CASE STUDY *B*

PROBLEM STATEMENT

Introduction

The Philo Pharmaceuticals Company is a major distributor of pharmaceutical products in Philadelphia and the surrounding area. The company consists of a central office in downtown Philadelphia along with ten distribution sites outside of the city. In order to better serve all its customers, the company wants to improve its communication capabilities.

A two-phase project is undertaken to accomplish the goal of improved intra-facility communications. First, Philo Pharmaceuticals wishes to directly link its central office with all its ten distribution sites throughout the state. Second, company wants the distribution sites to have the ability to communicate with each other.

Assumptions

1. We assume that there exists no physical obstructions which would block communication between the distribution sites or the central office (i.e., no mountains or skyscrapers lie in the direct path).

2. The gain of an antenna array equals the sum of the gains of the antennas within the array. We ignore the coupling effects between the antennas.

Part I

The chief engineer at Philo Pharmaceuticals has decided to use a linear antenna array to link the company's central office with the distribution sites. He wants to use a tower that already exists on the top of the central office building in downtown Philadelphia. A linear antenna array is a group of antennas (two or more) whose operation is coordinated. By having multiple antennas working together, the gain of the combined structure is increased to reach more distant targets. The array also gives Philo Pharmaceuticals the capability to communicate with all of the distribution sites using a single antenna structure only. The array can be 'electronically pointed' by controlling the amplitude and phase fed to each antenna within the array. This allows the antenna to communicate in any direction without having to physically move the antenna. Because of limited space on the tower, the antenna array can contain up to seven elements. *Figure 1* shows the possible antenna locations within the array. The positions must be filled in the exact sequence given in *Figure 1* (i.e. position 2 cannot be filled until position 1 is filled, etc.).

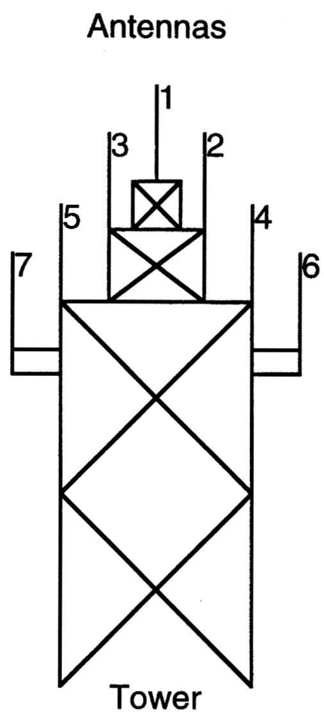


Figure 1 : Antenna array element locations.

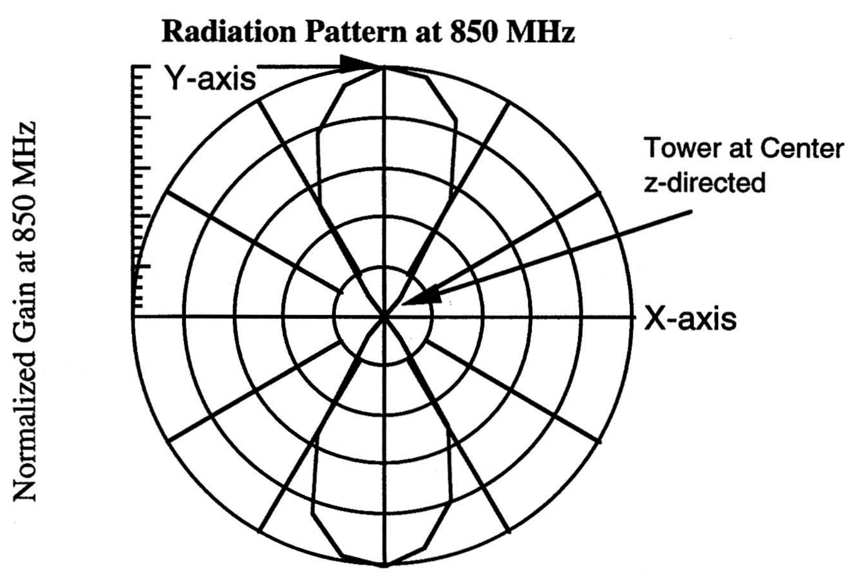


Figure 2: The plot of the main lobe for the normalized array factor of a linear antenna array with all elements fed in phase.

