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Knowledge based designing of broadband coaxial cable networks

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ABSTRACT

The objective of this research was to build a broadband coaxial cable network. One of the basic requirement of a network is the physical link transmission medium. For the purposes of this research, broadband coaxial cable was chosen as a physical medium of data communication. The approach taken in this research was to divide network design into three main steps. In the first step, the decision on topology of the network was determined. Both Star and Minimum Spanning Tree topologies were used and then the Esau-Williams Algorithm was employed to minimize the cable length. In the second step, various signal levels of the system were determined based on the longest cable route identified in the topology designed in the first step. In the third and final step, based on the previous steps, the active and passive devices were laid out in the cable route and their effects on signal levels along the cable, including cable attenuation, selecting tap values, frequency response and equalization, peak-to-valley response, tilted system operation and equalizer value calculations, were considered for the system layout.

The validation approach taken in this research was to examine the designed network and to determine wheather it met the MAP/TOP broadband specification. If the input/output levels of the design complied with the required system performance parameter, the results of the network design would also comply with the MAP/TOP broadband specification.

The tree structure of the network was then decomposed into a series of parent and child relationships with new constraints which met the overall constraints of the entire network. Devices were laid out according to the design parameters determined during system design which were in tern, based on MAP/TOP broadband specification and it had been demonstrated that prototype dBLAN produces a broadband cable cable network design which met the MAP/TOP broadband specification which verified and validated the developed system.

KNOWLEDGE BASED DESIGNING OF BROADBAND COAXIAL CABLE NETWORKS

Masters Thesis

by

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Approval Sheet

Title of thesis: Knowledge-Based Design of Broadband Coaxial Cable Networks

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CHAPTER 1

INTRODUCTION

The techniques and the devices of the broadband cable plant are well developed; the standard is established; it does provide reasonable bandwidth; and it has been proven to be cost-effective as seen by its widespread use in the Community Antenna Television (CATV) industry.

One of the basic requirements in a LAN is a physical link transmission medium. For the purposes of this research, broadband coaxial cable is chosen as the physical medium of data communications. Computer Local Area Networks (LANs) can help collect and deliver data for processing into useful information. Networks are invaluable in controlling and integrating physical automation processes. The automation of factories depends on rapid communication among a wide variety of equipment. This research is directed at the design the of physical medium in accordance with MAP/TOP Broadband specification for the local area networking requirements.

A network properly designed can be easily maintained and expanded. Systems built according to sound principals can be upgraded smoothly in the future to support new services, greater traffic, and new communication devices.

Three main steps can be identified in a cable plant design.

1. The inter-building topology of a network is determined when a LAN covers several buildings. The inter-building topology is determined for each building with the identification of tap locations in the building.
2. Various signal levels are determined based on the longest cable route identified in the first step to satisfy the system specifications. This step is called "SYSTEM DESIGN."
3. In this step the active and passive devices are placed in the right place along the cable route based on the result of the previous step. This step is called "SYSTEM LAYOUT."

Both inter- and intra-building topologies are heavily dependent on the requirements of a user. A typical intra-building topology originates as a utility, i.e, it aims to make cable system accessible at any point in the building. Therefore, the locations of taps dictate the intra-building topology. In this research the term "topology" is used for inter-building topology unless stated to be otherwise. There are no widely used systematic approaches for establishing LAN topology. The Esau-Williams algorithm is used to find a topology which minimizes the total distance between buildings.

The system design can be implemented reasonably well with trial and error approaches because the design steps are mostly algorithmic and engineering judgements are required in estimating system parameters which are unknown. The task in this step is how to find inputs and outputs of various amplifiers and facilitate future expansion.

The system layout involves many decisions such as what kind of a device to use for splitting the signal power. Such decisions are difficult to investigate with algorithms. All three steps mentioned above have elements for implementation as Knowledge-based systems. When developing the knowledge-based system, the domain of speciality should be limited. In this research the system layout phase (step 3) of coaxial broadband network design is chosen as the domain of interest for the knowledge-based (KB) system. The first two steps are implemented using conventional (algorithmic) programming approaches, and the third step is implemented as a KB system.

