Chapter 3
Cochannel Interference

SOURCE:

MOBILE CELLULAR TELECOMMUNICATIONS

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Cochannel Interference Reduction Factor

- q= D/R
- D = f(KI, C/I)
- where K_I is the number of cochannel interfering cells in the first tier and
- *C/I* is the received carrier-to-interference ratio at the desired mobile receiver

$$\frac{C}{I} = \frac{C}{\sum_{k=1}^{K_I} I_k} \qquad (2.3\text{-}3)$$

$$\frac{C}{I} = \frac{R^{-\gamma}}{\sum_{k=1}^{K_I} D_k^{-\gamma}} \qquad (2.3\text{-}4)$$

$$\frac{C}{I} = \frac{1}{\sum_{k=1}^{K_I} \left(\frac{D_k}{R}\right)^{-\gamma}} = \frac{1}{\sum_{k=1}^{K_I} (q_k)^{-\gamma}} \qquad (2.3\text{-}5)$$

$$q_k = \frac{D_k}{R} \qquad (2.3\text{-}6)$$

where q_k is the cochannel interference reduction factor with kth cochannel interfering cell

$$\frac{C}{I} = \frac{R^{-\gamma}}{6D^{-\gamma}} = \frac{q^{\gamma}}{6} \qquad (2.4\text{-}1)$$

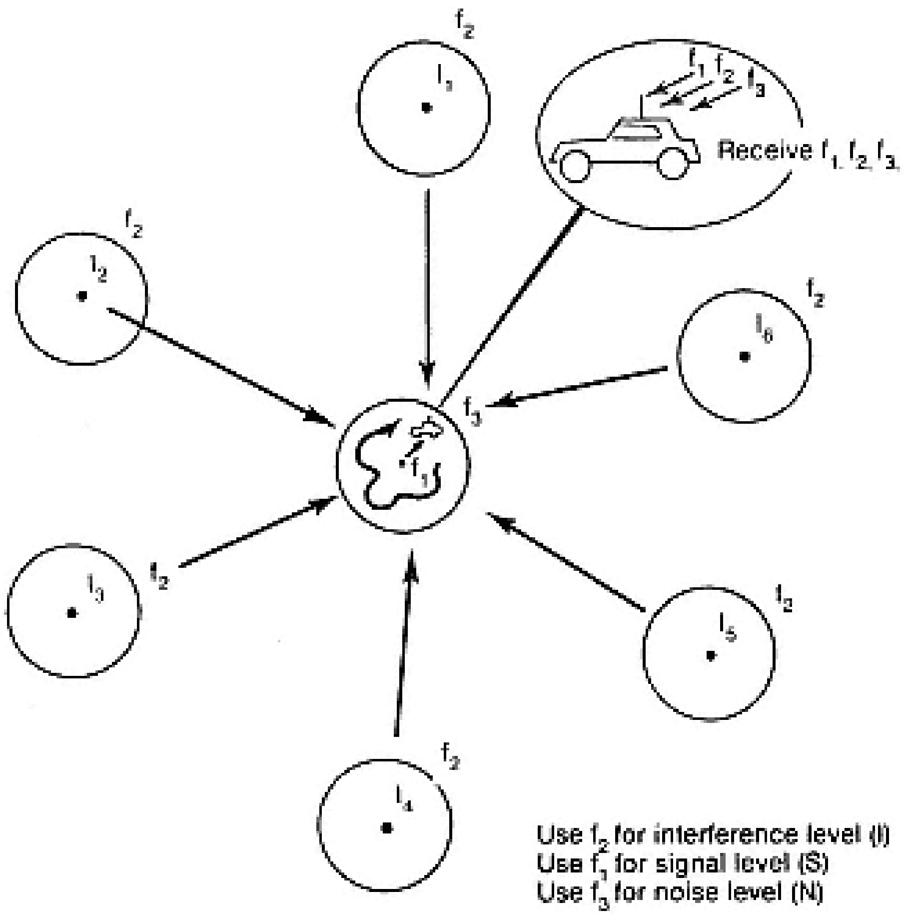
Thus $$q^{\gamma} = 6\,\frac{C}{I} \qquad (2.4\text{-}2)$$

- The propagation path loss is 40dB/dec
- Hence,
- q = (6* C/I) ^1/r
- = (6 * 63.1) ^ 1/6 = 4.41
- C/I = 18dB is measured by the acceptance of voice quality from the present receivers.

Exploring Cochannel Interference Areas in a System

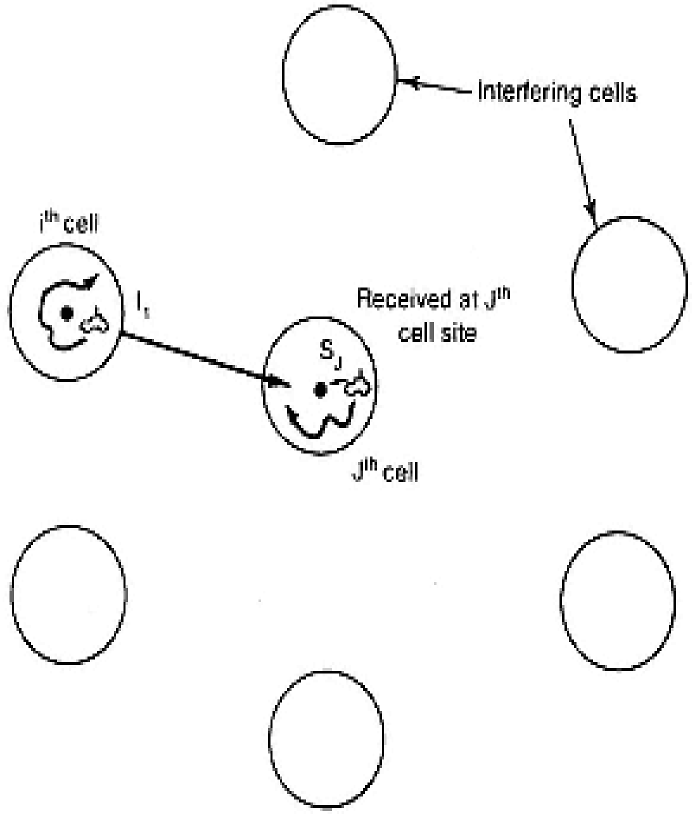
- For detection of serious channel interference areas in a cellular system, two tests are suggested.
- Test 1
- Find the Cochannel Interference Area from a Mobile Receiver

channel (f_1) records the signal level
channel (f_2) records the interference level
noise level is recorded in f_3



- 1. C / I >18 dB throughout most of the cell, the system is properly designed.
- 2. C / I <18 dB and C / N >18 dB in some areas, there is cochannel interference.
- 3. C / N and C / I <18 dB and C / N » C / I in a given area, there is a coverage problem.
- 4. C / N and $C /$ < 18 dB and C / N > C / I in a given area, there is a coverage problem *and* cochannel interference.

Test 2
Find the Cochannel Interference Area Which Affects a Cell Site



$$\frac{C_J}{I} = \frac{C_J}{\sum_{\substack{i=1 \\ i \neq J}}^{6} I_i}$$

Real-Time Cochannel Interference Measurement at Mobile Radio Transceivers

- signal is

$$e_1 = S(t)\sin(\omega t + \phi_1) \qquad (6.3\text{-}1)$$

- interference is

$$e_2 = I(t)\sin(\omega t + \phi_2) \qquad (6.3\text{-}2)$$

$$e(t) = e_1(t) + e_2(t) = R\sin(\omega t + \psi) \qquad (6.3\text{-}3)$$

- The received signal is

$$R = \sqrt{[S(t)\cos\phi_1 + I(t)\cos\phi_2]^2 + [S(t)\sin\phi_1 + I(t)\sin\phi_2]^2} \qquad (6.3\text{-}4)$$

- where

$$\psi = \tan^{-1}\frac{S(t)\sin\phi_1 + I(t)\sin\phi_2}{S(t)\cos\phi_1 + I(t)\cos\phi_2} \qquad (6.3\text{-}5)$$

-

$$R^2 = [S^2(t) + I^2(t) + 2S(t)I(t)\cos(\phi_1 - \phi_2)] \qquad (6.3\text{-}6)$$

$$X = S^2(t) + I^2(t) \qquad (6.3\text{-}7)$$

$$Y = 2S(t)I(t)\cos(\phi_1 - \phi_2) \qquad (6.3\text{-}8)$$

- the average processes on *X* and *Y* are

$$\overline{X} = \overline{S^2(t)} + \overline{I^2(t)} \qquad (6.3\text{-}9)$$

$$\overline{Y^2} = 4\overline{S^2(t)}\,\overline{I^2(t)}(½) = 2\overline{S^2(t)}\,\overline{I^2(t)} \qquad (6.3\text{-}10)$$

