Pinnacle Telecom Group

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Microwave Network Design: A Manager's Guide to the Engineering Process

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14 Ridgedale Avenue, Suite 262
Cedar Knolls, NJ 07927

Tel: 973-451-1630
Fax: 973-451-1994

www.pinnacletelecomgroup.com

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Introduction

This paper provides background on the process of engineering a point-to-point microwave radio system, and is intended as a manager's overview. The focus is not on the technical performance of each step in the engineering process, but rather the sequence of the steps and how each successive step relies for as input the information and data developed in the previous step.

Engineers have been designing microwave communications networks on a regular basis for more than 50 years, and the sequence of steps described in this paper represents a time-tested approach that, when applied, has proven to be most time-efficient and cost-effective.

Point-to-point microwave communications systems operate on a "line-of-sight" (LOS) basis, are subject to predictable propagation-related performance characteristics, must neither cause nor suffer objectionable RF interference with other systems using the same frequencies, and require an FCC license to be operated.

The paper will address, in tabular form, each step in the engineering process – highlighting the following factors:

- the specific purpose of each step and the elemental function performed;
- the necessary input data and the desired output of each step;
- the "usual" time frame; and
- what can "go wrong", and the impact on the overall process.

In addition, explanatory notes will describe, as appropriate, particular circumstances in which some of the steps in the process may be followed in a different order, for reasons of overall design efficiency.

The sequential steps we will describe are as follows:

1. Identification of Communications Requirements;
2. Selection of System Type;
3. Site Selection and Route Design;
4. Preliminary Path Profiling;
5. Field Path Surveys;
6. Final Path Profiling;
7. Path Propagation Performance Analysis;
8. RF Interference Analysis and Channel Selection;
9. Prior Frequency Coordination Notification and Response; and
10. FCC Licensing.

The use of "plain English" throughout the paper is intended to maximize clarity and understanding. In addition, please recognize that the process described here is an idealized one, nicely applicable to the average project, but not always followed to the letter in some projects (for good reason or bad). Moreover, this brief overview of the engineering process does not delve into the detailed techniques and nuances of microwave system design. Thus, we caution the reader about treating the descriptions provided here as a sort of “Bible”. Experienced engineers know that different projects occasionally require some modification of the normal design process, and they either wisely suggest it when it is appropriate, or otherwise adapt to clients’ particular needs as best they can.

Any questions about the material in this paper can be directed to Dan Collins at 973-451-1630, extension 102.

Step 1. Identification of Communications Requirements

PURPOSE	❑ Information developed in this step drives the entire rest of the process. What points need to be connected, with what capacity, and with what level of performance?
INPUT DATA	❑ Client-provided information on desired points of communication and necessary capacity – information sometimes developed with the assistance of an equipment manufacturer or consultant. ❑ "Industry-standard" per-link propagation performance requirements range from a minimum 99.999% availability (about 300 seconds of outage a year) to 99.9996% (about 125 seconds).
PROCESS	❑ Best-case scenario: "I need X capacity between points A and B (and C, D, …)" ❑ Worst-case scenario: "I have no clue." (That's okay, though – experts can help a client build the plan.)
OUTPUT	❑ Points of communication. ❑ Required capacity between points. ❑ Specified performance objective(s).
TIME FRAME	❑ Depends on complexity of the project.
CAUTION	❑ If the first step in the process is not right … ❑ … but that doesn't necessarily mean that as the project progresses there is *zero* flexibility; we recognize that new or changed needs may be identified as projects evolve – but each one will have to go through the sequential engineering process, and the changes could involve iterations of work already completed for other parts of the network.
SEQUENCE VARIATION	❑ None. This always comes first, although all of this work may already have been done by the client before contacting a microwave engineer or vendor. (See Step 4.)