1.1 Needs for the Research

Broadband coaxial cable systems use the components and basic technology developed for CATV cable systems, nonetheless, the design of LAN cable systems differ from the design of CATV cable systems in several respects:

- Most CATV cable systems are designed to carry signals in one direction from headend to subscribers. LAN Cable systems support two-way communication. Design of two-way cable system is significantly more difficult than design of one-way cable systems.
- CATV cable systems are designed to operate primarily in an outdoor environment while LAN cable systems are designed primarily for an indoor environment. LAN cable systems may require special

provisions for hostile industrial environments and building code requirements.

- Bandwidth for each channel in CATV is 6 MHz. In Manufacturing Automation Protocol (MAP)/Technical Office Protocol (TOP) broadband systems, unlike CATV systems, each user has his own requirements. A MAP/TOP broadband cable system requires large bandwidth, and two or three 6 MHz channels are combined for 12 or 18 MHz bandwidth. Also there is a need to subdivide a 6 MHz channel into several smaller subchannels for data and voice communications.
- The size of LANs is generally smaller than that of CATV system. Therefore, the number of trunk amplifiers required are usually less than that of CATV systems.
- Reliability and maintenance aspects of LANs are critical compared to a CATV system since equipment costing millions of dollars may sit idle if the communication network breaks down.

1.2 Research Procedure

The research procedure is composed of following steps:

1. Literature survey – This is to establish the unique contribution made by this research.
2. A sample problem – An example problem is the base for the development of the KB system. Based on this problem, different possibilities are added to reflect real world problems
3. Using the sample problem, appropriate knowledge representation and control schemes are developed.
4. Programing for designing network topology – The Esau and Williams algorithm is used to find the topology of the inter-building networks. The coding is done in Allegro Coral Lisp (version 1.1) on a Macintosh computer.

5. Writing of programs for system design – Based on the topology determined,system signal levels are determined within the required specifications. The coding is done in Allegro Coral Lisp on a Macintosh Computer.
6. Building a KB system – All coding is done in Allegro Coral Lisp on a Macintosh computer.

The overall structure of the system is shown in figure 1. The three main blocks of subproblems are identified for a design of broadband cable network as shown. The first block (Topology Block) determines how to connect buildings to minimize the cable run. The second Block (System Design Block) determines useable gains input/output (I/O) signals levels of amplifiers so that the cable system meets the specified requirements and specifications. The third block (System Layout Block) places active and passive devices in the right place on the cable route according to the results from block I and II.

1.3 Scope, Assumptions and Limitations

In order for this research to be meaningful and manageable, the following assumptions and limitations are utilized

- The system layout phase of the coaxial broadband network design is chosen as the as the domain of interest in the research of the KB system. The important thing to keep in mind in developing a KB system is to limit the domain of application.
- Minimization of total cost is not the ultimate objective. A satisfying approach to design is significant for purposes of this research. Thus mathematical optimization with regard to the cost is not pursued. Instead,heuristics are used to strike a balance between costs and system performance.
- Headend configuration – Although important in overall network design, detailed configuration of the headend devices will not be considered.
- Single cable – Single cable design will be considered.

- Redundancy – Redundant devices and cables for reliability are not considered.
- Installation for the status monitors is not considered.
- Power for the amplifiers is not considered.
- Installation, maintenance and alignment of the cable system will not be considered.
- Product specification (cables, taps, splitters, amplifiers,etc.) – The specifications of devices vary depending on vendors. Devices from one particular vendor are used for simplicity. If necessary, certain parameters of network devices are simply assumed.
- Distance is the major cost driver in the inter-building topology design.
- Design will be used on the MAP/TOP Broadband Specification. Subnetworks such as carrierband networks will not be considered.
- User friendliness – Though this is important in commercial products, but it is not an overriding consideration in the prototype system developed in this research.
- Output format – Results are frame of all nodes which contain all necessary design information. The information concerning each node is made available with simple commands while the system is in use.
- Maximum frequency considered is 450 MHz and the "High-Split" case is assumed.

The major motivation behind the actual implementation of a KB system design procedure for the cable plant is to be able to evaluate, using the practical example, how Artificial Intelligence (AI) techniques can be applied to a broadband cable network design problem.