- The signal-to-interference ratio

$$\Gamma = \frac{\overline{S^2(t)}}{\overline{I^2(t)}} = k + \sqrt{k^2 - 1} \qquad (6.3\text{-}11)$$

- The sampling delay time should be small enough to satisfy

$$S(t) \approx S(t + \Delta t), \qquad I(t) \approx I(t + \Delta t) \qquad (6.3\text{-}13)$$

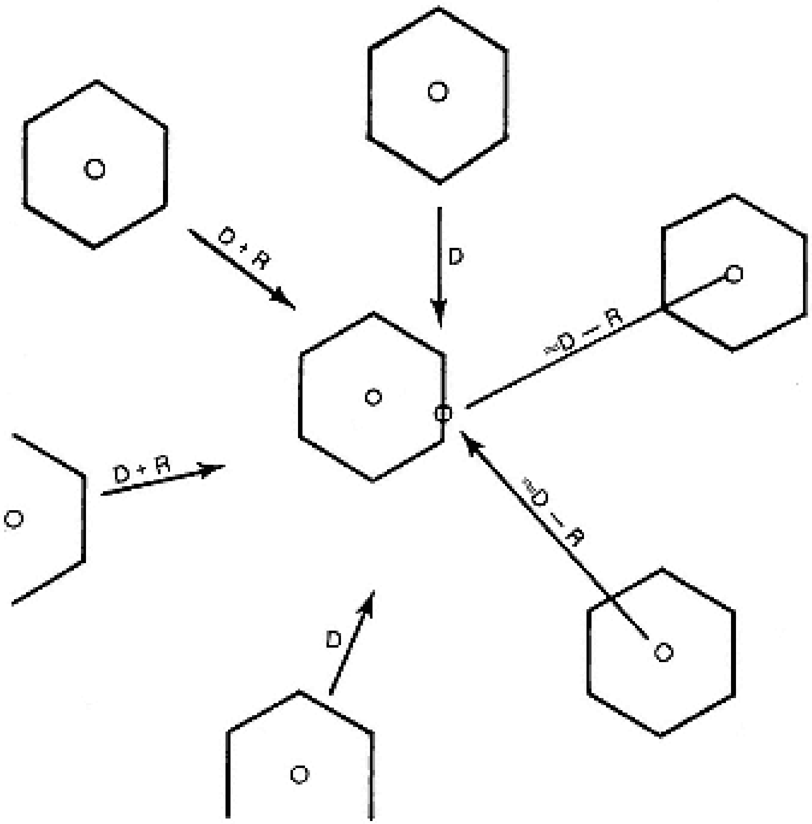
- Determining the delay time to meet the requirement of Eq. (6.3-13) for this calculation is difficult and is a drawback to this measurement technique.
- Therefore, real-time cochannel interference measurement is difficult to achieve in practice.

Design of an Omnidirectional Antenna System in the Worst Case

- The worst case is at the location where the mobile unit would receive the weakest signal from its own cell site but strong interferences from all interfering cell sites.

- To prove that a $K = 7$ cell pattern does not provide a sufficient frequency-reuse distance

Cochannel interference (a worst case).



$$C \propto R^{-4} \qquad I \propto D^{-4}$$

Then the carrier-to-interference ratio is

$$\frac{C}{I} = \frac{R^{-4}}{2(D-R)^{-4} + 2(D)^{-4} + 2(D+R)^{-4}}$$

$$= \frac{1}{2(q-1)^{-4} + 2(q)^{-4} + 2(q+1)^{-4}} \qquad (6.4\text{-}1a)$$

$q = 4.6$

C / I = 54 or 17 dB, which is lower than 18 dB.

use the shortest distance *D-R* for all six interferers as a worst case

$$\frac{C}{I} = \frac{R^{-4}}{6(D-R)^{-4}} = \frac{1}{6(q-1)^{-4}} = 28 = 14.47 \text{ dB} \qquad (6.4\text{-}1b)$$

- C / I received is always worse than 17 dB and could be 14 dB and lower.
- A heavy traffic situation
- The system must be designed around the C / I of the worst case.
- A cochannel interference reduction factor of
- q = 4.6 is insufficient.

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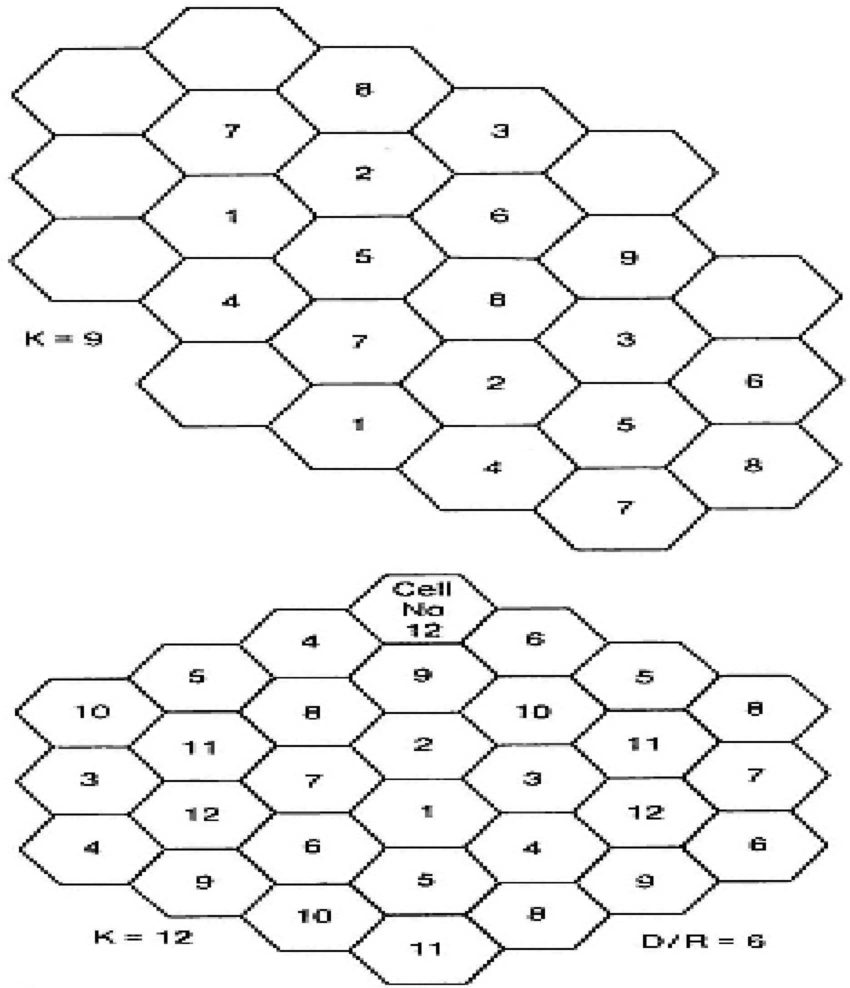
- In an omnidirectional-cell system, *K* = 9 or *K* = 12 would be a correct choice. Then the values of *q* are

- $$q = \begin{cases} \frac{D}{R} = \sqrt{3K} \\ 5.2 & K = 9 \\ 6 & K = 12 \end{cases} \qquad (6.4\text{-}2)$$

$$\frac{C}{I} = 84.5 \ (=) \ 19.25 \text{ dB} \qquad K = 9 \qquad (6.4\text{-}3)$$

$$\frac{C}{I} = 179.33 \ (=) \ 22.54 \text{ dB} \qquad K = 12 \qquad (6.4\text{-}4)$$