Step 2. Selection of System Type

PURPOSE	❑ Selection of a frequency band and type of system are basic inputs to drive the rest of the process.
INPUT DATA	❑ Points of communication. ❑ Capacity requirements for each link.
PROCESS	❑ Distance between points of communication determines usable frequency bands, as propagation characteristics of different frequency bands (combined with available technologies) effectively subject them to different maximum practical link lengths. ❑ Capacity requirements also determines frequency band, as the FCC channelization and maximum bandwidths allowed in different bands effectively set maximum per-channel and system capacity.
OUTPUT	❑ Frequency band. ❑ System technical characteristics (channel bandwidth, maximum transmitter power, noise and interference thresholds, typical range of antenna size and effective gain, and antenna line loss characteristics).
TIME FRAME	❑ From a few minutes to a few hours.
CAUTION	❑ Depending on the distances between desired points of communication, the initially-desired frequency band may later be changed (as each band has practical limits on maximum link length) – or intermediate repeater locations may have to be selected and used to stay within link length limitations.
SEQUENCE VARIATION	❑ This is the usual and necessary second step. The frequency band and system characteristics are important inputs for the work that follows. ❑ However, the selection of frequency band and particular system are subject to change if subsequent engineering says “no go”.

Step 3. Site Selection and Route Design

PURPOSE	❑ To provide at least a preliminary network layout to start the engineering work.
INPUT DATA	❑ Points of communication. ❑ Frequency band. ❑ Possible limitations on antenna heights, placement, type of antenna lines, etc.
PROCESS	❑ Loosely speaking, it's a "connect the dots" exercise, done in such a manner as to minimize the necessary number of lines (each link costs money).
OUTPUT	❑ Site locations (and limitations). ❑ Route layout.
TIME FRAME	❑ Varies widely (and sometimes wildly).
CAUTION	❑ Accurate site location data (latitude and longitude) is critical in the work that follows. ❑ Site selection "on the fly" is generally more expensive than when office-based homework has been done.
SEQUENCE VARIATION	❑ (See Steps 1 and 2.)

Step 4. Preliminary Path Profiling

PURPOSE	❑ To determine, at least on a preliminary basis, whether links between specified points are feasible, based on early estimates of necessary antenna heights to achieve line-of-sight. ❑ To identify critical points along each path that require on-site inspection to accurately determine the existence and height of potential obstructions over which the path must pass.
INPUT DATA	❑ Points of communication, identified by latitude and longitude (each accurate to the nearest second, or about 50 feet). ❑ Frequency band.
PROCESS	❑ A vertical-plane graphical representation of the path, called a *path profile*, is created for each link to show the height of terrain and

	assumed natural obstructions (trees) along the path. Terrain elevation data comes from digitized maps, and detailed checking of "critical points" (in terms of possible path clearance) is done using the highest resolution USGS maps. ❑ Antenna heights are set to provide appropriate path clearance over those potential obstructions – on a <u>preliminary</u> basis (because we cannot tell in the office and from USGS maps how tall any potential man-made obstructions may be, and sometimes the actual tree heights are different than assumed at this stage).
OUTPUT	❑ Preliminary antenna heights. ❑ Possible "no-go" decision if heights are excessive. ❑ Identification of critical locations along the path where path clearance needs to be set with accurate, "real-world" information on obstruction heights – information that will be collected during later field path surveys (Step 5).
TIME FRAME	❑ About one to three hours per path.
CAUTION	❑ If the input data – specifically the latitude and longitude of the sites in question – is not entirely accurate, this step and all the steps that follow will have to be repeated.
SEQUENCE VARIATION	❑ Some clients, knowing what they want and something about microwave systems, start the engineering process at this point.

Step 5. Field Path Surveys

PURPOSE	❑ To collect "real world" data on potential obstruction heights, so that (in the subsequent step) final antenna heights can be set to provide appropriate path clearance.
INPUT DATA	❑ Initial path profile. ❑ USGS map(s) with end points identified, the path line connecting them, and critical points noted along the path.
PROCESS	❑ Experienced field crew examine the end points, confirm latitude and longitude, as well as other information about the sites, and then walk or drive the path line and collect data on the existence and height of both natural and man-made obstructions, paying special attention to the "critical points" identified in the initial path profiling. Photographs are typically taken of critical obstructions.
OUTPUT	❑ Accurate, "real world" information on obstructions and their heights, to be used to finalize path profiles and antenna heights.
TIME FRAME	❑ Can easily run three or four hours per path – and sometimes more, depending on particular path characteristics and ease of access to the path line.
CAUTION	❑ If the site coordinates (latitude/longitude) used going into this step are not accurate, this effort may be completely wasted and have to be repeated. Too often, survey crews find errors in site locations, and work must be delayed while path profiles and path maps are adjusted.
SEQUENCE VARIATION	❑ In metropolitan areas (populated with many tall buildings), it is often more efficient to perform this step before even constructing an initial path profile. For example, it may be easy to visually confirm line-of-sight from one building to another.

