CHAPTER FIVE

5.1 Tower Systems and Mountings

Whether using a tower, a pole or a roof-top to operate an antenna site it is always necessary to plan ahead in order to maximize the number of facilities which can be placed at the location. Poor planning and positioning of actual antennas can cause pattern distortion, interference and many other physical problems which can put the tower at risk of falling over or compromise the physical integrity of a roof. Safety issues must also be addressed along with the possibility of creating harmful Radio Frequency Radiation (RFR) or at least the appearance of such. In this Chapter we outline tower types, mounting configurations and a few things to keep in mind when planning your facility from the start.

5.2 Tower Suppliers and Accessories

Steel is the a slang term for tower parts. Towers can be supplied from many reputable companies operating within the United States, Canada or even foreign countries. U.S. based dealerships and factory direct orders vary from company to company. Because towers and tower components are generally heavy, selecting a tower supplier nearby to your site can save substantial shipping costs. When a tower is ordered and shipped the transport company is usually not required to *off-load* the *steel* from the flat-bed trailer. Therefore a crane should be standing by to unload, as well as to erect, the tower sections or pieces. A crane rents by the day along with an experienced operator so it is a good idea to either contract for the entire installation or to understand the many factors involved and the sequence of events when managing your own construction. Project coordination adds about 15% to 20% to the cost of the tower installation. If you are experienced in construction or have a friend who can help you, the savings can be worth the effort. The downside is that if anything goes wrong on your job, such as an inexperienced worker or other catastrophe resulting in an accident etc., you will not be covered to the extent your supplier or contractor would have been either by liability protection or with replacement materials. Experienced *riggers* and *steeplejacks* do know their business. They waste little time in erecting towers. They have the tools and are actually amazing to watch. If you contemplate constructing more than one tower, the first project might best be served by contracting for the entire job and using it as a learning experience.

5.3 Using Local Subcontractors

Most tower suppliers who provide installation services, use *local subcontractors*. These subcontractors are usually approved by the manufacturer and must bid against other local or even regional subcontractors for jobs. If you plan to coordinate the construction project, you can get to know several subcontractors and their respective employees rather quickly. Obviously this is a good resource for your future construction needs. Tower manufacturers realize that tower construction and erection is a necessary part of their sales effort. Except for highly customized installations where tower manufacturers must provide direct warrantees for their product, as a general rule, they don't much care if you coordinate your own installation. All they want to do is sell the product. However they don't want the reputation of a failed installation either should you erect your tower incorrectly. Many large communication firms use turnkey installers which have been selected by competitive bidding. In other cases manufacturers set up *joint ventures* with installers or have their own subsidiaries to do the job for their clients. Then too, installation services could be a part of the overall order. This shouldn't be a major consideration if your business plan includes only a few towers. But it is good to know a little about how the process works from the beginning.

5.4 Seasonal Construction

Time of year for construction is also a factor effecting price and available crews. In the Winter months, special considerations for excavation and concrete pouring where there is a possibility of freezing must be taken into account. This may represent slightly higher foundation costs. However the incidence of work for local contractors taper's off and these companies might be looking for work to help meet their payrolls. Crews also move around a lot from job to job. It is not uncommon to find subcontractors using specialized foundation drilling equipment working in remote areas hundreds of miles from home installing foundation bases for towers that won't be needed for months. Once the equipment is in a given area it is a lot less expensive to do a series of foundations at one time. And one more thing, in many instances these crews work a seven day week in order to maximize their leased heavy construction equipment. The ideal negotiating strategy is to be in *no hurry* for the foundation allowing the subcontractor to work through his priorities and use your project as a fill-in job. However in the course of foundation installation be sure to "close the hole" as soon as possible to avoid safety hazzards or vandalism.

5.5 Professional Engineering Certification

In its informative little booklet entitled *Tower Specifications*, PiROD Inc. **http://www.pirod.com** a leading supplier of towers and accessories lists a few other concerns. Registered professional engineers (PE's) on staff can provide, along with your steel order, specifications that have been certificated in accordance with codes and standards. These so called *wet diagrams* are actually tower specifications which have been stamped or sealed with the PE's original signature. They are quite handy before local zoning boards. The specifications usually address a host of issues including structural integrity of the base design, the tower itself, suggestions on how many antennas and transmission lines can be installed on the tower and what to expect in your area of the country with respect to wind, hurricane, and ice storms. Having certificated diagrams demonstrates your due diligence also giving the local code inspector something to use as a point of reference when inspecting your foundation and approving your project along the way. Since the PE's actually work for the tower company, they are familiar with their product. Any failures or special circumstances that may have taken place with their customers in the past forms an experience base protecting your design. PE's can answer technical questions quickly and as a matter of course are experienced and can deal effectively with local code enforcers.

5.6 Ice and Wind Loading Considerations

Local zoning boards love to have PE's testify at their hearings but this in many circumstances is impractical and unnecessary when the design specifications for your tower have been pre-certified in accordance with established criteria. The fun part comes when the zoning board begins to understand some of the criteria and then attempts to set their own rules. An example. You may find that compliance with the current standard, EIA/TIA-222-E, for ice loading meets your insurance and construction needs. This standard provides two options concerning ice build up. The first option takes into account that an ice build up doesn't usually occur at the same time maximum winds can be expected. Thus ice loading at 75 percent of the required wind load, i.e. 87% percent of the wind velocity, is stated as being what the tower has been designed to survive under a recommended loading. Another approach is to require the maximum tower icing at the maximum wind velocity! It is obvious that if ice builds up on tower parts, considerable weight must be added to the structure. If the standard is *maxed out*, the zoning board can literally price your tower out of reach by establishing their own criteria. Suppose they direct that your tower must survive an 80 MPH mile wind while holding one inch (1") of ice build up. The cost to achieve this reliability is well within the tower manufacturer's capability. However these towers are not usually found in their catalog nor are they inexpensive. Some feel that it is the zoning board's way of saying: "*. . . we realize that the Federal Government has instructed us not to restrict your tower but they have given* ***us*** *the right to insure compliance with local codes and standards*". The effect here is to make your project's profitability more difficult. The alternative to restrictive coding is to insure against improbable loss. It is a lot less expensive to build the tower system to the national standards under EIA/TIA-222-E and insure the prospect of an improbable occurrence of ice and wind knocking down the facility at a later date.