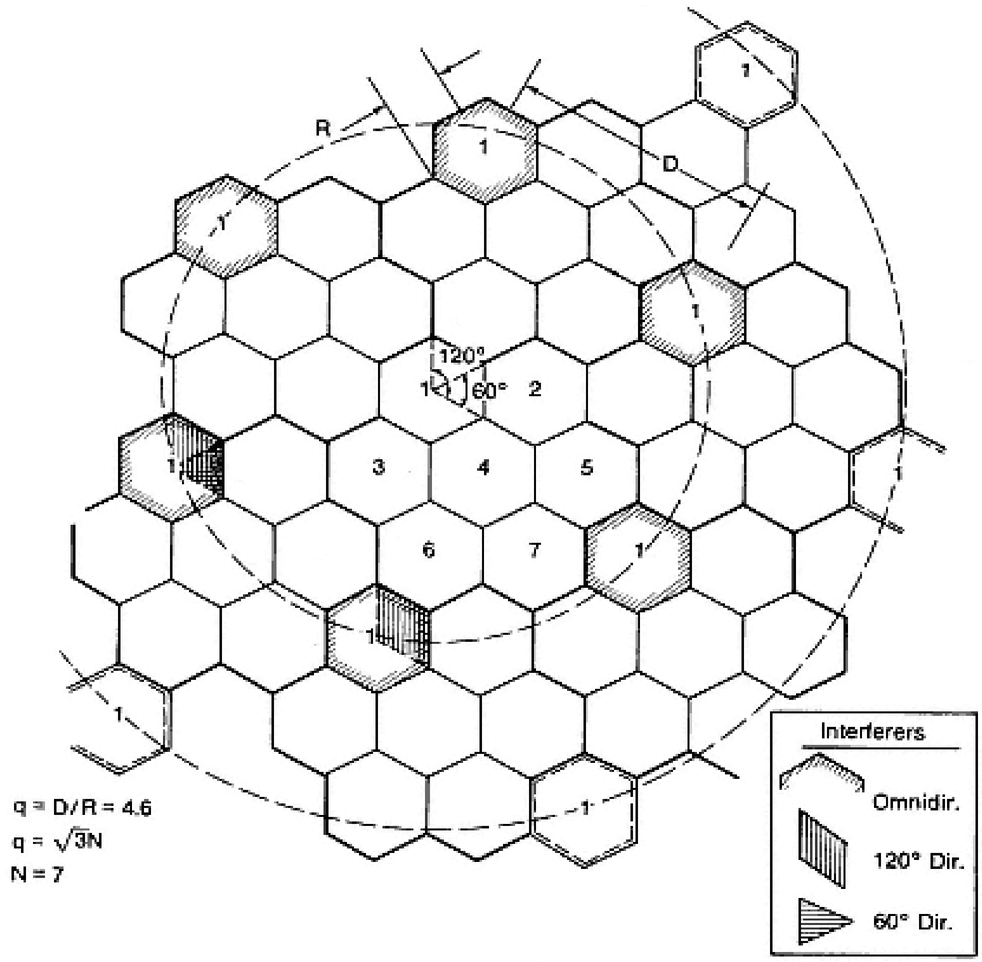
Interference with frequency-reuse patterns K = 9 and K = 12.



Design of a Directional Antenna System

- call traffic begins to increase
- use the frequency spectrum efficiently
- avoid increasing the number of cells
- When *K* increases, the number of frequency channels assigned in a cell must become smaller
- the efficiency of applying the frequency-reuse scheme decreases

Directional Antennas in K = 7 Cell Patterns



Three-Sector Case

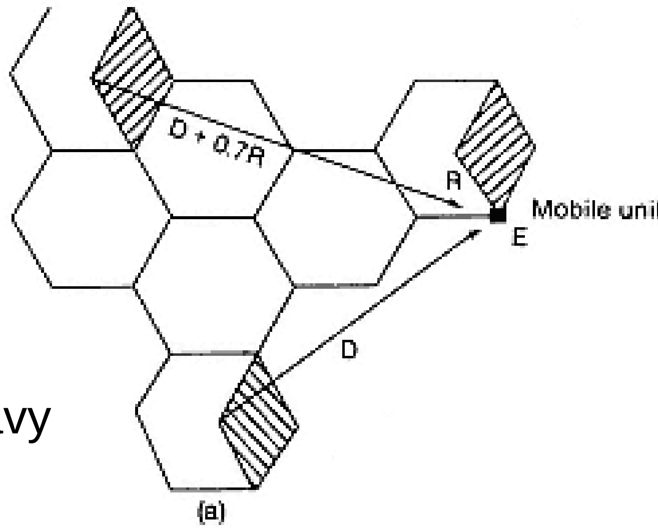
- The mobile unit at position *E* will experience greater interference in the lower shaded cell sector than in the upper shaded cell-sector site.
- This is because the mobile receiver receives the weakest signal from its own cell but fairly strong interference from the interfering cell.

$$\frac{C}{I}\text{(worst case)} = \frac{R^{-4}}{(D+0.7R)^{-4} + D^{-4}}$$

$$= \frac{1}{(q+0.7)^{-4} + q^{-4}} \qquad (6.5\text{-}1)$$

Let q = 4.6; then Eq. (6.5-1) becomes

$$\frac{C}{I}\text{(worst case)} = 285\ (=)\ 24.5\ \text{dB} \qquad (6.5\text{-}2)$$



C / *I* could be 6 dB weaker than in Eq. (6.5-2) in a heavy traffic area as a result of irregular terrain contour and imperfect site locations. The remaining 18.5 dB is still adequate.

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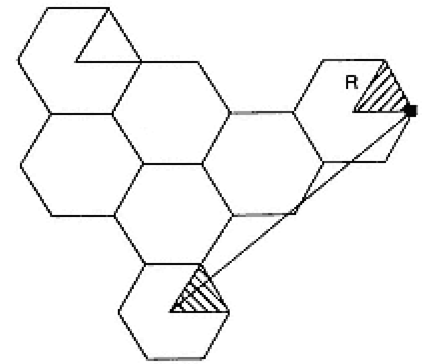
(a)



(b)

- **<u>Six-sector Case</u>**
- divide a cell into six sectors by using six 60°-beam directional antennas
- only one instance of interference can occur in each sector

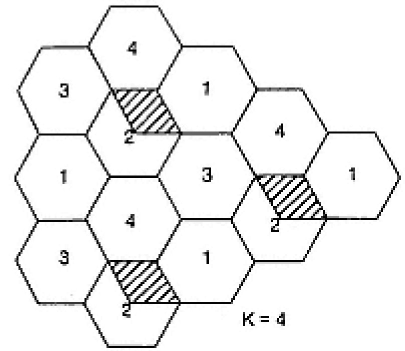
$$\frac{C}{I} = \frac{R^{-4}}{(D + 0.7R)^{-4}} = (q + 0.7)^4 \qquad (6.5\text{-}3)$$

- For q = 4.6, $\frac{C}{I} = 794\ (=)\ 29\ \text{dB} \qquad (6.5\text{-}4)$

- subtract 6 dB from the result of Eq. (6.5-4), the remaining 23 dB is still more than adequate.
- When heavy traffic occurs, the 60°-sector configuration can be used to reduce cochannel interference.

Directional Antenna in K = 4 Cell Pattern

- <u>Three-sector Case</u>
- $K = 4$, the value of



$$q = \sqrt{3K} = 3.46$$

$$\frac{C}{I}(\text{worst case}) = \frac{1}{(q+0.7)^{-4} + q^{-4}} = 97 = 20 \text{ dB} \quad (6.5\text{-}5)$$

- If, 6 dB is subtracted from the result of Eq. (6.5-5), the remaining 14 dB is unacceptable.

Directional Antenna in K = 4 Cell Pattern

- <u>Six-sector Case</u>
- There is only one interferer at a distance of
- $D + R$
- With q = 3.46

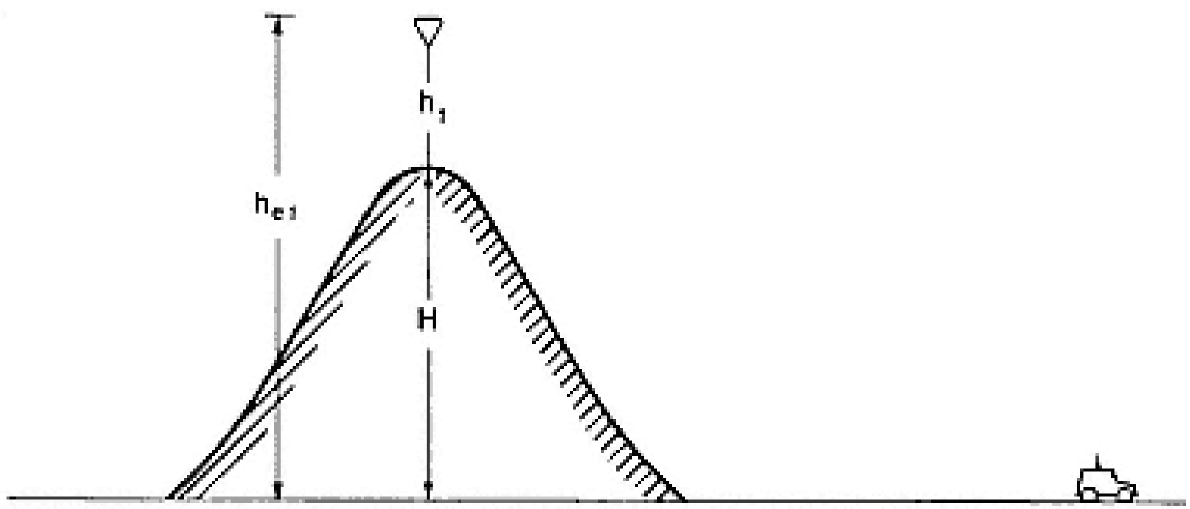
$$\frac{C}{I}(\text{worst case}) = \frac{R^{-4}}{(D+R)^{-4}} = \frac{1}{(q+1)^{-4}} = 355 = 26 \text{ dB} \qquad (6.5\text{-}6)$$