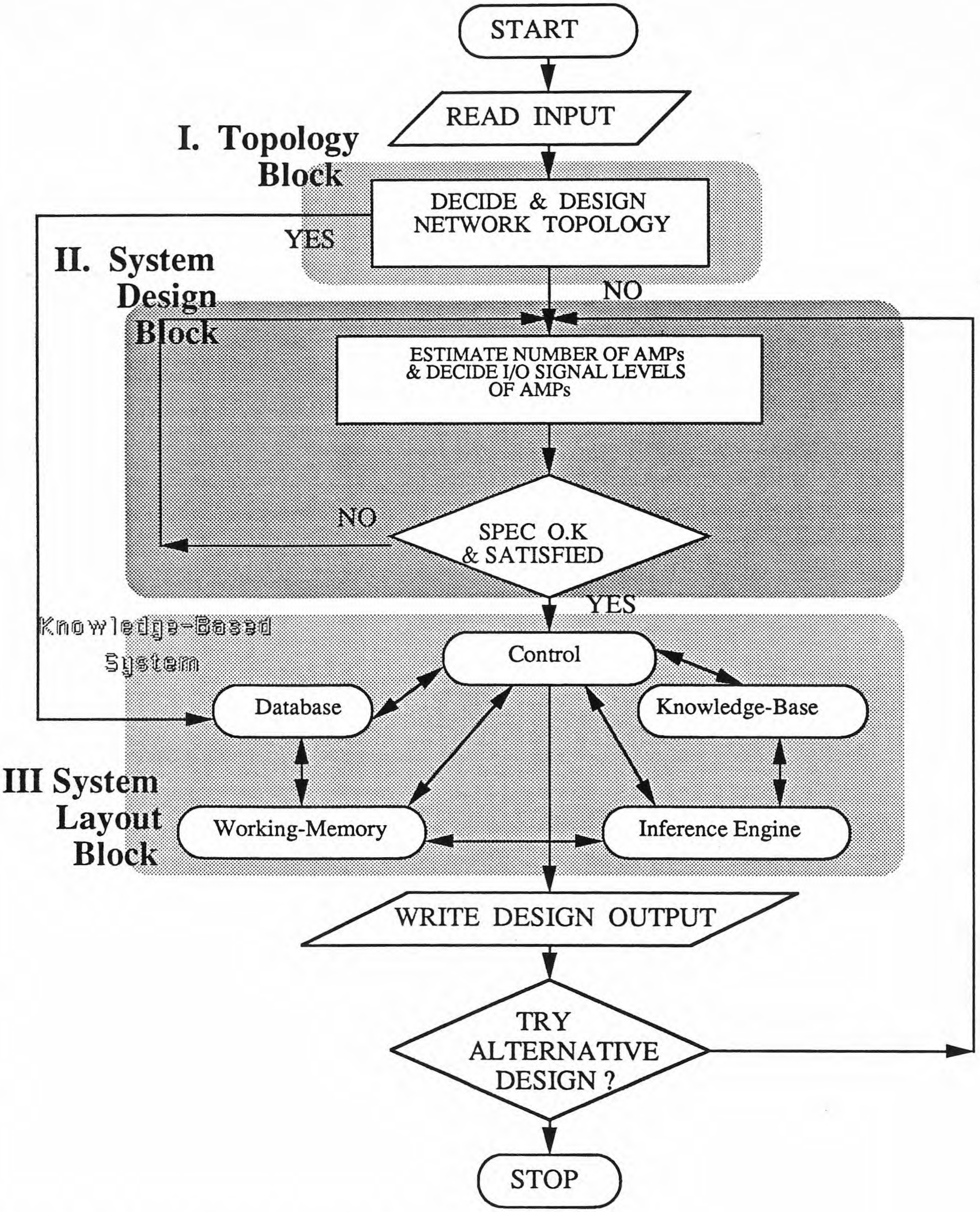


Figure 1-1. Flow diagram of broadband design system.

CHAPTER 2

PROBLEM IN DESIGNING COAXIAL BROADBAND NETWORK

2.1 INTRODUCTION

A Hypothetical broadband network design problem is given in this chapter to convey the nature of situation under the study. Consideration is given to the topology design, system design and system layout phases and the problems associated which each phase are discussed. Details are given in later chapters.

The purpose of the network is to provide communication from every node to all others. A signal from the headend is sent to all the nodes in the network. The signal at any node must be strong enough for a device on that node to be able to duplicate correct information as originally sent. Likewise, a signal from a device should reach the headend with enough signal power wherever that device may be located in the network.

2.1 Basic Steps in Designing

The problem in designing a broadband coaxial network is divided into three basic steps. The first step is how to connect buildings when a network covers several buildings. The second step is how to determine input/output levels and gains of various amplifiers in the network to satisfy the requirements and specifications. The third step is how to select devices along the cable route to satisfy the signal requirements in every node in the network. An example broadband network problem is used to discuss these issues.