The main beam of the antenna array represents the direction in which a communication link is possible. The spacing between the antennas is half of a wavelength (.3m at 850MHz). The

Omnidirectional Collinear Antennas

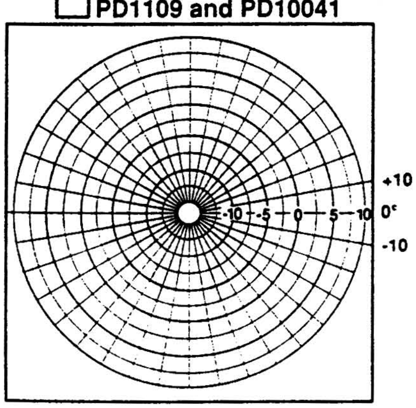
ELECTRICAL SPECIFICATIONS	PD10041	PD10041E	PD1110	PD10017
Frequency Range - MHz	806-960	824-894	806-960	800-960
Gain - dBd	7.5	7.5	9.0	10.0
Bandwidth - MHz for 1.5:1 VSWR	60	70	35	35
Vertical Beamwidth 1/2 Power Points	8°	8°	6°	5.5°
Maximum Power Input - Watts	500	500	500	500
Lightning Protection	Direct Ground	Direct Ground	Direct Ground	Direct Ground
Termination - Direct	N-female	N-female	N-female	N-female
Flexible Extension Supplied - in. (mm)	18 (457) RG393/U with N-male connectors			

Note: All VSWR data referenced to 50 Ohms.

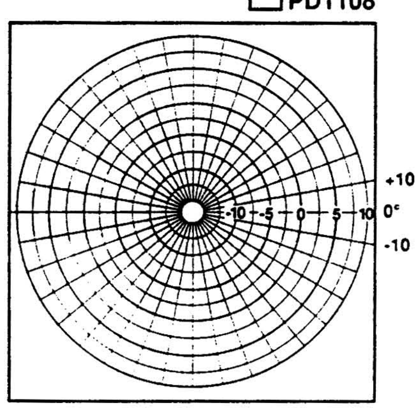
COST	$2000	NOT A CHOICE	$2500	$3000

MECHANICAL SPECIFICATIONS	PD10041	PD10041E	PD1110	PD10017
Overall Length - ft. (m)	10.42 (3.18)	10.42 (3.18)	13.17 (4.02)	15.17 (4.63)
Element Housing Length - ft. (m)	8.25 (2.52)	8.25 (2.52)	11 (3.35)	13 (3.96)
Support Pipe Diameter - in. (mm)	2-3/4 (70)	2-3/4 (70)	2-3/4 (70)	2-3/4 (70)
Support Pipe Length - in. (mm)	24 (610)	24 (610)	24 (610)	24 (610)
Weight - lbs. (kg)	19 (8.62)	19 (8.62)	20 (9.07)	25 (11.3)
Radiating Element Material	Copper	Copper	Copper	Copper
Element Housing Material	Fiberglass	Fiberglass	Fiberglass	Fiberglass
Support Pipe Material	6061-T6 Aluminum	6061-T6 Aluminum	6061-T6 Aluminum	6061-T6 Aluminum
Wind Loading Area Flat Plate Equivalent - ft.^{2} (m^2)	1.33 (.124)	1.33 (.124)	1.70 (.158)	2.00 (.186)
Rated Wind Velocity - mph (km/hr)	125 (201)	125 (201)	100 (161)	100 (161)
Lateral Thrust @ 100 mph - lbs. (kg)	53.2 (24.1)	53.2 (24.1)	68 (30.9)	80 (36.4)
Bending Moment @ 100 mph 1 in. (25.4 mm) Below Top of Support Pipe - ft./lbs. (m/kg)	190 (26.3)	190 (26.3)	340 (47.1)	480 (66.5)
Mounting Hardware - Supplied	PD46 Clamp Set	PD46 Clamp Set	PD46 Clamp Set	PD46 Clamp Set
Mounting Hardware - Optional	PD241 Wall Mount. PD246 Pole Mount, PD10024 Side Mount (Short). PD10028 Side Mount (Long)			
Shipping Weight - lbs. (kg)	36 (16.3)	36 (16.3)	37 (16.8)	46 (20.9)
Shipping Volume - ft.^{3} (m^3)	2.43 (.068)	2.43 (.068)	2.74 (.077)	2.97 (.084)
Shipping Mode	Common Carrier	Common Carrier	Common Carrier	Common Carrier