- If 6 dB is subtracted from the result of Eq. (6.5-6), the remaining 21dB is adequate.
- Under heavy traffic conditions, there is still a great deal of concern over using a K = 4 cell pattern in a 60° sector.

- Two disadvantages of 60° sectors are that
- (1) they require more antennas to be mounted on the antenna mast and
- (2) they often require more frequent handoffs because of the increased chance that the mobile units will travel across the six sectors of the cell.

Reducing the cochannel interference by lowering the Antenna Height

- On fairly flat ground or in a valley situation, lowering the antenna height will be very effective for reducing the cochannel and adjacent-channel interference.
- **On a High Hill or a High Spot**
- the effective antenna height is $h_1 + H$.
-



(a)

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- If we reduce the actual antenna height to $0.5h_1$, the effective antenna height becomes $0.5h_1 + H$. The reduction in gain resulting from the height reduction is

$$G = \text{gain reduction} = 20 \log_{10} \frac{0.5h_1 + H}{h_1 + H}$$

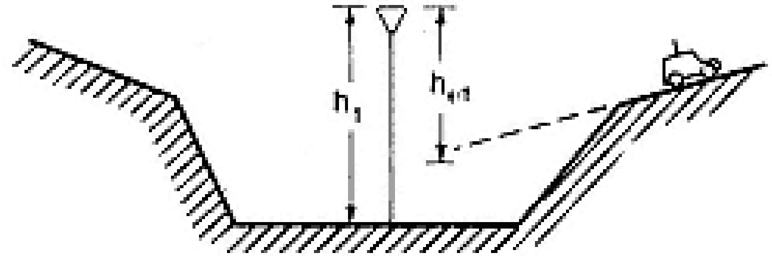
$$= 20 \log_{10} \left(1 - \frac{0.5h_1}{h_1 + H}\right) \qquad (6.6\text{-}1)$$

- If $h_1 \ll H$,

$$G \approx 20 \log_{10} 1 = 0 \text{ dB}$$

- lowering antenna height on the hill does not reduce the received power at either the cell site or the mobile unit.

(a)



- **<u>In a Valley</u>**

(b)

- The effective antenna height as seen from the mobile unit shown is h_{e1}, which is less than the actual antenna height h_1. If h_{e1} = 2/3h_1 and the antenna is lowered to 1/2h_1, then the new effective antenna height

$$h_{e1} = \tfrac{1}{2}h_1 - (h_1 - \tfrac{2}{3}h_1) = \tfrac{1}{6}h_1$$

- Then the antenna gain is reduced by

$$G = 20 \log \frac{\tfrac{1}{6}h_1}{\tfrac{2}{3}h_1} = -12 \text{ dB}$$

- the lowered antenna height in a valley is very effective in reducing the radiated power in a distant high elevation area.

- **<u>In a Forested Area</u>**
- The antenna should clear the tops of any trees in the vicinity
- Decreasing the height of the antenna would not be the proper procedure for reducing cochannel interference because excessive attenuation of the desired signal would occur in the vicinity of the antenna and in its cell boundary if the antenna were below the treetop level.

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- Reduction of cochannel interference in a cellular mobile system is always a challenging problem.

- (1) **increasing the separation between two cochannel cells**
- not advisable
- as the number of frequency-reuse cells increases, the system efficiency decreases

- (2) **using directional antennas at the base station**
- good approach when the number of frequency-reuse cells is fixed.
- The use of directional antennas in each cell can serve two purposes:
- (1) further reduction of cochannel interference if the interference cannot be eliminated by a fixed separation of cochannel cells and
- (2) increasing the channel capacity when the traffic increases.

- (3) **lowering the antenna heights at the base station**
- not recommended
- such an arrangement also weakens the reception level at the mobile unit

Reduction of Cochannel Interference by Means of a Tilted Antenna Pattern

- There are two ways to tilt down the antenna patterns;
- **The electronic down-tilting** is to change the phases among the elements of a collinear array antenna.
- **The mechanical down-tilting** is to down-tilt the antenna physically.

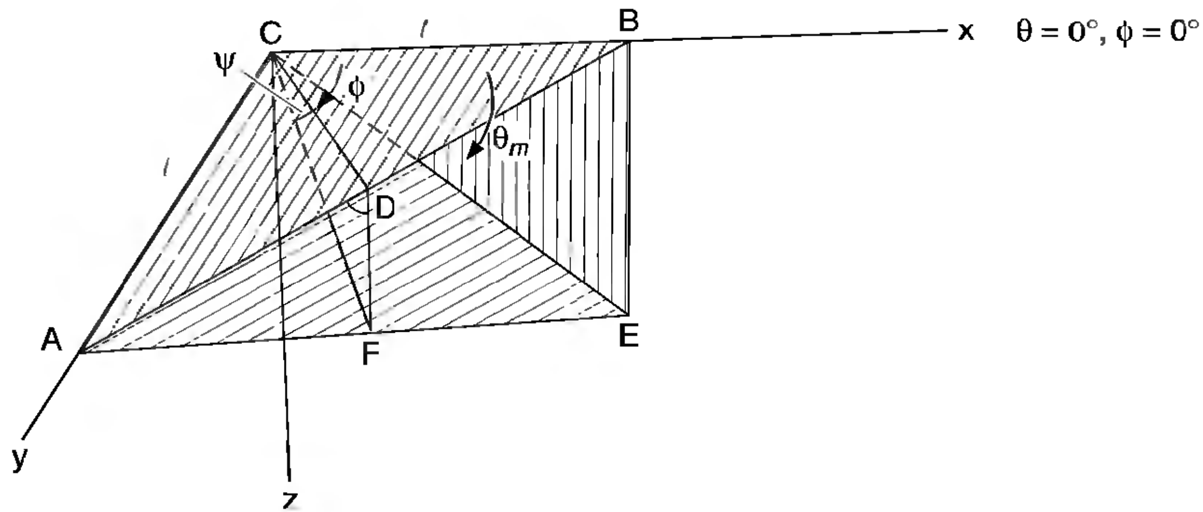

Figure 16.12 Coordinate of the tilting antenna pattern.

$$\sin\frac{\theta}{2} = \frac{d}{l} \tag{6.7-3}$$

$$\frac{\overline{DB}}{\sin\phi} = \frac{l}{\sin(135^\circ - \phi)} \tag{6.7-4}$$

$$\overline{CD} = l\,\frac{\sin 45^\circ}{\sin(135 - \phi)} \tag{6.7-5}$$

$$\frac{\overline{AD}}{\overline{DF}} = \frac{\overline{AB}}{2d} = \frac{\sqrt{2}l}{2d} \tag{6.7-6}$$

$$\overline{AD} = \overline{AB} - \overline{DB} \tag{6.7-7}$$

$$\cos\psi = \frac{2\overline{CD} - \overline{DF}}{2\overline{CD}} = 1 - \frac{\overline{DF}}{2\overline{CD}} \tag{6.7-8}$$

$$\cos\psi = 1 - \cos^2\phi\,(1 - \cos\theta) \tag{6.7-9}$$

or

$$\psi = \cos^{-1}\left[1 - \cos^2\phi\,(1 - \cos\theta)\right] \tag{6.7-10}$$

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- If the tilt angles are very close, down-tilting has no effect in reducing the interference.
- In order to increase the angle separation, the antenna height can play a big role.
- The down-tilting can help in strengthening the weak signal spots in the cell.