Figure 2-1 shows a hypothetical multi-plant factory complex which requires a MAP/TOP broadband network. Heavy tap concentration areas are identified as circles and labeled as plant 0,1,2, ..., 9. It is assumed that the area covered by each circle is large and the tap concentration of each circled area is heavy. In the case of small size networks, the network design problem corresponds to one circled area. The connection point in each

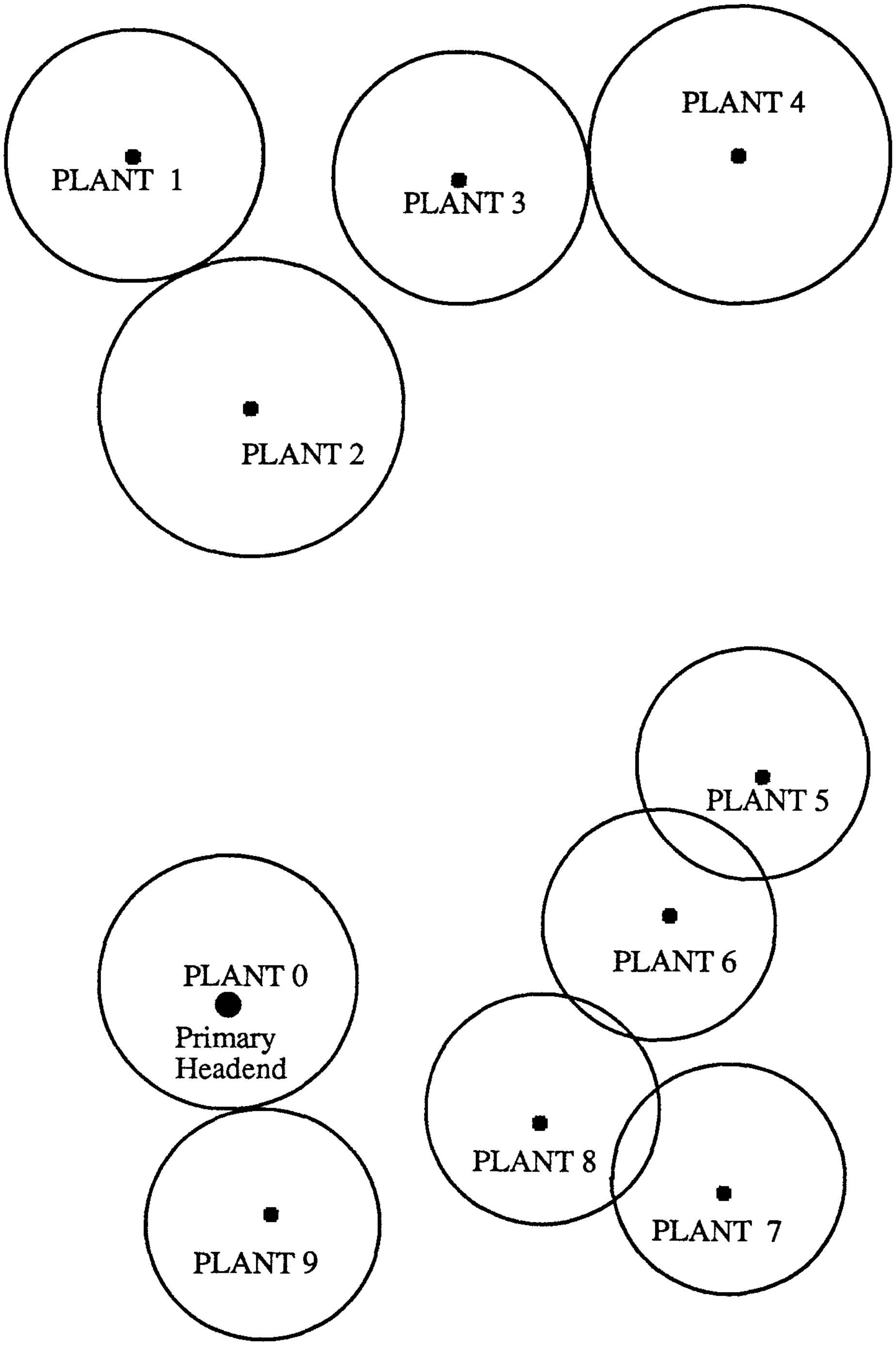


Figure 2-1. A hypothetical layout of a factory and plant locations.