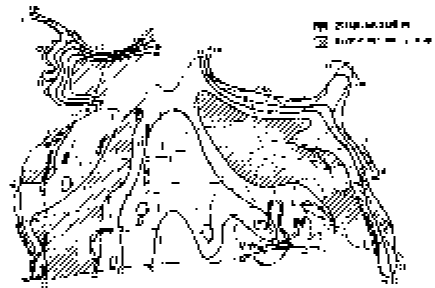

Fig. 5.6 Wind speed map showing tendency of prevailing winds for determining tower loading.

Ice and wind are not the only hazzards to dropping a tower. Tornado, hurricane, plain old "rust" along with improper antenna installation can do the job very effectively. Most of the standards can be found in the *Electronics Industry Association Structural Standards for Steel Antenna Tower and Supporting Structures*. As the basis for design of minimum acceptable standards, the code forms the starting point in tower design. You can of course specify additional capacity to these standards as a margin of insurance against the unforseen or less likely occurrence of unusual conditions. But the tower design taking into account all the standards can be corrupted very easily when technicians start to *hang* their antennas and transmission lines without supervision. After all, your objective is to attract customers to the site. It is real easy to add five or ten antenna systems to a tower while at the same time departing from the original design criteria. And there are more codes to reference as well. Standard Building Codes, Uniform Building Codes, even the National

Electric Code all reference communication installations. Another one is the American National Standards Institute or ANSI. That is why it's a good idea to have a PE sign the specifications. The certification gives your project the credibility it needs.

5.7 Fall Zones

A *fall zone* is another new standard that zoning boards are imposing. The presumption being that the ground around the base of the tower should be fenced in for a circumference which is equal to the height of the tower as the radius. The possibility of the entire tower falling over in a straight line from its base is remote. This regulation can add acres of land to your ground space requirement and multiply the chain link fence cost by several magnitudes. Even guyed towers, where three triangular guy line points support the tower, presents little justification for a 100% fall zone. If the anchor point is improperly installed, is too light, or is sabotaged there is a possibility that the tower will collapse along a plane perpendicular to the lost support line. However it is highly unlikely that all support guys will fail simultaneously and towers usually collapse in a distorted gyration of sequential steps resulting in a pile of rubble well within a 100% fall zone. Because there is little engineering justification for a 100% (or greater) fall zone, zoning boards may be inclined to distort the danger of this occurrence in order to discourage installations and evoke public concern. Self supporting towers tend to fold over on themselves and the only monopole failures reported were a result of an improperly designed base. Fall zones of 25% to 50% are well within reason. But this whole issue is a relatively new specification and has rarely been applied to power company poles, high voltage transmission towers, or even trees planted along Main Street USA or even in your own back yard. Trees tend to fall over with wind and ice as well, and can cause just as much havoc as a tower falling over. But a well designed tower, properly installed is a lot less likely to cause property damage or injury than that old oak tree in your back yard.

5.8 When a Tower Falls Over

When a *super* tower (800' or more) goes down, it can create a real mess and usually winds up on the front page of a lot of newspapers. The fact that the print media is competing with the broadcast media might have something to do with the coverage. Indeed, from time to time there have been construction accidents in which portions of a tower failed during erection, taking a worker with it. Thus in the minds of the regulators it seems to be pretty risky business so they want assurances that your tower will not wind up on the front page of the local newspaper.

Many of these new codes deal with the same issues from differing perspectives, i.e. one code deals with wind loading in terms of *psf* or wind pressure, while another refers to wind velocity expressed as *mph*. The engineering is the same but the definitions cause confusion and the appearance that the industry is unsure of what it should do. This fact has been the subject of thousands of transcripted pages before zoning boards and code enforcement hearings keeping a lot of solicitors and independent engineering consultants in business. An older version of the EIA code, (EIA RS-222-C) used to express *wind loading in pounds per square foot of pressure applied against the full height of the tower*. The fact is however, this pressure may vary at different height levels along the tower itself. It could be negligible for example at the base of the tower and up to 30 psf at the 300' foot level. Not only that, it may vary in different parts of the country. Subsequent revisions to the standard merely reset this reference height to 33 feet above the ground for a time. The standard was modified several times until the current EIA/TIA-222-E was released which supposedly represents the best technology to date. It is important for you not to entertain any "other" definition or standard than those currently accepted. The reason is that previous versions of the standards are virtually impossible to correlate with each other with any certainty which can be understood by the regulating authorities.

5.9 Engineering Diagrams and Blueprints

When ordering a tower from a catalog check the prices for engineering diagrams and prints. In some cases these can be provided *with* the order or they may be a *separate cost* item. Most manufacturers will not loose your tower order for the sake of picking up $1500 dollars worth of prints. But many times users will require the prints to see if approvals can be obtained prior to ordering the tower. The tower manufacturer can often provide similar installation diagrams (not your project) as a starting point, but when you get down to the actual construction diagrams, the order should be entered before your can expect to get the custom prints. Negotiate! It goes both ways. Most zoning boards do not need your actual prints if your tower is nothing out of the ordinary. In fact the least information and detail you present at this point will be to your advantage. Do not specify manufacturer nor show potential loading nor base details.