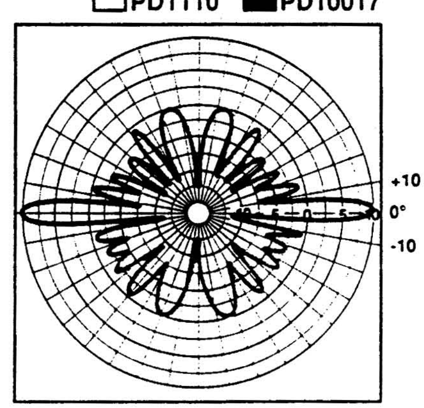
VERTICAL PATTERN
PD1109E and PD10041E
PD1109 and PD10041



VERTICAL PATTERN
PD1108



VERTICAL PATTERN
PD1110 PD10017



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Omnidirectional Collinear Antennas

Ordering Information

Item Number	High Wind Version	Frequency Range - MHz
PD1108-1		806-866
PD1108-2		825-890
PD1108-3		900-960
PD1108-4		820-880
PD1108-5		835-895
PD1109-1		806-866
PD1109E		824-894
PD1109-5		860-920
PD1109-6		895-960
PD10041-1		806-866
PD10041E		824-894
PD10041-3		860-920
PD10041-4		900-960
PD1110-1		800-836
PD1110-2	PD1110HW-2	820-855
PD1110-3	PD1110HW-3	845.5-880.5

Item Number	High Wind Version	Frequency Range - MHz
PD1110-4		865-900
PD1110-5	PD1110HW-5	925-960
PD1110-6	PD1110HW-6	806-841
PD1110-7		831-866
PD1110-8		862-898
PD1110-9	PD1110HW-9	900-935
PD1110-10		885-920
PD10017-1		800-836
PD10017-2	PD10017HW-2	820-855
PD10017-3	PD10017HW-3	845.5-880.5
PD10017-4		865-900
PD10017-5	PD10017HW-5	862-898
PD10017-6	PD10017HW-6	925-960
PD10017-7	PD10017HW-7	806-841
PD10017-8		900-935
PD10017-9		831-866

ELECTRICAL SPECIFICATIONS	PD1108	PD1109	PD1109E
Frequency Range - MHz	806-960	806-960	824-894
Gain - dBd	5	7.5	7.5
Bandwidth - MHz for 1.5:1 VSWR	60	60	70
Vertical Beamwidth 1/2 Power Points	12°	8°	8°
Maximum Power Input - Watts	500	500	500
Lightning Protection	Direct Ground	Direct Ground	Direct Ground
Termination - Direct	N-female	N-female	N-female
Flexible Extension Supplied - in. (mm)	18 (457) RG393/U with N-male connectors		

Note: All VSWR data referenced to 50 Ohms.

