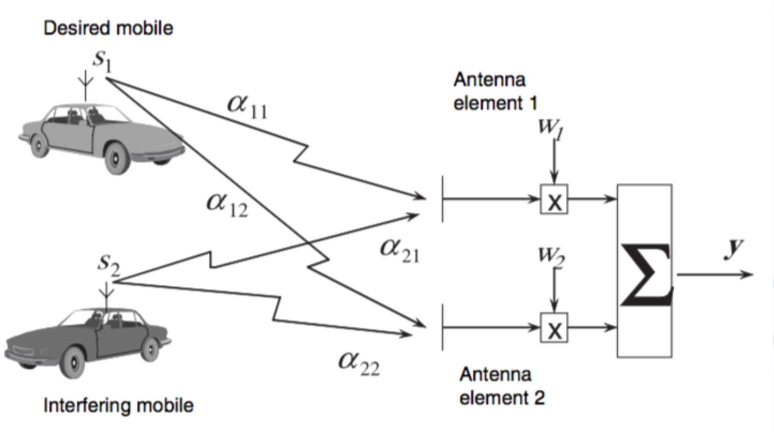
- The individual antenna elements are connected to a single RX or TX by feedlines that feed the power to the elements in a specific phase relationship.
- The radio waves radiated by each individual antenna combine and superpose, interfering constructively to enhance the power radiated in desired directions, and interfering destructively to reduce the power radiated in other directions.
- When used to receive, the outputs of individual antennas combine in the receiver with the correct phase relationship to enhance signals received from the desired directions and cancel signals from undesired directions.

Example of radiation pattern obtained using a 8×8 phased array antenna



Outline

Smart antenna to minimize uplink interference



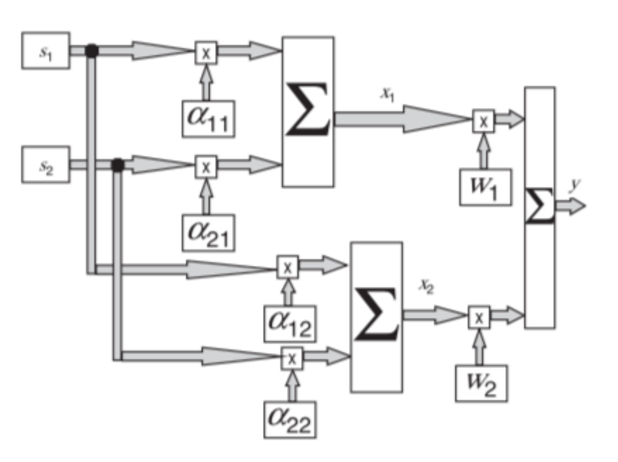
Smart antenna to minimize uplink interference

- Let s_1 and s_2 be co-channel signals received at RX station with a smart antenna having two independent elements and a combiner that combines the received signals once weighted by complex coefficients w.
- The channels from mobile i to the antenna element element j are denoted by a_{ij}, including all antenna, path loss, shadowing and fading effects.

Minimization of the interfering signal

If the RX station can accurately estimate a_{ij}, then a proper choice of the weights can be made to minimize the output due to the interferer while leaving the desired signal unaffected.

Processing



$$
\begin{aligned}
x_1 &= s_1 a_{11} + s_2 a_{21} \qquad (1)\\
x_2 &= s_1 a_{12} + s_2 a_{22}
\end{aligned}
$$

Processing

- The output of the combiner is given by:

$$y = x_1 w_1 + x_2 w_2 \tag{2}$$

- which leads to:

$$y = s_1(a_{11} w_1 + a_{12} w_2) + s_2(a_{21} w_1 + a_{22} w_2) \tag{3}$$

- To cancel the interfering signal, the following condition must be satisfied: $y = s_1$:

$$\begin{aligned} a_{11} w_1 + a_{12} w_2 &= 1 \\ a_{21} w_1 + a_{22} w_2 &= 0 \end{aligned} \tag{4}$$

Smart antenna to minimize uplink interference

Minimization of the interfering signal

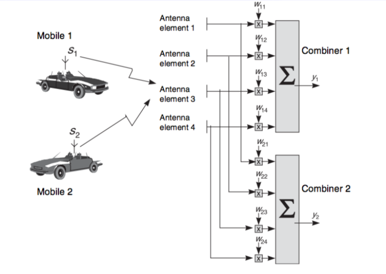
A proper choice of the weights can completely remove interfering co- channel signals.

- TX station must be able to estimate the channels between each of the mobiles and each of the antenna elements.
- The number of elements is at least equal to the number of mobiles in order to solve the resulting system of simultaneous equations.

In practical cases, the optimum weights would have to be estimated in the presence of noise, so an interferer is not removed completely. Instead, the weights are chosen to maximize the signal-to-interference-plus-noise ratio (SINR).

Outline

Dual combining for two-channel SDMA



A second combiner has been added, with inputs from the same antenna elements. The second combiner weights are chosen to eliminate the signal from mobile 1 and retain the signal from mobile 2. In this situation the system would be simultaneously communicating with two mobiles in the same cell on the same frequency/time/code channel.

This is space division multiple access (SDMA)