Types of Non-cochannel Interference

- Adjacent-channel Interference
- Near-End-Far-End Interference
- Interference between systems
- UHF TV Interference
- Long distance interference

Adjacent-channel Interference

- next-channel (the channel next to the operating channel) interference
- neighboring-channel (more than one channel away from the operating channel) interference.

Next-Channel Interference

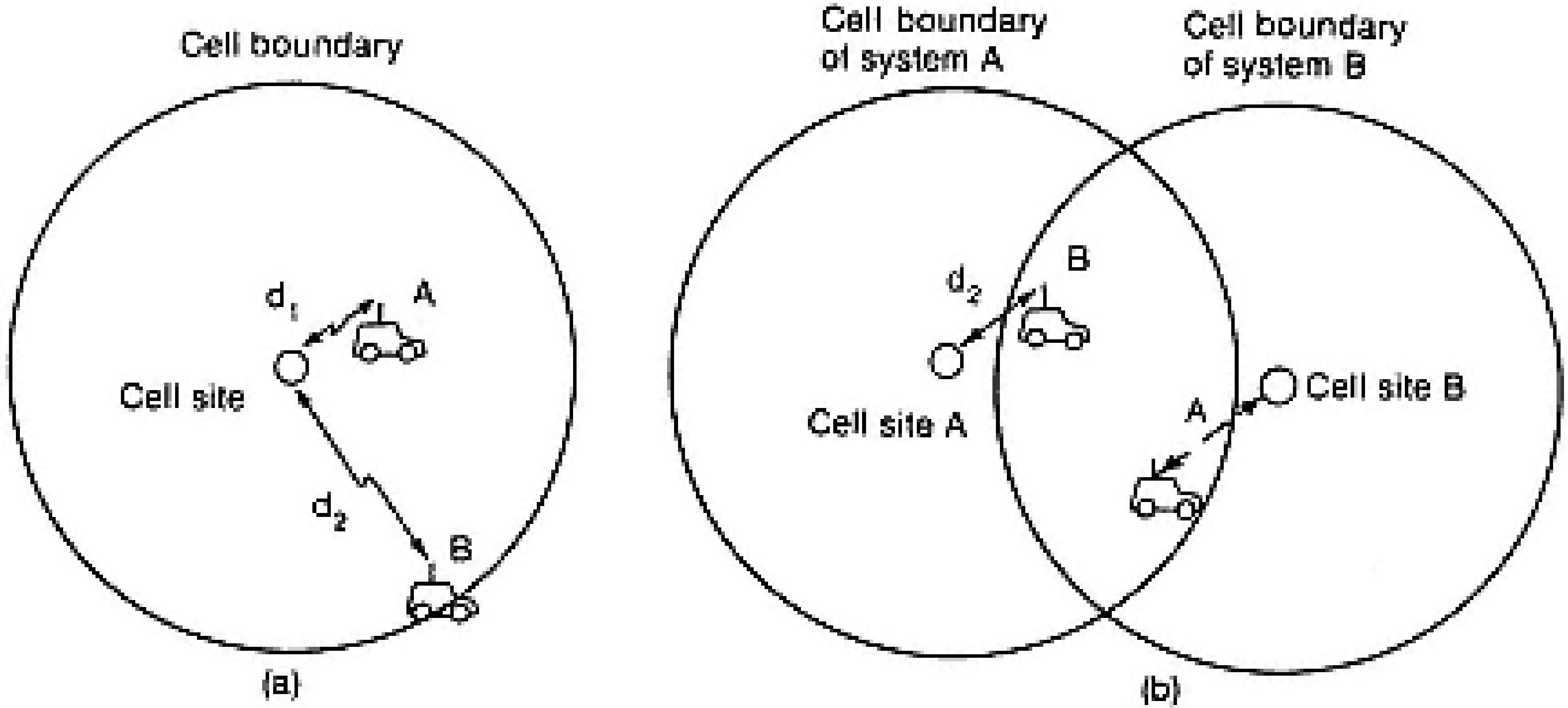
- next-channel interference will arrive at the mobile unit from other cell sites if the system is not designed properly.
- mobile unit initiating a call on a control channel in a cell may cause interference with the next control channel at another cell site.
- The filter with a sharp falloff slope can help to reduce all the adjacent-channel interference, including the next-channel interference.

Neighboring-channel Interference

- The channels which are several channels away from the next channel will cause interference with the desired signal.
- a fixed set of serving channels is assigned to each cell site.
- If all the channels are simultaneously transmitted at one cell-site antenna, a sufficient amount of band isolation between channels is required for a multichannel combiner to reduce intermodulation products.

Near-End-Far-End Interference

- *In One Cell*
- *In Cells of Two Systems*



Near-End-Far-End Interference
In One Cell

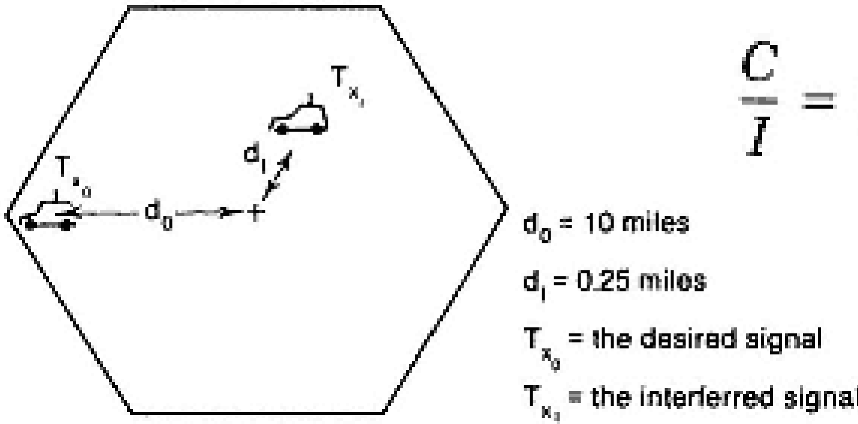
- The close-in mobile unit has a strong signal which causes adjacent-channel interference
- In this situation, near-end-far-end interference can occur only at the reception point in the cell site.

Near-End-Far-End Interference *In Cells of Two Systems*

- the frequency channels of both cells of the two systems must be coordinated in the neighborhood of the two-system frequency bands.

Avoidance of Near-End-Far-End Interference

- The near-end mobile units are the mobile units which are located very close to the cell site.
- These mobile units transmit with the same power as the mobile units which are far away from the cell site.



$$\frac{C}{I} = \left(\frac{d_0}{d_I}\right)^{-\gamma} \quad (7.4\text{-}1)$$

- d_{0}- The distance between a calling mobile transmitter and a base-station receiver
- d_I - The distance between a mobile transmitter causing interference and the same base-station receiver.
- The ratio d_I/d_0 is the near-end-far-end ratio.
- The effect of the near-end-far-end ratio on the carrier adjacent-channel interference ratio is dependent on the relative positions of the moving mobile units.

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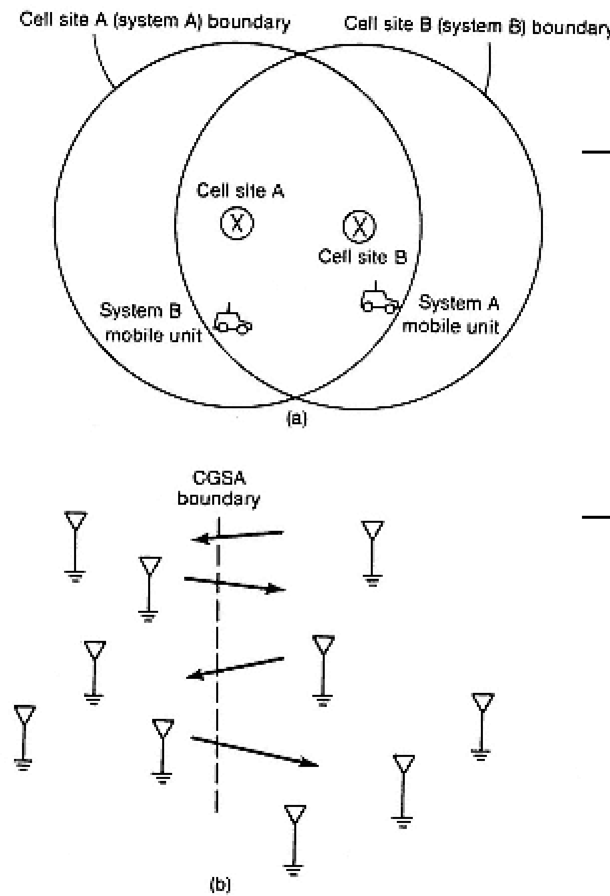
Interference between Systems

- *In One City*
- *In Adjacent Cities*

Interference between Systems

In One City



Intersystem interference. (*a*) System A cell sites in system B cell coverage; (*b*) interference between two cellular geographic service area (CGSA) systems.