MECHANICAL SPECIFICATIONS	PD1108	PD1109	PD1109E
COST	$1600	$1800	NOT A CHOICE
Overall Length - ft. (m)	8.27 (2.52)	10.42 (3.18)	10.42 (3.18)
Element Housing Length - ft. (m)	6.10 (1.86)	8.25 (2.52)	8.25 (2.52)
Support Pipe Diameter - in. (mm)	2-3/4 (70)	2-3/4 (70)	2-3/4 (70)
Support Pipe Length - in. (mm)	24 (610)	24 (610)	24 (610)
Weight - lbs. (kg)	10 (4.5)	17 (7.71)	17 (7.71)
Radiating Element Material	Copper	Copper	Copper
Element Housing Material	Fiberglass	Fiberglass	Fiberglass
Support Pipe Material	6061-T6 Aluminum	6061-T6 Aluminum	6061-T6 Aluminum
Wind Loading Area Flat Plate Equivalent - ft.^{2} (m^2)	0.85 (.079)	1.28 (0.119)	1.28 (0.119)
Rated Wind Velocity - mph (km/hr)	100 (161)	100 (161)	100 (161)
Lateral Thrust @ 100 mph - lbs. (kg)	34 (15.5)	51 (23.2)	51 (23.2)
Bending Moment @ 100 mph 1 in. (25.4 mm) Below Top of Support Pipe - ft./lbs. (m/kg)	68 (9.4)	180 (24.9)	180 (24.9)
Mounting Hardware - Supplied	PD46 Clamp Set	PD46 Clamp Set	PD46 Clamp Set
Mounting Hardware - Optional	PD241 Wall Mount, PD246 Pole Mount, PD10024 Side Mount (Short), PD10028 Side Mount (Long)		
Shipping Weight - lbs. (kg)	29 (13.2)	35 (15.9)	35 (15.9)
Shipping Volume - ft.^{3} (m^3)	1.4 (.04)	2.43 (.068)	2.43 (.068)
Shipping Mode	Common Carrier	Common Carrier	Common Carrier

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Omnidirectional Collinear Antennas

806-960 MHz

Super Stationmaster™ Series

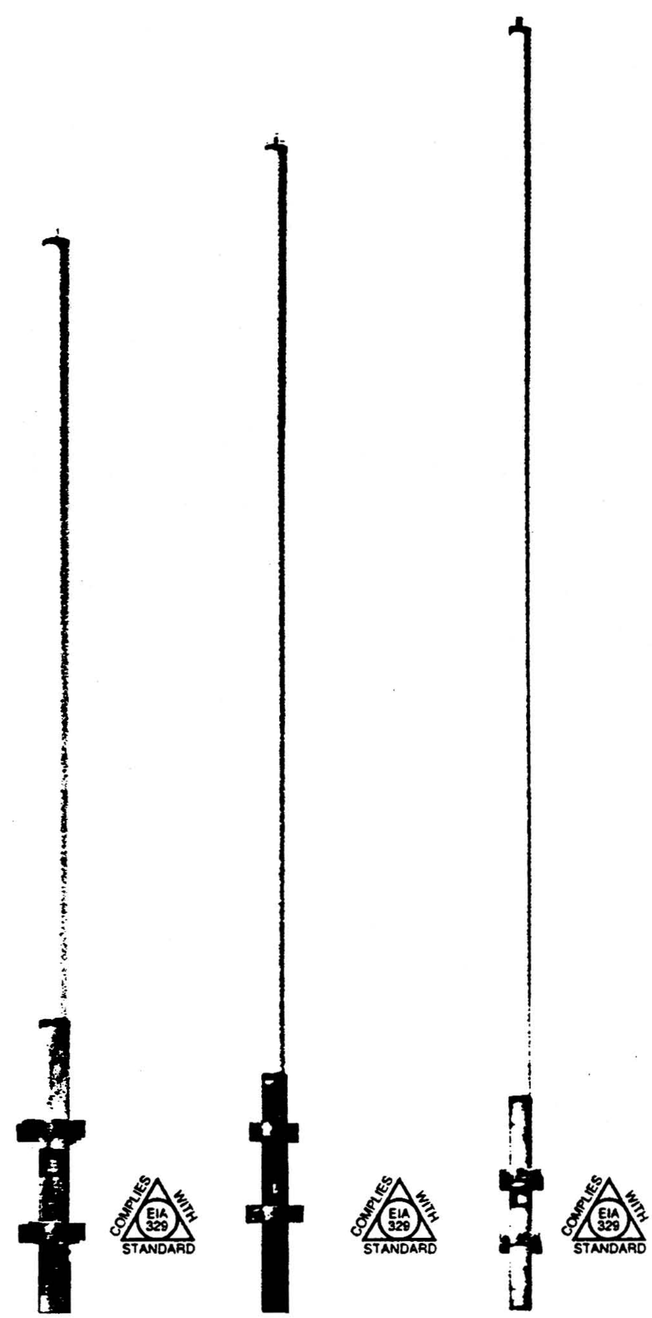
PD1108	**5.0 dBd Gain**
PD1109	**7.5 dBd Gain**
PD1109E	**7.5 dBd Gain**
PD10041 Heavy Duty	**7.5 dBd Gain**
PD10041E Heavy Duty	**7.5 dBd Gain**
PD1110	**9.0 dBd Gain**
PD10017	**10 dBd Gain**