Node	0	1	2	3	4	5	6	7	8	9
0	-	2100	1340	2400	3140	2460	1960	1940	1420	740
1	2100	-	1240	1340	2460	2880	2800	3360	2860	2840
2	1340	1240	-	1060	1960	1780	1620	2160	1640	2000
3	2400	1340	1060	-	1100	1800	2000	2800	2400	3040
4	3140	2460	1960	1100	-	1500	2000	2860	2660	3700
5	2460	2880	1780	1800	1500	-	640	1460	1420	2760
6	1960	2800	1620	2000	2000	640	-	880	780	2180
7	1940	3360	2160	2800	2860	1460	880	-	460	1820
8	1420	2860	1640	2400	2660	1420	780	460	-	1440
9	740	2840	2000	3040	3700	2760	2180	1820	1440	-

Figure 2-2. Distances between hubs of the plants in feet.

building and the distances between buildings (or plants) are also assumed to be known. The connection points of nodes, represented as small black dots in the figure , may represent the location of the headend for the subnetwork in that particular plant. The distances between the plants are shown in figure 2-2. The primary headend is assumed to be located in plant 0 in the figure 2-1.

The location of taps and the distances between them are assumed to have been determined. Tap locations in one section of plant 4 are shown in figure 2-3, other sections have similar tap locations. However, the shaded areas will not be considered to make this example problem simple. In this example problem, the distance between taps is 100 feet and eight-port taps are assumed to be used. The distance of 100 feet between taps from the consideration of maximum length of drop cable allowed. From the maintenance point of view, it will be much easier to maintain the network if each branch of the tree is standardized as much as possible. The approach of design will certainly cost more. but in the event when the network goes down and if it can be repaired quickly because of the design approach used, it will eventually save extra cost.

2.2.1 Designing the Topology

There are 10 plants in the factory. What methodology should a designer use to find a near-optimum topology ? The solution approach used in this research is to find a topology so that the total distance between plants is minimized. Minimum distance between plants means that the number of trunk amplifiers used will be minimum. Consequently, the cost of trunk amplifier minimized. Since the number of trunk amplifier used is minimum, the reliability of the network will be better than other alternative topologies.

2.2.2 Designing the System

Suppose the topology of the network is determined as in figure 2-4 and the A1 node in the plant 4 sends the message to the B1 node of plant 8. The signal goes through feeder and the trunk cable of the headend remodulator H1, in frequency channel say, F11. In the Hl remodulator, the signal is demodulated and the original signal is recovered and this recovered signal is modulated back into another frequency channel, F01, and is sent through trunk and feeder cable to the B1 node. At the same time, the A2 node in plant 6