An example. You may wish to install the base for a 190' lattice (self supporting) tower. You may also wish only to seek approval for a 120' structure. By constructing a 120' tower on a 190' foot base, you may easily add seventy feet (70') of *steel* at a later date. You can actually order the tower designed for this extension. It is a lot easier to modify an existing structure than to replace it or apply for the entire structure height if controversial, at the onset. It's easier on the pocketbook too. Use your understanding of the zoning board *hoops* you'll have to go through as well. If your zoning board hasn't got around to setting up an antenna structure ordinance yet, you may want to slide through prior to enactment with all you can get. On the other hand, if your board has been hardened with previous presentations by the big boys, (often a ploy to make it difficult for additional users) they might be less objecting to a preliminary design with some expansion wording skillfully inserted into your application which *provides for future potential use while insuring that a need for additional towers will be minimized"*. If approved, you can return to the board in a few years for the extension. Things become a bit easier especially if the board is a new one and figures they didn't make the original decision.

5.10 Site Selection

In Chapter Two site identification was emphasized. In this section we are more concerned with the quality of the site. The first point is that there should be sufficient land allocated for the site and its future development. If the land is your own this may not be a problem. However if it is your intention to lease or option land, be sure to provide sufficient area for the type of tower you intend to construct, any restrictions such as fall zones which might be imposed, ground construction for shelters roads and right-of-ways. Other important considerations are soil type, land topography, the possibility of nearby natural or man made structures distorting your client's radiation pattern and location of the nearest airport.

Soil Type - Remember the "grassy knoll" on your property. Could that be an ideal location for the tower? Well maybe! It is a knoll because the geology under the top soil could be solid rock. There are mounting systems which mount into rock but the preparation of the base can be more expensive than the tower itself. Likewise, if the land is swampy, you may have an excellent ground system but no place to install a stable concrete tower base. If upon excavation you hit ground water or a water table before reaching the required base depth designed for installation, concrete will not cure properly and extraordinary installation conditions will need to be applied. Moving the tower location a mere hundred feet (100') could in many instances solve both of these problems and will have little effect upon the ultimate use.

Land Topography - Sloping hills, abutments and irregular terrain could create some unusual base considerations. It's not that a tower base can't be installed under these conditions but it makes equipment used at the site more difficult to operate and in some cases the land must be surveyed, leveled and cleared in order to provide the installation anyway. Here is a another true life example. While designing a microwave control station at a new police barracks, the tower height was calculated, the tower ordered and delivered to the site. Unknown to the engineering department was the fact that the contractor "leveled" the land for the building construction pushing about 20 feet of ground away from the tower location. When the tower was installed at the specified location the path for the microwave was no longer established, a mystifying development until it was learned what had happened. Fortunately the tower was expandable and the situation was corrected quickly. Even though the tower wound up being at the same height above average terrain (HAAT) it was now twenty (20) feet higher than that which was approved by the township. The matter was quickly resolved. Although situations like this don't happen everyday it is a clear example of what can happen if you do not keep track of the effects of everybody else's work at your site.

Nearby obstructions - Positioning your tower near a billboard, tall trees, another tower or even a building can create shadowing effects blocking portions of the coverage for your client. Although this is sometimes done on purpose, the trick is be out in the open as much as possible. Another favorite recommendation of zoning boards is to allow you to put your tower (usually on their land) in a tower cluster or "farm". Separation is required not only for pattern distortion but also for adjacent channel interference. When this type of interference is encountered it is better to separate vertically than horizontally. It is easier to manage interference on your own tower than to try to get someone on a tower within close proximity to correct a problem effecting you. If possible, stay away from antenna farms. They represent competition that you do not need (by providing clients with alternative sites at the same location) and present a host of other problems you just don't need to deal with at this point.

5.11 Tower Type

By now it is obvious that there are many different types of towers and antenna support structures which can be utilized. The decision to use any one type of tower is based upon many of the considerations already outlined. In many respects economics will be the underlying consideration. As a generalization, guyed towers represent the best tower for the money if the additional ground space is already available. Guyed towers can be erected at just about any height up to the super tower status. They can be easily loaded and expanded and require a bit more maintenance over their useful life. Lattice towers are self supporting and generally are practical in design to about three hundred feet. They are designed for a fixed loading and may not easily be expanded if not provided for in the original design. The monopole by far is the most expensive of the three and represents the least amount of multiple purpose application although monopole technology is improving with additional mounting options and loading designs being provided every day. Height is also a consideration for a monopole. The taller the pole the higher the ratio to overall cost especially at heights in excess of two hundred feet (200'). The problem with the monopole is that it is perceived as being the least *objectionable looking* structure when seeking approval. Accordingly it may be the only type permitted other than stealth systems.

And there are of course several variations and combinations of the above. Wooden poles have their application discussed in Chapter Three. Multiple close spaced guyed towers, or "doubles" were popular in the early 50's and provide greater loading if the *face* of the two towers is oriented towards the service area. Cross pieces between the two guyed towers positioned say twenty to thirty feet (20' to 30') apart provide a substantially greater mounting opportunity for a larger number of clients.

Conversions are also very attractive alternatives to commercial towers. An old fire tower, observation tower or similar system can be converted for antenna installation use. Usually a conversion took place prior to building code applications for tower structures. A local welder would merely *scap* iron and reinforced plates, here and there, erecting a base above ground after which tower members or sections would be attached. Some conversions are pretty creative but by today's standards would be difficult to obtain approval to modify let alone operate.

Tower *buildings* were also popular during the early 50's. It is basically a *tall* steel girder reinforced cinder block building with mounting opportunities and floors for equipment mounting. AT&T-tm used these buildings commonly for their mountaintop microwave systems for years and many are still in use today. From time to time and mostly due to satellite and fiber-optic technology a few of these sites have been declared surplus and sold to private investors. They are very nice installations even today but somewhat impractical under modern construction techniques and cost limitations.