These center-fed collinear antennas ensure consistent gain and impedance across the operating frequency band, and are specifically designed to meet various omnidirectional requirements for mobile radio services in the 806-960 MHz bands. Copper alloy radiating elements are encased in a weatherproof fiberglass low loss housing and permanently attached to a 6061-T6 aluminum support pipe.

The PD10041 antenna is a rugged version of the PD1109 having a wind velocity rating of 125 mph (200 km/hr). A pressurization option (PD1252) is available for PD1108, PD1109, PD1109E, PD1110, PD10041, PD10041E and PD10017 facilitating pressurization to 12 PSIG. *The above antennas may be mounted inverted. Specify option PD1254. The series is also available with high wind version radomes (200 mph rated wind velocity).*

Various reflector assemblies are shown on pages 97 and 98. Contact our Customer Service Department for specific pattern requirements.

• **Fiberglass construction**	Protects radiating elements in hostile environments.
• **Copper radiating elements**	Minimizes possible generation of intermod products.
• **Center-fed design**	Eliminates beamtilt across the band.



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TO	From Node										
Node	0	1	2	3	4	5	6	7	8	9	10
0	0	3	4	5	6	2	6	5	6	4	5
1		0	2	x	x	4	x	x	x	x	x
2			0	3	x	x	x	x	x	x	x
3				0	2	x	x	x	x	x	x
4					0	x	x	x	x	x	1
5						0	3	x	x	x	x
6							0	2	x	x	x
7								0	x	3	x
8									0	2	2
9										0	x
10	S	y	m	m	e	t	r	i	c		0

Given this matrix is symmetric, only the upper triangular part is shown. We use an "x" to indicate an infinite cost corresponding to the case of no direct communication link between two nodes.

a) Using the link costs presented in the matrix above, solve the shortest path problem using Dijkstra's Algorithm to determine the least cost (least delay) to communicate from ***node 1,*** *to each of the other nodes.*

b)Discuss a procedure for adding an additional site to the network. Does this nearest neighbor network facilitate the addition of a node? How will the network be affected by the new addition? What problems arise if the network is greatly expanded, e.g., if an additional 5 sites were to be added in the next year?