Interference between Systems *In Adjacent Cities*

- Two systems operating at the same frequency band and in two adjacent cities or areas may interfere with each other if they do not coordinate their frequency channel use.
- Most cases of interference are due to cell sites at high altitudes
- In any start-up system, a high-altitude cell site is always attractive to the designer.
- Such a system can cover a larger area, and, in turn, fewer cell sites are needed.
- However, if the neighboring city also uses the same system block, then the result is strong interference, which can be avoided by the following methods.

- 1. **The operating frequencies** should be coordinated between two cities.
- The frequencies used in one city should not be used in the adjacent city.
- This arrangement is useful only for two low-capacity systems.
- 2. If both systems are high capacity, then **decreasing the antenna heights** will result in reduction of the interference not only within each system but also between the two systems.
- 3**. Directional antennas** may be used.
- For example, if one system is high capacity and the other is low capacity, the low-capacity system can use directional antennas but still retain the high tower.
- In this situation frequency coordination between the two systems has to be worked out at the common boundary because all the allocated frequencies must be used by the high-capacity system in its service area but only some frequencies are used by the low-capacity system.

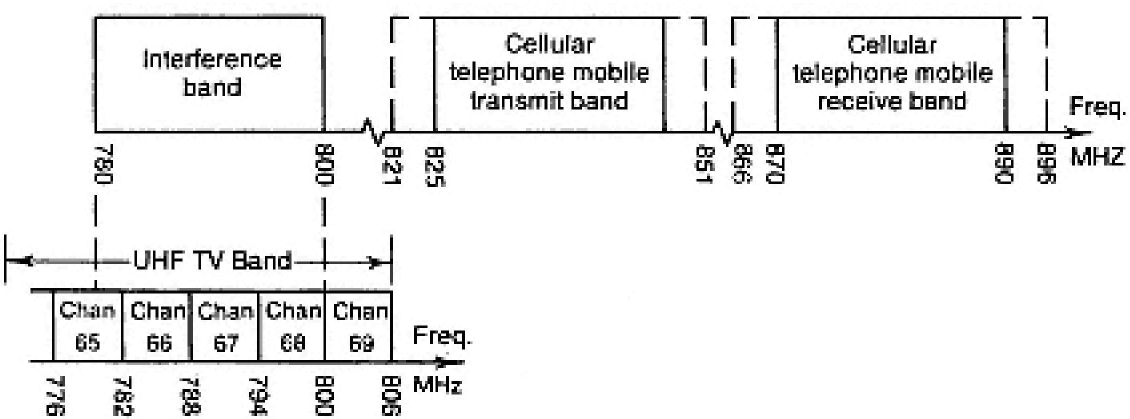
UHF TV Interference

- Two types of interference can occur between UHF television and 850-MHz cellular mobile phones.

- *Interference to UHF TV Receivers from Cellular Mobile Transmitters*

- *Interference of Cellular Mobile Receivers by UHF TV Transmitters*

- Interference between TV and cellular mobile channels is illustrated in Fig



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- Some UHF TV channels overlap cellular mobile channels.
- These two types of service can interfere with each other only under the following conditions.
- 1. ***Band region with overlapping frequencies***.
- Two services have been authorized to operate within the same frequency band region.
- 2**. *Image interference region***.
- The TV receiver or the cellular receiver (mobile unit or cell site) can receive two transmitted signals, for instance, one from a TV channel and one from a cellular system, and produce a third-order intermodulation product which falls within the TV or the mobile receive band.

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- Let f_{Tm} = mobile transmit frequency

  = f_{Rc} = cell-site receive frequency

  = f_{Tc} 45 MHz
- f_{Rm} = mobile receive frequency

  = f_{Tm} + 45 MHz

  = f_{Tc} = cell-site transmit frequency

  - $f_{T,\mathrm{TV}}$ = TV transmit frequency
  - $f_{R,\mathrm{TV}}$ = TV receive frequency

Third-order intermodulation gives the following results in two cases of interfering UHF TV receivers.

- *Case 1*. *When the mobile transmitter is located near a TV receiver*

$$2f_{Tm} - f_{T,\mathrm{TV}} = f_{Rm} \tag{7.9-1}$$

- Let

$$f_{Tm} = f_{Rm} - 45 \tag{7.9-2}$$

then

$$f_{Tm} = f_{T,\mathrm{TV}} + 45 \tag{7.9-3}$$

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- mobile transmit frequency f_{Tm} lies in the 825- to 845-MHz band
- TV transmit frequency $f_{T,\mathrm{TV}}$ lies in the 780- to 800-MHz band,
- f_{Tm} will interfere with the TV receiver as seen from Eq. (7.9-3).
- This interference region is called the *image interference region*.

- *Case 2*. *When the cell site transmitter is located near a TV receiver*
- Let

$$2f_{Rc} - f_{T,TV} = f_{Tc} \tag{7.9-4}$$

then

$$f_{Rc} = f_{Tc} - 45 \tag{7.9-5}$$

and

$$f_{Tc} = f_{T,TV} + 90 \tag{7.9-6}$$

- cell-site transmit frequency f_{Tc} lies in the 870- to 890-MHz band,
- $f_{T,TV}$ lies in the 780- to 800-MHz band,
- f_{Tc} will interfere with the TV receiver, as shown in Eq. (7.9-6).
- This interference region is called the image interference region.

Interference of Cellular Mobile Receivers by UHF TV Transmitters

- *Case 1*. Let

$$2f_{Tm} - f_{T,TV} = f_{Rm} \tag{7.9-8}$$

Then

$$2f_{Tm} = 2(f_{Rm} - 45) \tag{7.9-9}$$

and

$$F_{T,TV} = 2f_{Tm} - f_{Rm} = f_{Rm} - 90 \text{ MHz} \tag{7.9-10}$$

- the mobile unit receiver frequency f_{Rm} lies in the 870- to 890-MHz band,
- $f_{T,TV}$, which lies in the 780- to 800-MHz band,
- will interfere with the mobile unit receiver, as shown in Eq. (7.9-10).

- *Case 2*. Let

$$2f_{Rc} - f_{T,TV} = f_{Tc} \quad (7.9\text{-}11)$$

Then $$f_{Rc} = f_{Tc} - 45 \quad (7.9\text{-}12)$$

and $$f_{Rc} = 2f_{Rc} - f_{T,TV} - 45 = f_{T,TV} + 45 \quad (7.9\text{-}13)$$

- cell-site receiver frequency f_{Rc} lies in the 825- to 845-MHz band,
- $f_{T,\mathrm{TV}}$, which lies in the 780- to 800-MHz band, will interfere with the cell-site receiver as shown in Eq. (7.9-13).

- *Case 3*. When a mobile receiver approaches a TV transmitter, it is easy to find that transmission from the TV station will not interfere with the reception at the mobile receiver

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- *Case 4*. When the cell-site receiver is only 1 mi or less away from the TV station, interference may result.
- when the cell site is very close to the TV station, the interference decreases as a result of the two vertical narrow beams pointing at different elevation levels.
- For this reason it is advisable to mount a cell-site antenna in the same vicinity as the TV station antenna if the problems of shielding and grounding can be controlled.