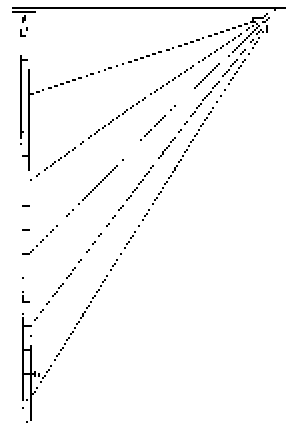

Fig. 5.11.1
Guyed tower

The following discussions cover the typical tower systems you are likely to encounter:

Guyed Towers. A guyed tower requires enough ground space to position supporting *guy lines,* the number of which is dependant upon height and loading, typically attached to three (3) anchors, each of which forms an equilateral triangle. With the tower positioned in the exact center of the triangle, the *distance from the base* to the anchor point is approximately 70% of the tower height. If the tower is to be used for larger microwave dishes especially near the top, eighty percent 80% may be the rule. Each of the three (3) guy legs in this case would be approximately 125% of the tower height. This is a rule of thumb and can certainly change a bit but in general it is a good indicator of how much ground space will be required when designing a guyed tower system. As a practical example, suppose you intend to construct a two hundred foot (200') guyed tower. If the base is located at the exact center of an equilateral triangle, each of the three (3) sides of the triangle (guy lengths) would be two hundred-fifty feet (250'). The distance from the tower base to each of the anchor points would be one hundred-forty feet (140'). The *area* of the ground space needed (one side squared times 433) would have to be a minimum of twenty-seven thousand sixty-two square feet, 27,065.5sq.ft. or slightly greater than six tenths 6/10ths. of an acre. (27,065.5/43560 - where 43,560 is the number of square feet in an acre).

The above example and ground space plot may be altered to suit existing land conditions and specific anchor points so the land does not necessarily have to be symmetrical. If guy lines are moved closer to the base of the tower to use less land, greater forces will be applied to not only the resultant force "pulling down" on the tower (requiring a stronger tower) but to the guy lines themselves and their respective anchors. There is a point of diminishing returns where less land use results in greater construction costs to achieve the same loading. It is not uncommon for these percentages to be reduced to forty percent (40%) to achieve the same standards, but the trade off could be substantially greater material cost. Use a professional engineer if your design is any thing out of the ordinary.

Fig. 5.11.3
A 300' Self-supporting tower

Self Supporting Towers. If the design calls for a tower height in *excess* of one hundred feet (100') a guyed tower is substantially less expensive to construct. The availability and cost of the land is the limiting factor in this decision. Self supporting towers, however in heights of up to about three-hundred feet (300') can be erected in several configurations allowing substantial loading capability. Taller self supports are possible but may be cost prohibitive. Triangular and four point bases are provided by many tower manufacturers with several different types of construction. Tubular steel pipes, solid rod and angle-constructions techniques are employed in differing designs. Essentially the tower is delivered with a bucket (a rather large bucket at that) of nuts and bolts and skids of pipes or members of various sizes pre drilled and ready for assembly. All that is required is the diagram and a couple of heavy duty torque measuring socket wrenches. Once the base and the preliminary foundation sections have been installed, are plum and the concrete cured, construction may begin. Sections may be assembled on the ground and hoisted into position using a crane or gin pole. Or the tower can be assembled in the "air" one piece at a time.

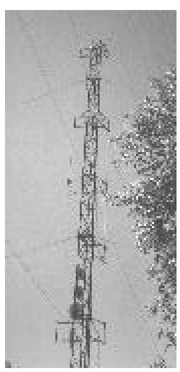

Fig. 5.11.2
Actual guyed tower

Angle (iron) stock towers pick up a bit more wind loading than solid rod tubing types but are less expensive. The problem with solid rod construction however is that it is substantially heaver than angular steel or hollow tube tower members. One advantage of solid construction is that corrosion *from the inside out* is eliminated. Because sections are pre welded, drilled and flanged, erection is a lot easier and the structure is easer to paint and maintain. Hollow round tubes require that *drain holes* be made in the base to allow water entering the inside to drain out. Should these holes become blocked with rust particles or dirt water can build up in the leg, freeze and literally burst the tubing. Angular steel is the least expensive to produce but is difficult to paint if required due to the increased irregular surface area. In addition since all the members are all bolted together, routine re-tightening is required. It also takes a bit longer to erect these systems. The wind drag on this type of tower is also greater than the tubular types. The decision to select any of these methods of construction is of course a trade off in the cost of the *steel*, erection and maintenance. In general however, solid tubing for the base and graduating to hollow tubing for the upper sections is about the best of both worlds and provides the greatest versatility and utility in multiple mounting applications.

Fig. 5.11.4
Typical Tower "zone"

As you observe many self supporting lattice towers and monopoles in service today the first thing you will notice is essentially only one user has been installed. Although this trend is changing, many of these towers were constructed with single applications in mind and generally can not be loaded much beyond what is observed. They were what I call *minimum bid single application towers* erected at a time when communication companies had no clue that there would be an additional four to seven companies in the same market. As a result, these towers either require *beefing up*, replaced or can not be used at all without jeopardizing the loading of the existing carrier's facilities. Re-engineering these facilities is under way but in some instances the engineering can cost more than a tower replacement. Should the tower be in a *grand-fathered* zoning region, the carrier may have no choice but to go with what is standing. In addition the height of these towers meets the needs of the existing carrier only, not a new carrier who might need a higher HAAT than that which the tower provides. There are

Fig. 5.11.5 Sabre Monopole with three platforms

a lot of factors effecting the reuse of existing towers but since the rents are the same, *your position of owning a tower with substantial capacity near a tower with no additional capacity can be a prudent move.* But you must be sure that the existing facility will not be upgraded in the future or your competitive edge will be neutralized.

Site Savvy

Building your tower near a carrier's single purpose tower which

Monopoles - A relatively recent development, the monopole is a single element, flanged or sectioned concentric pipe, bolted to a huge concrete base and extending upward to a desired height. Transmission lines are pulled up *inside the pole* and emerge at the top and bottom through little pre-cut doors for that purpose. Because the pole section diameter decreases in circumference as the pole tapers higher and higher, the maximum number of transmission lines stuffed inside the monopole is entirely dependant upon the diameter of the pole at the top point where they emerge. Usually a pedestal or platform is erected at the top of the pole. On some models this platform actually extends above the top of the monopole. Antennas are attached to mounting pipes on the pedestal railings. The platforms are triangular and can be shifted around on the pole to establish any required face directional orientation. A small *catwalk* enables the technician to walk around to each antenna for testing or replacement. The climb to the top is accommodated by foot holds attached or welded up the side of the pole. A safety cable also runs up along the same side.