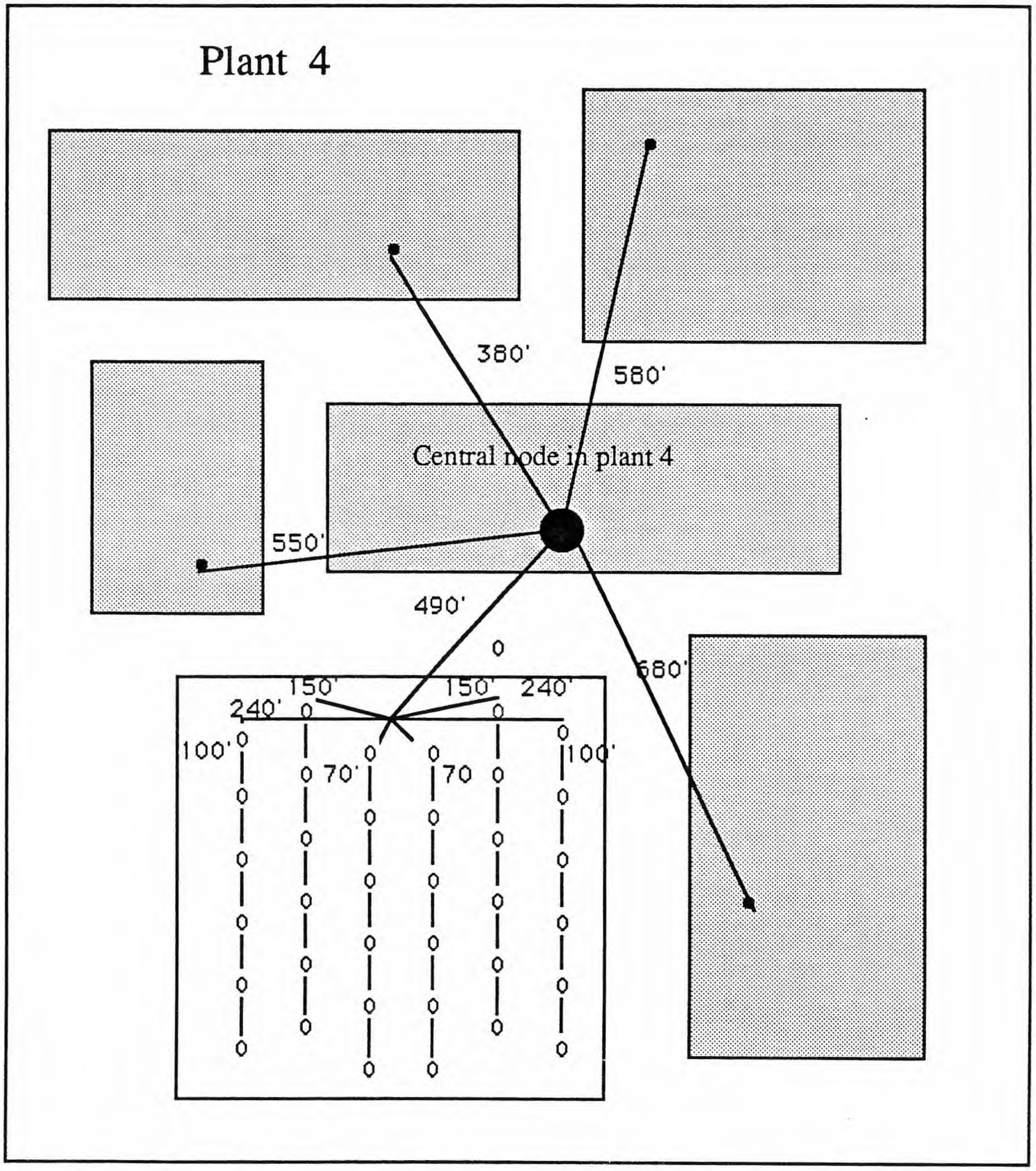


Figure 2-3. One typical section of tap locations in plant 4.

sends a message to B2 node in plant 1. The signal goes through feeder and trunk cable to the headend translator , H2, in frequency channel, F12. In the H2 translator the signal is translated to frequency, F02, and is sent through trunk and frequency cable to the node B2, etc. There are two type of signal paths in a single cable system, one going toward the headend called "inbound" and other going away from the headend called "outbound." In the example, F11 and F12 are inbound (frequency) signals, and F01 and F02 are outbound (frequency) channels.

Each signal path is further subdivided into trunk and feeder cable systems, i,e., trunk outbound, feeder outbound, trunk inbound and feeder inbound. Amplifiers used in each signal path have different parameters to suite the different characteristics of that particular path.

The problem in system design, is to determine input/output signal levels and gain of various amplifiers to meet cable system requirements. Finding the right parameters is a difficult task because a change of parameters on one path effects parameters of other paths and the noise and distortion characteristics are such that an increase in C/N ratio means a decrease in distortions performances and vise versa. The allocation of system requirements to different signal paths in order to meet total system requirements has significant effect to the cable system. Details will be discussed later.

2.2.3 Selection of Devices in System Layout

The problem in the system layout step is how to select devices along the cable route to ensure the proper signal levels in every node on the network. Constant decisions and judgements are required in selection of devices along the different branches of the network to meet requirements and specifications. A selection of device depends on the signal level at a particular point. Input/output signal levels of amplifiers must conform to the level found in the system design phase. Cable loss varies with the frequency. This results in cable tilt. An equalizer must be inserted to correct for cable tilt. Particularly, the inbound layout process is a difficult task because the location of devices are dictated by the location of outbound devices and the passive devices have the flat loss whereas cable loss dependent on frequency. Other problems associated with system layout will be discussed later