Long-Distance Interference

- *Overwater Path*
- *Overland Path*

Power Control

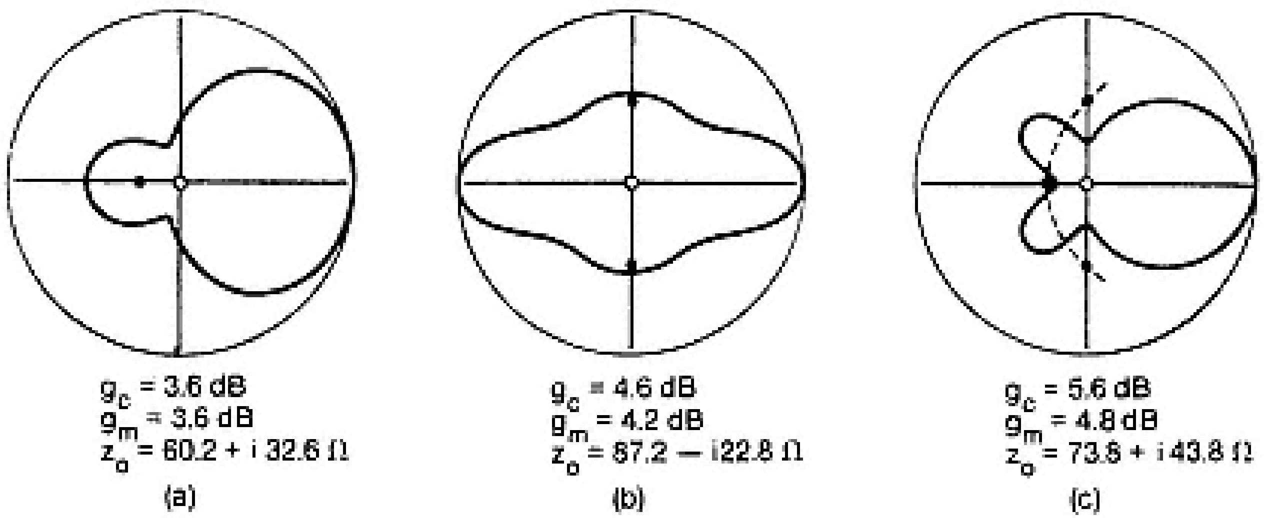
- ***Who Controls the Power Level?***
- The power level can be controlled only by the mobile transmitting switching office (MTSO),
- not by the mobile units
- there can be only limited power control by the cell sites as a result of system limitations.

Use of Parasitic Elements

- Interference at the cell site can sometimes be reduced by using parasitic elements, creating a desired pattern in a certain direction.
- Currents appearing in several parasitic antennas are caused by radiation from a nearby drive antenna.
- A driven antenna and a single parasite can be combined in several ways.

1. *Normal spacing*.

- Parasitic elements with effective interference reduction. (*a*) One-quarter wavelength spacing; (*b*) one-half wavelength spacing; (*c*) combination of *a* and *b*.



- cell-site directional antennas with a non-wind-resistant structure: a four-element structure that has only one active element.

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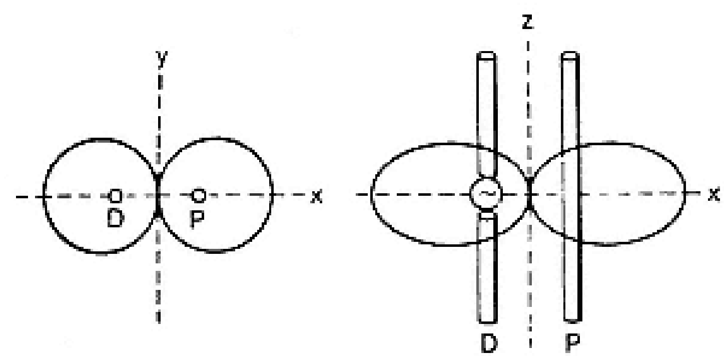
2. *Relatively close spacing*.

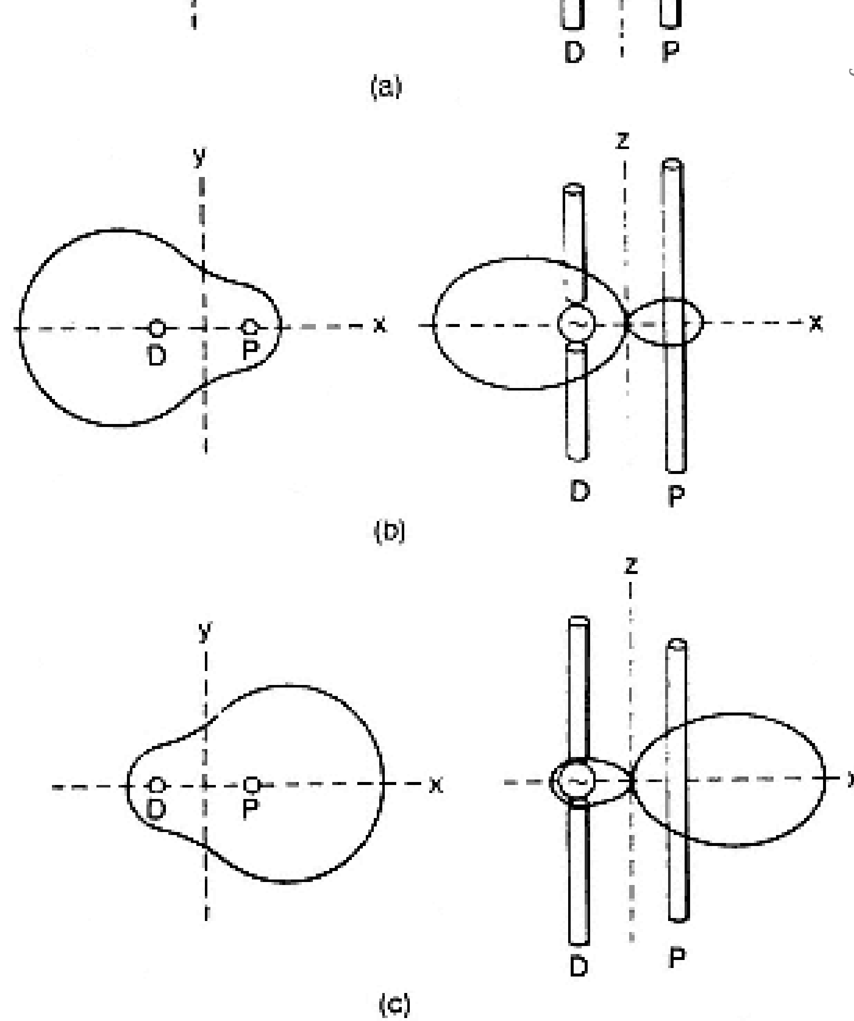
- In relatively close spacing two elements are placed as close as 0.04l.
- Three cases can be described here.

a. *The lengths of two elements are identical*.

- Two elements, one active and one parasitic, are separated by only 0.04l.
- At this close spacing, the current flowing in the parasite is very strong.
- The two elements form a null along the *y* axis in the horizontal plane and along the *z* axis in the vertical plane.
- There is a directive gain of 3 dB relative to a single element.
- The horizontal pattern and the vertical pattern of the closely spaced arrangement are shown



(a)



b. The length of the parasite is
5 percent longer than that
of the active one.
>> A directive gain of 6 dB is obtained.

c. The length of the parasite is shorter than that of the active one.
>> the parasite acts as a director
>> A gain of 8 dB is obtained.

Diversity Receiver

- The diversity scheme applied at the receiving end of the antenna is an effective technique for reducing interference because any measures taken at the receiving end to improve signal performance will not cause additional interference.

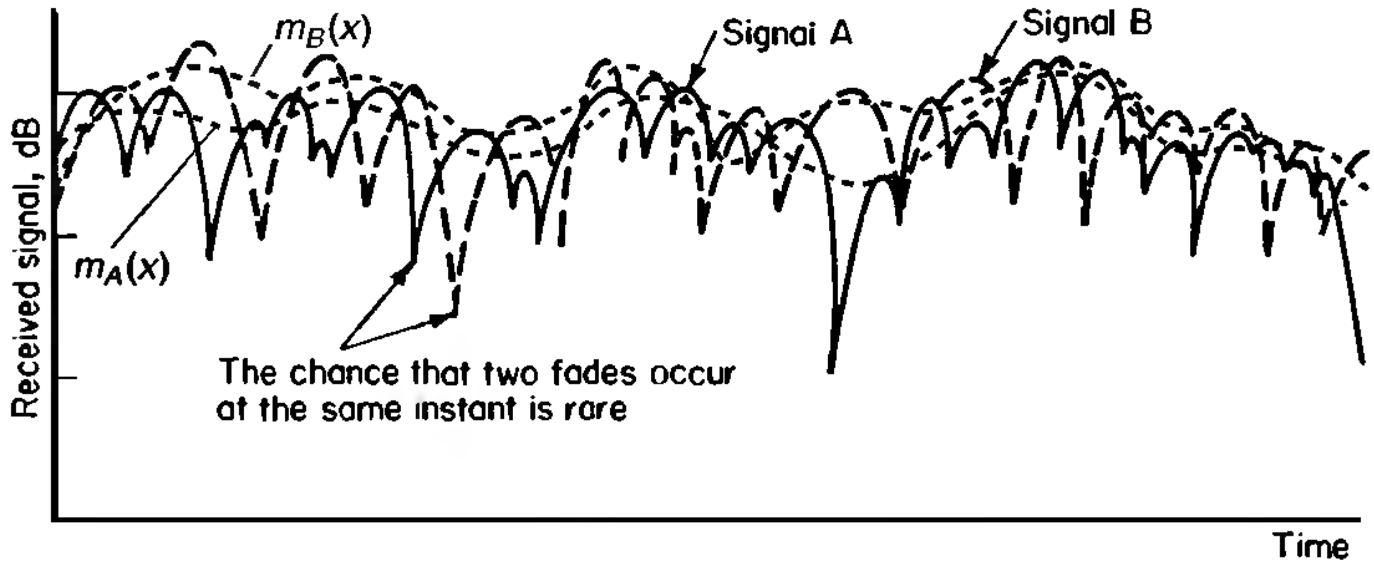


Figure 9.1 Uncorrelated fading signals.