5.12 Types of Antennas, Patterns and Directivity

A monopole is relatively expensive when compared to other types of support structures. Also, loading considerations assume that most of the antennas installed on a monopole will be small high frequency "sticks", panels or sectorized antennas. Because these antennas have a very narrow beam width which directs RF energy forward, the rear of the antenna ("off the back") will not be distorted by the pole or mounting member itself. By clustering several 60° degree beam width sector antennas around the platform, there is little or no pattern distortion because these antennas are *unidirectional* rather than *omnidirectional* which would have to be mounted on the top of the monopole out in the clear. If microwave dishes are also added to the monopole at a high pont, the stability of the pole must be greatly increased to prevent what is termed microwave *sway and twist.* This is the tendency for the tower to actually rock slightly under severe wind conditions. An inch or so sway usually won't effect the performance of a panel or omnidirectional antenna, but it could significantly alter a microwave dish path causing reduced signal strength or loss of signal (LOS) all together. It is obvious from this situation that microwave paths established using monopoles work a lot better if the dish is not located near the top of an *underrated* pole. Positioning the microwave dish further down the pole might prove usable due to lessening effects of *sway.*

There are five (5) basic types of antennas which mount on towers or supporting structures.

The Omnidirectional Antenna - This antenna consists of either a single quarter wave element or several quarter wave elements phased together and mounted inside a tubular "*stick*". At VHF and UHF commercial frequencies these antennas may vary anywhere between about two to six inches (2" or 6") in diameter and from four to twenty feet (4' to 20') in length. Substantially longer "sticks" if not mounted at the very top of the tower, usually require two (2) mounting points. One at the base or feed point of the *stick* and the other at the top of the *stick* to prevent it from swaying in the wind. The top support is of course non metallic as a metal support pipe at this point might distort the antenna pattern. Stand alone *sticks* are substantially heavier to prevent swing when no top support pipe is used. Thus there may be a weight difference in the two types of antennas depending upon where they are mounted and their overall length. Short *sticks*, four to eight feet in length (4' to 8') don't swing much in the wind. Also because their vertical beam width is wider, even if they did swing several degrees, the pattern wouldn't be effected greatly. Twenty-foot (20') *sticks* however, swing quite a bit unless the support tube is a lot heavier or the *stick* is braced at the top. Usually longer antennas have substantially narrower beam widths, sometimes as narrow as 7°, a swing of a few inches can lift the radiation pattern right out of a coverage area. Keep this in mind as it also effects loading and pricing.

A paging antenna for example may consist of several co-linears *inside* one (1) single **tube** all fed by one (1) transmission line. In the PCS and cellular service however each antenna is usually fed separately requiring a single transmission line for each radiating element. *Transmission lines substantially add to tower loading* by adding wind drag, additional surfaces upon which ice can form and if improperly bundled or run up the sides of the tower can even restrict additional antenna mounting. This is due to mounting positions or lines getting in the way. On FAA regulated towers, transmission lines might also need to be painted *red & white* every twenty feet (20') or so. Because transmission lines run inside the monopole they would not have to be painted using this support system.

In some cases, radiating elements known as "hairpins" are not contained within the *stick* but strapped to the outside of a tube and fed with a coaxial harness or *power divider*. This type of antenna is very versatile because each "hairpin" or dipole can be oriented to shape the radiation pattern in an infinite number of ways without being at the top of the supporting structure. Because the supporting pipe is at ground potential (hopefully), the radiating elements are not as vulnerable to lighting as they would be using the co-linear design. These antennas are practical to about 900 MHz. and are usually fed with one single transmission line. If these antennas can be mounted far enough away from the antenna supporting structure on extended brackets, the blocking effect of the tower is reduced significantly, *but loading is increased*.

Your client will sometimes object somewhat to being positioned anywhere but at the top of the tower and will usually insist upon not being *too close* to anyone else's antenna. Pattern distortion and RF interference is the concern. What you need to know here is that pattern distortion and RF interference is a function of frequency and may or may not occur as predicted by your client's adherence to a rule of thumb. In addition the effects are predictable, measurable and correctable. Which means that if concerns are voiced you must contractually control your options to place clients at their optimum location consistent with *your* objectives for co-locating additional customers. This concept was previously explored when the effects of permitting a communication carrier the option of mounting sector antennas on a building elevator penthouse wall to the exclusion of any additional client was explained. Failing to take this into account will result in significant capacity reduction on your tower limiting your revenue potential.

Another point to consider is that if one tower face or building wall points towards a major population density (service objective) which is the target of your client's radiation pattern, everyone will want to mount on this face to the exclusion of the others causing undue loading bias. A predictable tendency not easy to correct after the fact. Thus positioning of the tower legs and mounting brackets in the initial design can substantially increase the loading in a desired direction if it is considered prior to installation. This effect can creep up on you without notice so care must be taken to visually inspect a series of installations.

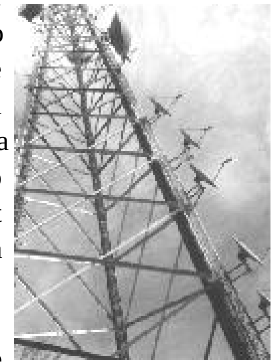

Fig. 5.12.1 Pager down-link dishes mounted low on a tower leg

Sector Antennas - Sector antennas solve many pattern design requirements for a host of telecommunication services. Consisting of moderate to high gain antennas contained in radomes, both the vertical and horizontal beam widths can be controlled or adjusted. It takes a series of three, six or nine antennas (literally wrapped around your supporting structure) to provide the desired coverage in vectors of approximately 40° to 60° degrees. In addition, sector antennas can be tilted down or up in the vertical plane to shape a pattern with a great deal of precision. Add to the fact that each antenna radiating element is fed with its *own separate* transmission line the selection of which sector to use at what time, and the power applied to that sector becomes a controllable parameter in the operation of the system. Sometimes referred to as *intelligent antennae*, better service, including service to more subscribers, better range, less noise, fewer call drops, and overall improved service will result. In addition, because these systems are wide band in nature *more than one service can utilize the same array at the same time*. A point which requires contractual consideration if you do not know what is happening.