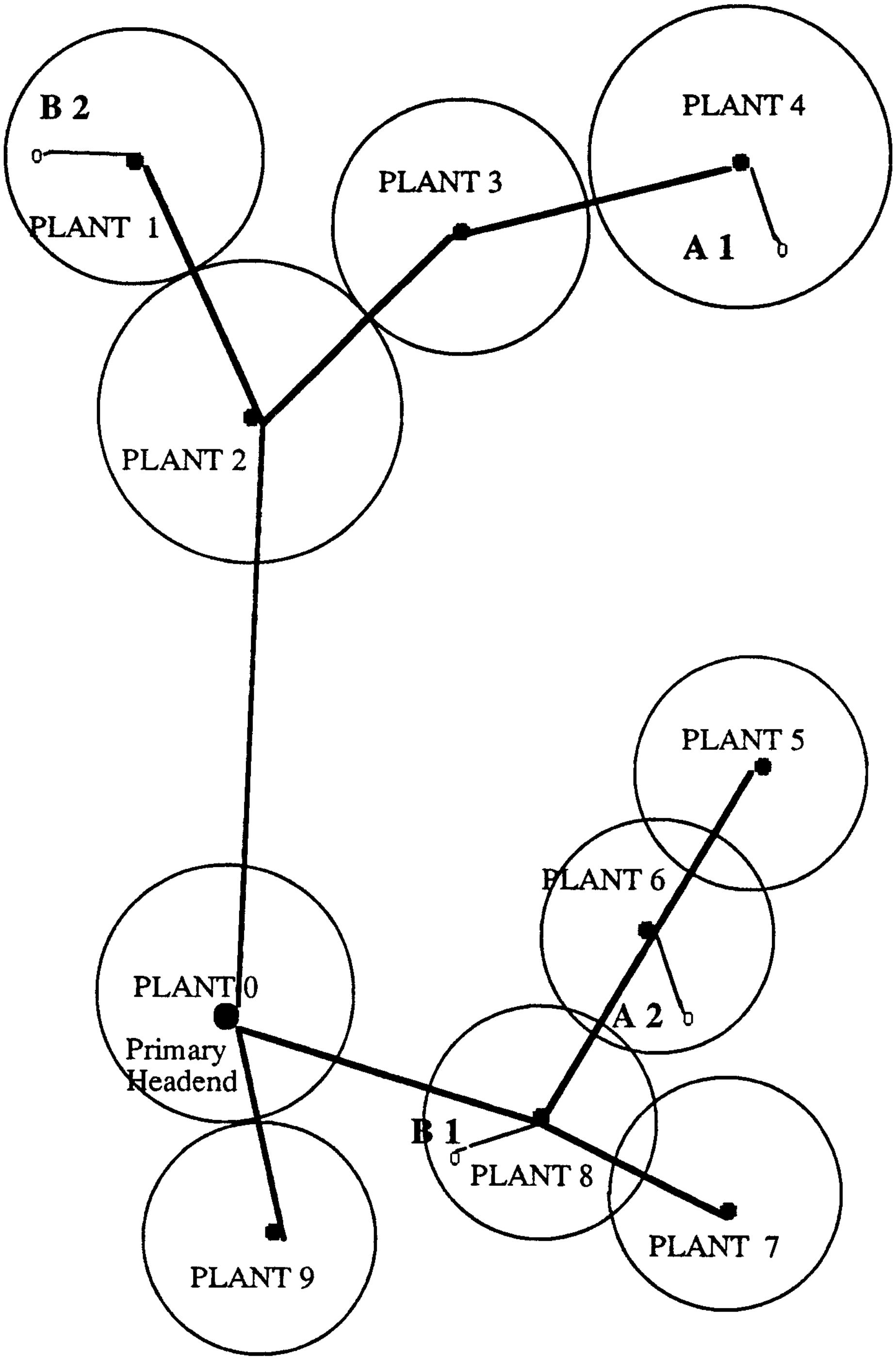


Figure 2-4. Topology of the network and locations of nodes.

Following problems must be considered in designing a broadband network.

- How to satisfy the MAP/TOP broadband specifications?
- How much future expansion should the network provide?
- How to make it easy to maintain the network?
- How to provide continuous year-round operation regardless of temperature variations?
- What are the requirements for the network? Can it be quantified? does design take such requirements into considerations?
- What size of cable should be used in the trunk and feeder
- How to allocate frequency bandwidth for different applications? What if there is conflict in assigning bandwidth?
- How to design a network which costs less and satisfies all the given requirements?

In order to deal with these problems, a knowledge-based must have ways or mechanisms to represent network design problems and control mechanism to feed certain information to the right modules in the KB system to provide knowledge. further details are discussed later.