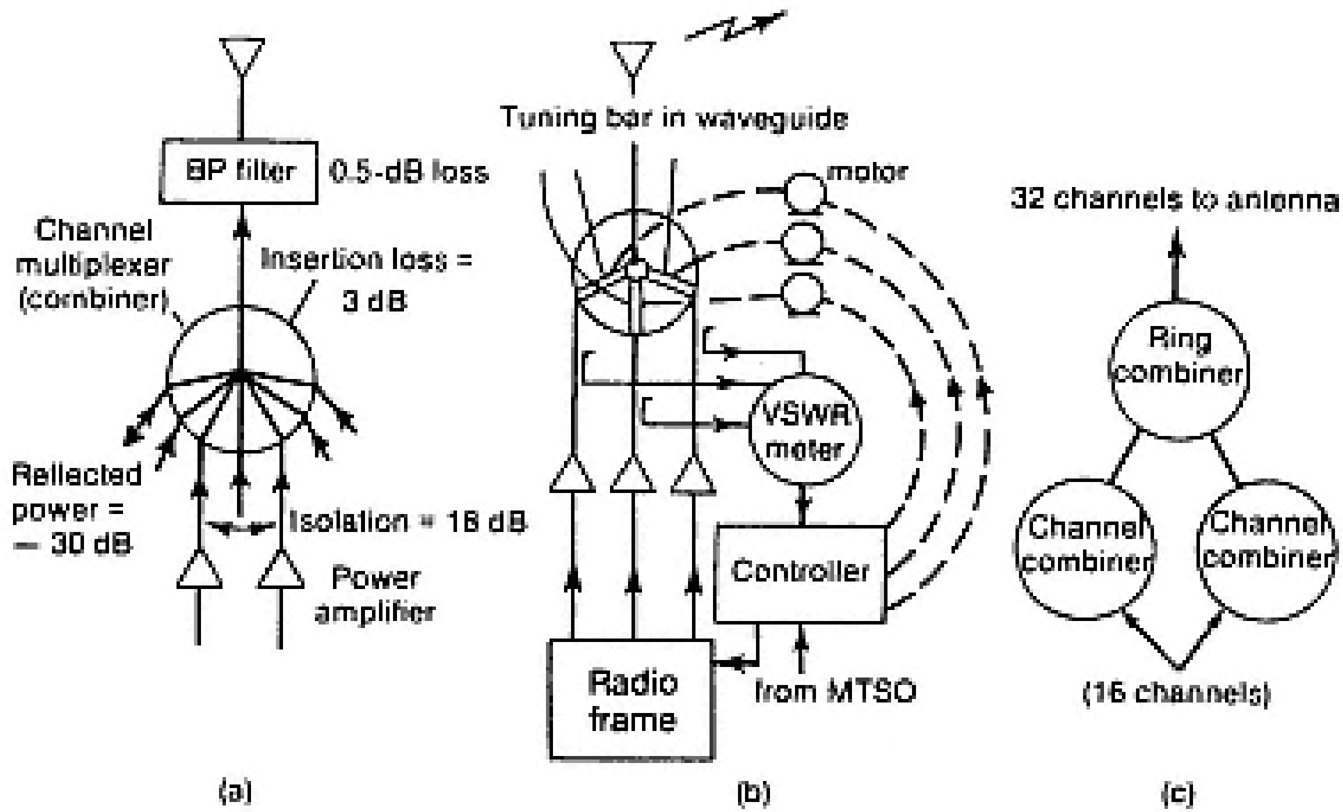
Cross Talk
A Unique Characteristic of Voice Channels

- In a mobile cellular system there is a pair of frequencies, occupying a bandwidth of 60 kHz, which we simply call a ''channel.“
- A frequency of 30 kHz serves a received path, and the other 30 kHz accommodates a transmitted path.

Channel Combiner

- A channel combiner is installed at each cell site.
- Then all the transmitted channels can be combined with minimum insertion loss and maximum signal isolation between channels.
- we can eliminate the channel combiner by letting each channel feed to its own antenna
- Then a 16-channel site will have 16 antennas for operation.
- It is an economical and a physical constraint.

Different kinds of channel combiners.
(*a*) Fixed-tuned combiner,
(*b*) tunable combiner,
(*c*) ring combiner.



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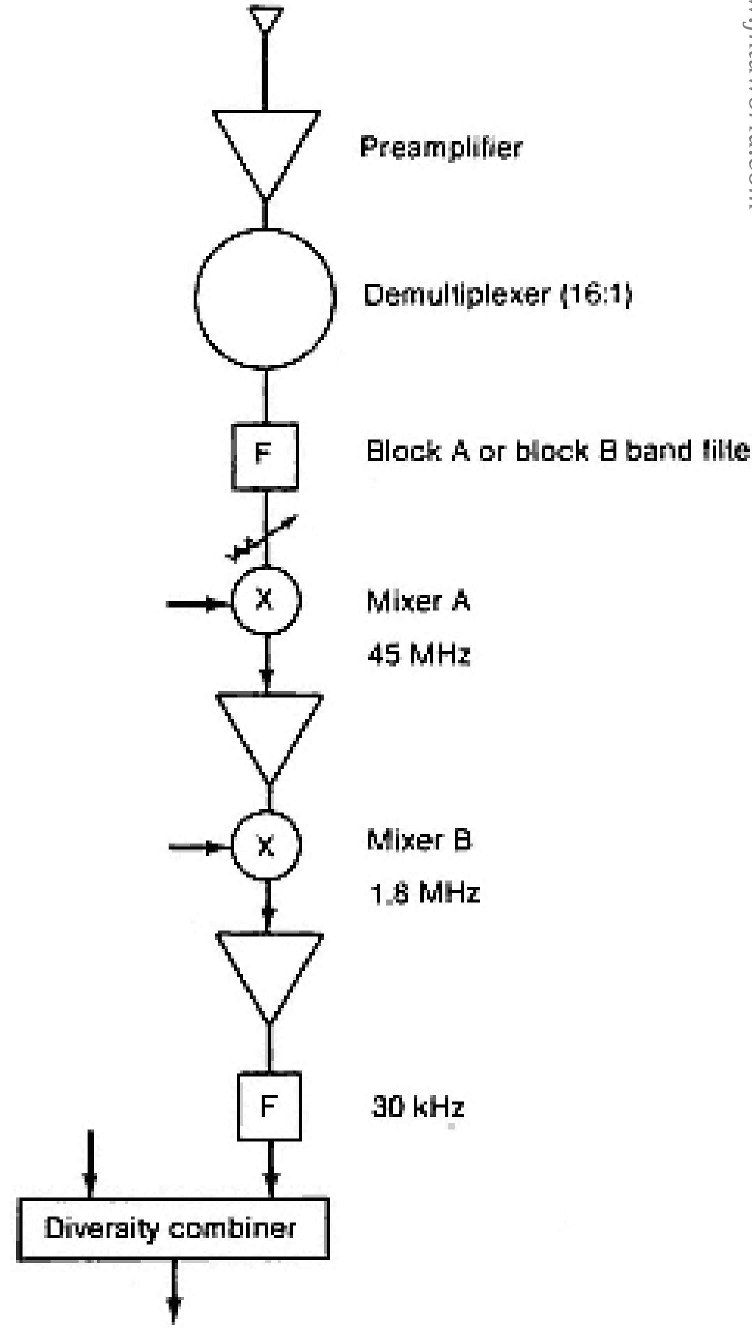
Demultiplexer at the Receiving End



- Every cell site has been assigned to one of three SAT tones.