When considering the effect of such an array upon your supporting structure it is important to note that these antennas do not need to be mounted in the clear nor at the top of your tower (if the HAAT at the mounting point is sufficient) as they have virtually no radiation or reception off the back or mounting pipe and can literally be fastened directly to the tower leg itself without pattern distortion. Secondly, remember that each antenna must be feed with its own coax cable and because the frequency is in the 800 to 2000 MHz. range, these cables are going to be quite large in diameter (typically 1 5/8" or greater). Finally, it is not uncommon for sectorized systems to evolve, so be careful to provide for this expansion at the onset. If a telecommunication company starts out with several *sticks*, but indicates that it intends to move to a sectorized antenna(s) at a later date, they may try to lock in expansion rates based upon the initial configuration, not the supporting hardware and structure involved by maxing you out at nine antennas and nine transmission lines.

Microwave and Satellite Dishes - The third type of antenna finding its way on you're supporting structure will be microwave dishes. These parabolic antennas can be very heavy, very large and when mounted inside fiberglass radomes (protection envelopes) create a tremendous amount of wind loading. So much so that many microwave dishes have built in heating elements to melt ice build up. Ice will distort the pattern and lessen path reliability so the heating elements are not primarily added to decrease your loading but to maintain dish reliability. This also means another conduit suppling AC power from mains running up your tower to the dish which is often overlooked when pricing the customer's needs and calculating tower loading. In addition, it is a common practice for microwave users to want to install an *ice shield* just above the dish which is between four to twelve feet (4' to 12') in length in order to protect the microwave antenna from ice slabs falling down from above. An ice slab may not hurt the antenna much but it sure can jerk a dish out of alignment interrupting its path. These shields also add substantially to the loading mix and must be taken into account in not only the design but the pricing of the installation. Microwave dishes should be reviewed by a professional engineer for a statement of their loading effects prior to installation and up-load paging traffic to a satellite, then distribute a single channel loaded with data to multiple transmitter sites over large coverage areas. The advantages are that telephone lines are not required and that all the transmitters in the network will receive their data simultaneously. The disadvantages are obvious. A micro meteor can wipe out the satellite and put 40 million paging subscribers "off the air" without a backup distribution plan. However the use of a satellite distribution system allows many paging companies to simulcast their paging traffic on all their transmitters at once.

Should multiple transmitters with overlapping coverages be on the air at the same time, a great deal of interference would result if the data and the frequency is not aligned carefully. In fact if *simulcasting* is done properly two overlapping signals might actually enhance each other, improving the overall paging coverage. Most of these dishes are small aperture, about three feet (3') in diameter, and are fixed (aimed) at geostationary satellites in orbit. If your site does not have a clear path towards the Western sky, low to the horizon (especially in the East) it may be necessary to mount these dishes on a tower leg.

When designing your antenna site be sure to consider aligning your shelter or building to permit mounting several of these dishes along the roof rather than using your tower. They need only be higher than the highest predicted snow fall and do not always have to be mounted on your tower.

GPS Antenna - Another small antenna utilized by communication clients is the GPS antenna. The operation of the GPS as a navigational and locating device was reviewed in Chapter Three. However another function of value to the communication carrier is the reception of an accurate time base. National Institute of Standards and Testing (NITS) timing signals are used to calibrate transmission frequencies and other system timing devices and electronic clocks crucial to proper data transmission, logging and frequency accuracy. These antennas are very small and do not need to be mounted on the tower. They are often overlooked in the facilities description in the site agreement.

Ground plane - Some antennas require sufficient space for a ground radial system mounted just below the radiating element. At lower frequencies these radial lengths can be significant and cause pattern distortion to other types of antennas mounted nearby on your tower. Ground plane antennas are usually unity gain, are omnidirectional and can be driven at high power levels. They are used primarily at Low Band 35 and 45 MHz. paging applications, rural and some UHF applications. Other variations of this antenna beam the rf energy directly up in a *cone pattern* used in some aviation applications. In general this antenna is not as common as the other arrays and will more than likely not be a significant factor to your overall plan.

Yagi and Other Specialized Antennas - Many local communication clients may use in-band, 75 MHz., 450MHz. or 950Mhz. remote stations to control their base stations or repeaters located on your tower. These antennas are highly directive and point specifically to the remote station. The only requirement is an unobstructed path to a point (in a valley below for example) where the reciprocal low power control station is located. They look a lot like small TV antennas consisting of a boom with multiple elements attached along the same plane. There are several types of Yagi antennas that create some concern for tower loading. A three to four element yagi for 75 MHz. applications, any fixed receive antenna used in the FM Broadcast Service (FCC Part 73) where a translator might be employed and finally any CATV application where receivers for TV channels two through six (2 to 6) are used. These Yagi antennas can be quite large, heavy duty and must be mounted on tower legs at various points. When icing conditions are encountered, these units can also get quite heavy and must be considered in your loading considerations. They are essentially receive only systems (except for some 72-75 MHz. applications) and use much smaller transmission cable because the frequencies utilized are lower thus reducing the loss considerations encountered at higher frequencies.