Step 6. Final Path Profiling

PURPOSE	❑ To set final antenna heights.
INPUT DATA	❑ Preliminary path profile. ❑ Results of field path survey.
PROCESS	❑ The preliminary path profile is modified to incorporate "real-world" obstruction height data, and antenna centerlines are set to provide appropriate path clearance.
OUTPUT	❑ Final path profile and antenna centerline heights. (A path engineering report is provided with that information, as well as photographs of key obstructions.)
TIME FRAME	❑ An hour or less to determine final antenna heights, and some additional time preparing the path engineering report.
CAUTION	❑ None. Field path surveys are the best way to assure proper line-of-sight clearance. (There is always a risk taken in settling on antenna heights and line-of-sight simply based on an office-based path profile.)
SEQUENCE VARIATION	❑ (See above.)

Step 7. Path Propagation Performance Analysis

PURPOSE	❑ To determine whether performance will meet expectations, or the path's technical parameters should be modified (or the network necessarily be re-designed) to meet the specified performance criterion.
INPUT DATA	❑ Path length, frequency band, and system technical data (transmitter power, antenna gain, antenna line loss, noise threshold). ❑ Specified link and network performance criteria.
PROCESS	❑ The above inputs are fed into standard formulas used to predict link "availability" (or, conversely, outage time). ❑ If the specified per-link performance criterion is not met, it is possible that the combination of links still meets the overall network performance criterion, and missing

	the criterion on one (or more) links is acceptable. Antenna space diversity or larger antennas may help meet the per-link criterion. If those are not sufficient, it may be necessary to use shorter path lengths (i.e., re-design the network using existing sites, or add repeater sites). The last resort: accepting slightly sub-standard performance because the cost of a fix is simply not worth it. Note that the worst effects of refractive multipath fading normally occur around 2 a.m. for a few evenings in the Spring and Fall. Perhaps the risk is manageable. In addition, in the frequency bands affected by rainfall attenuation, a link may get absolutely “bombed” once in a ten-year period (hopefully not in the first year), and get along nicely otherwise. The rain statistics used in path analysis are long-term, and are probably only accurate when applied to a ten-year period.
OUTPUT	❑ Confirmation that the performance specification will be met, at least on a predictive basis.
TIME FRAME	❑ An hour or less.
CAUTION	❑ Performance calculations are based on mathematical models of long-term propagation characteristics and, as such, are no real guarantee of short-term performance.
SEQUENCE VARIATION	❑ In frequency bands subject to rainfall attenuation, this step should probably be done before route design, to ensure maximum practical path lengths are not exceeded in the initial design.

Step 8. RF Interference Analysis and Channel Selection

PURPOSE	❑ To determine whether "interference-free" channels are available, and sufficient number of them to satisfy the capacity requirement. (Note that no service is actually "free" of any interference; the term "interference-free" is used to mean the interference levels are within acceptable limits.) ❑ To develop information necessary for the next-step FCC-required prior coordination notification.
INPUT DATA	❑ Station locations (lat/long), respective ground elevation AMSL, frequency band, respective antenna types and AGL centerlines, transmitter power, receiver interference threshold (based on channel capacity and equipment type)
PROCESS	❑ The above data is fed into computerized interference analysis programs and databases of systems using the same frequency band, interference levels are calculated, and comparisons made to standard interference-protection objectives. ❑ If objectives are not met, changes in parameters such as antenna patterns may resolve the problem.
OUTPUT	❑ Identification of "interference-free" channels. ❑ Possible changes in intended antennas, to avoid interference problems by using better radiation patterns.
TIME FRAME	❑ Several hours per path.
CAUTION	❑ While there may be reasonable confidence about channel selection at this point, final assurance of an "interference-free" operation is not really provided until the next-step frequency coordination notification-and-response process has been completed.
SEQUENCE VARIATION	❑ There may be specialized circumstances – such as known frequency congestion problems – that might suggest performing this step before a field path survey, for reasons of efficiency and cost.