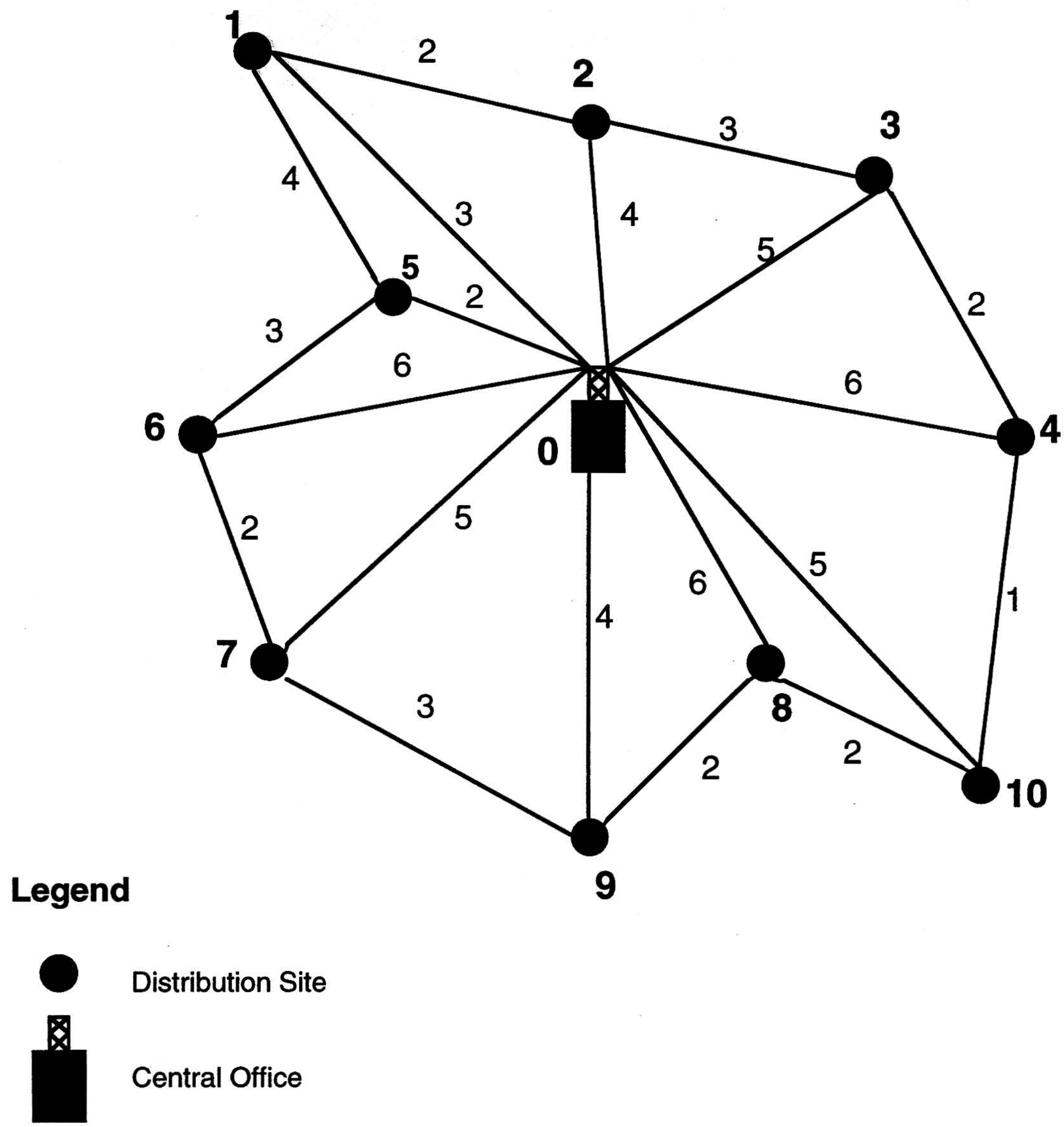

Figure 4 : The locations of the distribution sites relative to the central office.