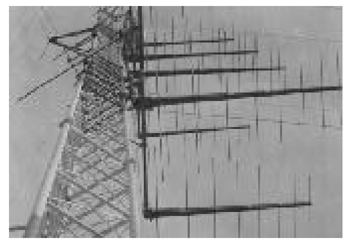

Fig. 5.12.2 Yagi antennas add substantial loading to the tower

In addition to Yagi antennas are special application antennas such as FM broadcasting or VHF/UHF TV transmitting antennas. In most cases these antennas require a top un-obstructed mounting, however there are many designs which work well when side-mounted. Usually a tower will be constructed for this application in the first place so it is unlikely you will have a commercial broadcaster as an add-on client. However, with the introduction of translators and low power TV, MDS and FM systems, add-on commercial broadcasters may still show up at some point in time. With the recent release in HDTV applications, substantial power will be required to a much heavier TV antenna. Thus a whole new class of tower is being considered. A *cooperative super tall* TV tower may be in the offering which might eventually free up an existing TV tower which incidently needs to be used for a time in supplying conventional TV service.

A word about high power TV and FM antenna systems. Should these systems be mounted at the top of your tower, some consideration should be given to the non-ionizing radiation hazard presented by these strong RF fields. Essentially having the same effect as a microwave oven on human tissue, the skin will begin to heat up slowly raising the body temperature. If the signal levels are high enough and the exposure is long enough the body temperature could be raised to a point where unconsciousness could occur. Not a good thing to happen to a technician who is climbing your tower. Notification on the tower at the point where excessive RFR is encountered is not only responsible it is the regulation. We will have much more to say on this subject in Chapter Nine.

5.13 Significance of Positioning and Combiner Technology

The type of antenna, mounting hardware and how it is fed to the transmitter becomes a significant consideration when determining tower loading vs. pricing. A single "stick" fed with one transmission line, may in fact be a combination of several antennas within a fiberglass tube or mounted on a pipe. The antenna may be used for both transmission and reception simultaneously with the use of special duplexing equipment or a two-conductor transmission line in what appears to be a single cable.

Some system operators, realizing that reception systems can be contaminated by transmission facilities operating too close reserve the upper most portions of their tower for reception systems allocating a lower portion for transmission and microwave applications. This would only be possible if a good deal of the tower height is at usable HAAT and not just there to position an antenna above the tree-line. For example, if a four hundred foot (400') guyed tower on a hill top provided clear coverage above the trees from the one hundred foot (100') level to the horizon, then about three hundred feet (300') would be usable for various antenna mounting applications. Since line-of-sight from the 100' foot to 400' level would be almost equal, it wouldn't matter much where antennas were mounted. In this case the site operator designated the top one hundred feet (100') on the tower for receive only applications and transmitting antennas from the three hundred foot (300') level down to the tree-line.

As can be seen from this example, a closely guarded secret of tower height does not necessarily have to be to divulged to achieve a single desirable HAAT for one application. It can also provide a usable *range* for many co-located applications. A concept not fully appreciated by zoning boards in the past.

Should the height of the tower be fixed to a HAAT for a given application, some services might still work fairly well *beneath* the design height. If space is at a real premium, a site operator may install a single wide band antenna at the top of the tower and feed it with a high quality low loss single transmission line into a *combiner*. **www.wacomprod.com** Subscribers desiring a receive application (in addition to their transmission facilities) merely "plug" their systems into the *combiner* and share a common antenna.

Combiners also can be applied to transmission facilities as well. So theoretically for a group of 900 MHz. paging clients, a single antenna could be used by everyone. There are trade offs. Power to combined systems is wasted in the process, certain frequencies are incompatible with each other and if any part of the system is corrupted or fails, all the users go down. Objections are very vocal in these systems and must be expertly managed one hundred percent (100%) of the time with no exceptions. There is just too much at stake. Where it works, for example, is on the runway of a large airport; a single tall structure in the middle of a metropolitan area, or in an industrial park that allows *only one* antenna! That one antenna, referred to as a *must have site*, can do a substantial amount of work under carefully controlled conditions. An RF consulting engineer can put such a system together and there are several companies that manufacture highly reliable *combiners*. **www.telewaveinc.com** The technology exists but it is not the preferred method of site utilization. However sometimes it's the only ball game in town.

5.14 Tower Lighting Systems

We will have a whole lot more to say about tower lighting systems in a later chapter but for loading considerations it is safe to say that the top position on the tower, conduits and heavy mounting accessories are all part of the FAA requirement when tower lighting is necessary. These systems can be extensive and costly requiring maintenance and monitoring with severe penalties levied upon the site owner if anything goes wrong. Towers are lighted because it has been determined that they represent a possible hazard to aviation operations. Fortunately the criteria under FCC Part 17 is fairly straight forward and there is not a whole lot of confusion as to what is required and how the system should to operate. In recent actions however, zoning boards (am I picking on them again?) in their zeal to "protect the public" have created some rather absurd regulations. In one instance there was that requirement to paint a monopole *sky blue* so that it would "blend into the sky". In another we were required to paint the PCS panels on just the antenna, *international orange* (apparently not aviation orange) to make the antenna "visible to a local ultra light aircraft operator" who used his back yard as an airstrip. Both *orders* were totally out of line with regard to FAA regulations but nevertheless were conditions in order to receive building approval. If by chance an aircraft or helicopter ever collided with the "sky blue" tower, I wonder where the liability would be directed? Or do zoning board members have *sovereign immunity*? At any rate it is best to comply with FAA regulations or at least obtain an FAA determination as to what regulations apply to your structure or building. They are obligated to provide a formal response to your formal application using their form whenever there is a question or an "order" relative to aviation hazzards related to your tower.

5.15 Intermodulation, Distortion and Interference.

Although as an antenna site owner/operator you may never be required to correct an interference problem arising between your tenants, you may be required to coordinate or negotiate a solution. Accordingly your site agreement should contain wording to the effect that you have this responsibility and right. However, usually it is the custom for any new entrant to your site to coordinate and pay for a solution to any problem which arises. The logic here is simple. If the new tenant had not installed their equipment at the site there would be no problem. Or stating it differently, if the new tenant were expelled, the problem would go away with the tenant.