Step 9. Prior Frequency Coordination Notification and Response

PURPOSE	❑ To satisfy the FCC requirement for frequency coordination, and to obtain assurance of non-interference.
INPUT DATA	❑ All system technical data (save the performance calculation).
PROCESS	❑ Prior coordination notifications (PCNs) must be distributed to the operators of all other systems sharing the same frequency band within the coordination distance (up to 250 miles for other microwave systems, and often farther for satellite earth stations). Most operators have "designated frequency coordination agents" to whom the PCNs are sent. ❑ Other parties are given approximately 30 days to review and respond to a PCN. The response can either be a "clearance" (i.e., okay to go) or an objection related to potential interference. If no response is received within the FCC-specified 30-day response period (plus a few days for time in the mail), the regulations allow for treatment of "no response" as "no objection".
OUTPUT	❑ Identification of "interference-free" channel frequencies, along with all final system technical parameters.
TIME FRAME	❑ About 35 days (if there are no objections received from other parties), but longer if there are objections that require resolution (perhaps an additional two to four weeks).
CAUTION	❑ There occasionally can be "surprise" objections, when two different parties issue PCNs for conflicting paths at roughly the same time (so neither party had access to the other's information in advance, and could perhaps design around it).
SEQUENCE VARIATION	(See Step 8.)

Step 10. FCC Licensing

PURPOSE	❑ To obtain authorization to operate the system.
INPUT DATA	❑ All system technical data, plus certain administrative data on the licensee.
PROCESS	❑ Preparation of FCC Form 601. ❑ The FCC now requires the license application be filed electronically, using its Universal Licensing System (ULS). If a licensee provides us with its ULS ID and access password, we can create the application and store it in the system for the licensee's review and electronic submission; without the ID and password, we can only provide a hard copy of the necessary inputs, which the licensee will have to input into the system.
OUTPUT	❑ Submission of the FCC license application normally allows operation to commence immediately. (You don't have to wait for the FCC to provide a hard-copy license.) Please note the "Caution" below.
TIME FRAME	❑ Usually about two hours – but longer is a waiver request needs to be included.
CAUTION	❑ If an FCC license application includes a request for any waiver of the FCC Rules, operation <u>cannot</u> begin until the FCC acts on the waiver request. The most common waiver request involves use of frequency bands shared with satellite communications, and the FCC requirement for a waiver to be granted in each case a microwave antenna's main axis points within two degrees of the geostationary satellite orbital arc. Even though such waivers are always granted by the FCC, this typically delays operation by three months. (A radiated power limitation applies, but typically has no effect on system design.)
SEQUENCE VARIATION	❑ This step is always last.

Conclusion

Hopefully, the foregoing provided useful background on the process of designing a microwave network and engineering the individual links that comprise it.

The process is designed to work smoothly and efficiently, and it does do that. Experience, however, shows that occasionally one or more steps in the process result in a "no go", and portions of the work have to be repeated. That is actually a normal (and effective) part of the process, and indeed the sequence of steps is designed to either smoothly go from start to finish successfully, or at least obtain a legitimate "no go" result as cost-effectively as possible. In other words, if a plan is eventually going to be determined to be infeasible, it's better to find out as early as possible.

The cautions we offer the reader are as follows. First, if input data is not accurate, work (and money) will be wasted; take the time to avoid the "garbage-in, garbage-out" syndrome. Second, if there are unnecessary "rushes to judgment" and the normal sequence is not followed, the overall engineering costs will likely be much higher than they could have been, as portions of the process are necessarily repeated. Remember that the process sequence is designed to deliver critical information to each successive step. When the steps are taken in order and no roadblocks are encountered, the money is well spent. Even if legitimate roadblocks are encountered, the money is still well spent as long as little as possible was spent determining the roadblock. But your money is badly spent when it is unnecessarily spent.

Pinnacle Telecom Group, LLC

14 Ridgedale Avenue – Suite 262
Cedar Knolls, NJ 07927-1106
Tel 973-451-1630 Fax 973-451-1994

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