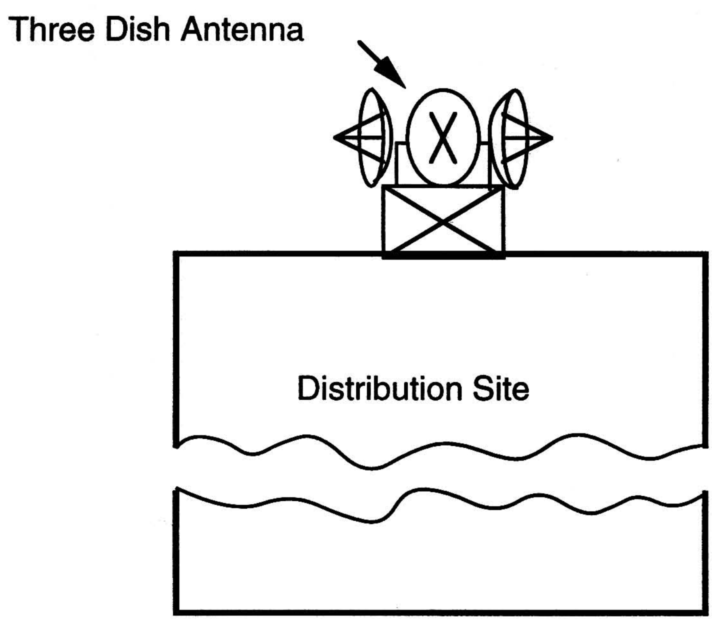

Figure 3: The parabolic dish configuration on top of each distribution facility.

The neighbor to neighbor links create a path connecting each node to every other node. The network which is formed is shown in *Figure 4.*

The lines connecting the nodes (distribution facilities) show the links which exist. Each node has the capability of transmitting and receiving, therefore all of the links are bi-directional. The numbers on the links show the cost incurred in using each link. The cost is expressed in terms of the delay in seconds caused by other communication traffic on the link. For example, to communicate between node 3 and the central office there would be a cost of 5 seconds. The link costs will be constantly changing based on the amount of traffic present on each link, the matrix of link costs, on the following page, shows an example of typical link costs.

normalized array factor plot for a linear antenna array with all antennas fed in phase is shown in *Figure* 2.

The main lobe shown above can be rotated by changing the relative phase and amplitude fed to each antenna. This gives Philo Pharmaceuticals the capability to direct the beam towards each of its distribution sites outside of Philadelphia. The main beam of the array pattern can be directed towards the target, however, the individual antennas must provide enough gain so that all of the targets can be reached. For our design problem, we need to use omnidirectional antennas (i.e., antennas radiating the same amount of energy in all directions along the horizontal plane). By assumption #2, the gain of each individual antenna in the array sum up in the far field. For example, if we have a two antenna array with one antenna having a gain of 9dB and the other with a gain of 10dB, the antenna array will have a combined gain of 19dB. By making the above approximation we are neglecting the mutual coupling which exists between the individual antenna elements. Since it has been empirically determined that coupling effects are small, we assume they can be neglected. This approximation enables us to solve this problem using a linear program.

The chief engineer for Philo Pharmaceuticals calculates that the minimum gain required, for the sum of the individual antenna gains, is 50 dB. This result takes into account the distance between the antenna tower and the receivers, the noise in the system, and the required signal to noise ratio at the receiving antennas. Because we neglected the coupling effects between the antennas, the chief engineer compensates by making the minimum required gain 54dB. He also determines that we need at least three antennas in our array to provide the necessary directivity in the array factor plot.

The chief engineer further estimates that the tower can only safely hold an array with a total weight of at most 130 lbs. This upper bound is calculated taking into account the maximum winds that are possible in Philadelphia and the geometry of the existing tower.

The specification sheets for the component antennas are appended to the end of this report.

a)Design an antenna array which meets all the above constraints at the <u>*least cost to the company.*</u> *Use a linear program formulation for the design. Solve the LP and use rounding to the nearest integer to find the answer.*

Part II

The antenna array will give Philo Pharmaceuticals the capability to communicate from the central office to all of the distribution sites. The array, however, can communicate with only one distribution site at a time. The company also wants the distribution sites to be able to communicate with each other to insure that all the demands of its customers are met.

The chief engineer decides to form a network by connecting each of the distribution sites directly with two of its neighbors. Each distribution site will have three dish antennas, one for communicating with the central office two for communicating with its two neighboring distribution sites.