In reality interference can take many forms. An example. If two tenants (number #2 and #3) each operate a paging transmitter there might be no problem at all until both transmitters are "keyed up" (turned on) at the same time. An *odd order frequency product* can be created which falls across the input band pass of another tenant; we'll call this tenant number #1. Because #1 has been there from the beginning, this tenant's control receiver is now completely useless. Who is to blame? Tenant #3 because he was the last to arrive at the site? Tenant #2? Now things get difficult.

Before you notify tenant #3 that he will have to leave your site or that his transmitter is to blame, you must make several determinations. First and foremost are all three tenants operating their systems in good engineering design? Is everyone using proper shielding, coax cables and grounding? Is the equipment modern and type-accepted? I operated a paging site a few years back which interfered with a nearby resident's TV set. No amount of engineering "tricks of the trade" nor devices solved the problem. The TV was an old black & white Silvertone-tm produced in the late fifties. The solution was to purchase the resident a new color TV which complied with current FCC regulations. The problem was never corrected but a solution was possible.

The next step is to understand what is causing the problem. Interference can take several classic forms which are well understood and pack a host of solutions to try. If transmitters are not properly aligned or are running excessive power they will spill spurious radiation out of the proper band pass causing interference. A device which allows a technician to actually *see* what is going on is called a *Spectrum Analyzer*. It will find the problem quickly, and put values on each parameter so that calculations and remedies can be tried. Are the antennas too close to each other? If the antenna is removed from tenant #1's equipment does the interference go away?

One of the most common causes of interference is intermodulation distortion (IM). When signals combine in a non-linear device they may create other undesired signals (small transmissions on other frequencies) which pass through the original transmitter amplifier tuned circuits and then are radiated out to an antenna. Often the insertion of a filter or other active device in any or all of the systems can attenuate one of the signals or both of them to the point that the offending signal is virtually eliminated and thus the problem is corrected. But non-linear devices don't have to be transmitters. They can be rusty bolts, dissimilar metals joined together, even a pile of old antennas and pipes lying out back behind the transmitter shelter. Fortunately the non-linear device doing the signal mixing, can also be located easily by using calibrated DF (direction finding) equipment or a tunable field strength meter. Can you believe that at one time I spent a couple of hours looking for a *non-linear translator* that turned out to be an old corroded door hinge? A shot of oil and the interference went away!

Another type of interference is caused by harmonic energy being improperly radiated by a transmitter which is incorrectly tuned. Usually this interference is a *direct multiple* of the actual transmit frequency or one of the intermediate frequencies used in deriving the output frequency of a given transmitter. This type of interference is relatively easy to deduce and correct as all the numbers must divide down to known frequencies.

Adjacent channel interference occurs when transmit frequencies of relatively high power are just too close (say within 100 KHz. or less) to a receiver frequency. So much energy is allowed to enter the receiver on a frequency which is close but not exactly on channel, that the desired receive frequency is *covered up* by the adjacent channel energy. Once again filters help quite a bit but nothing short of changing the frequency will completely solve this problem.

Co-channel interference and cross-talk occurs when two transmitters on or near the same frequency overlap into one receiver location. Either the transmission of one of the signals is too strong, or an antenna requires reorientation. Fortunately this type of interference is intra system and won't be a problem to other tenants. The problem however is that it may initially be diagnosed as another type of interference which gets everyone else all upset until the problem is identified.

Finally there is signal blockage which is caused when tree growth, or new construction or other new obstruction blocks a previously clear path creating a coverage problem. Most tenants will want exit clauses inserted into their agreements to allow them to move their facilities should this problem arise and not be resolvable.

You certainly do not have to be an RF engineer to manage these difficulties. There are many good texts which deal with the practical solutions to these and a host of other common and exotic interference problems. You must however keep the personalities involved calm and focused to act quickly to get to the bottom of the situation and make a decision. Failure to do so will result in your not only losing tenants but you will gain the reputation for a *dirty* site. That is the kiss of death to your marketing program and there is no need for it to happen. The site acceptance survey is one good way to screen tenants to be sure equipment will be compatible. It also provides data which can be used by your new tenant to compute probable and thus avoidable problems prior to installation. Once the problem is solved it merely goes away and everyone is happy again.

5.16 Tower Safety Equipment and Hardware.

Tucked in the back of almost every tower supplier catalog are products used for the safety and convenience of tower maintenance personnel. Towers usually have optional ladders and climbing tools as a part of the overall project which can be ordered and installed at the time of the initial construction. Most tower manufacturers have a good selection of safety materials and information concerning their products along with tips on tower safety for both installation and operation. Collecting these brochures is a good idea and lots of practical information can be obtained from them. Because you rent tower space you will more than likely have little control over who climbs your tower. You can however have posted tower climbing rules to protect you from apparent negligence. Hard hats for example *are an absolute must* when working around a tower because it is very easy for a technician to drop a galvanized *U-bolt* from the two hundred foot (200') level which can penetrate the human skull to about a half an inch or kill someone instantly. Rigging and safety belts should be sized for the man. Canvas buckets for tools and small parts, safety lines, slide clasps and pulleys allow ground crews to pull up and position heavy antennas during installation. If you indicate in your contract that experienced antenna crews must be utilized you at least will have set some standards for personnel climbing your facility. What you don't want to happen is an accident caused by the negligence or improper equipment on the part of a technician resulting in a liability lawsuit directed to you for negligence. A good defense against this occurrence will always be safe modern equipment and posted (and acknowledged) rules and regulations. And don't forget the all important waiver of liability clause!

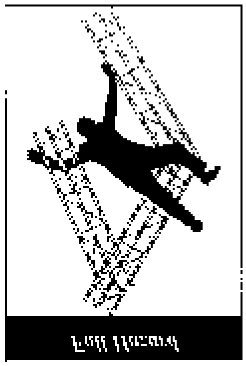

Fig. 5.16 Order safety brochure from Rohn® at 309-697-4400