2.2 MAP/TOP Broadband Specifications.

The following items, relevant to the research, are recommended for a general factory facility cable system configuration.

1. A 450 MHz high-split configuration to provide channel space for future devices.

2. A distributed star cable routing configuration for reliability and maintainability.
3. Interlaced distribution with staggered spacing of the taps at alternate column locations.

4. Eight -port taps.

5. Headend located in computer center.

6. Sufficient taps installed in office areas to provide one and one-half user outlets per office for every 100 square feet of open area. Each 200 square feet of laboratory or manufacturing space shall have an space outlet.

The type and size of the trunk and distribution cables should be chosen according to the application and operational environment. Some of the section criteria for cables, recommended in MAP/TOP specifications, are as follows.

1. Trunk and distribution cables shall be either 0.500 inch or 0.750 inch cable as appropriate to the design.

2. All shields shall be aluminum. The dielectric shall foam and the inner foil shall be bonded to the dielectric. The center conductor shall be solid bare copper covered steel, 18 AWG for RG-6 type and 14 AWG for RG-11 type cable.The connectors shall be the specific type required for the specific cable used.

3. Since neither the noise nor the shielding effectiveness can be completely quantified or specified, the cable system design approach is to set a maximum length for drop cable. The concept is to limit the total quantity of the flexible cable used in the cable system. Although the maximum cable length is specified, it is recommended that all drop cables should be as short as possible. Drop cable length in factory should not exceed the following lengths shown in table 2-1.

Table 2-1. Maximum drop cable length allowed.

Cable Type	Cable length in feet	
	Factory	Office
RG-6	100	60
RG-11	150	100

4. RG-59 Cable shall not be used for drop cables. It can make an intermittent connection when mated with a female connector that has previously been mated with an RG-6 cable.

5. All drop cables of the common type and the area of the facility shall be designed to have the same physical length. For example, in an office area, all drop cables may be 60 feet of RG-6 cable and in factory area, all drop cables may be 150 feet of RG-11 cable.

6. The user outlet is the end of the drop cable. Interface units can either be connected directly to the drop cable or connected to the droop cable through a user cable connecting the interface device and the user outlet. If the user cable is required, it should be of the same type as the drop cable and not exceed 15 feet in length.

The following are the summary of the requirements from the MAP/TOP Broadband specifications.

Frequency range, High-split	5 - 174 MHz (Inbound, minimum) 234 - 450 MHz (Outbound, minimum)
Path Loss _ Design	44 dB ± 3 dB (Outbound, inbound)
Path Loss _ Operational	44 dB ± 6 dB (Outbound, inbound)
System Frequency Response	< 3 dB or m/10 + 1.5 dB, whichever is greater. Where m is the number of amplifiers in cascade.
Channel Frequency Response	< 1.5 dB (across any 6MHz channel) < 2.0 dB (across any 12MHz channel) < 2.0 dB (across any 18MHz channel)

System Transmit Signal Level	< or = + 54 dBmV
Carrier -to-Noise Ratio	> or = 43 dB (outbound) > or = 40 dB (inbound)
Carrier-to-Composite Triple Beat Ratio	> or = 53 dB
Cross Modulation Distortion	> or = 53 dB
Carrier-to-Discrete Second Order Beat Ratio	> = or 60 dB
Carrier-to-Discrete Third Order Beat Ratio	> or = 60dB With 66 dBmV Test signal
Hum Modulation	< or = 37 dB
Return Loss	> or = 16 dB
Outlet-to-Outlet Isolation	> or = 25 dB.

CHAPTER 3

Designing the Network Topology

The first step in designing a network is the topology of a network. This is an important part in broadband design because reliability, maintainability, future expansion, costs, etc. depend on it. Both star and minimum spanning tree (MST) topologies deserve consideration as the topology of a MAP/TOP network.

The cable costs for a tree-type structure is inherently less costly than a star type configuration for the same centralized system application. The effort to minimize cable lengths in MST networks create critical links which increase the Interdependence of sections of the network. In this chapter the Esau-Williams algorithm is presented with modification to suit the cable network design. The algorithm first connects all terminal nodes to the center node. This is a star topology.

It then attempts to insert those links between nodes that minimize the cost. In other words, a connection to the center node is replaced with the connection to the other nodes when there is a cost reduction.

3.1 Techniques for Topology Design

There are many ways to design a network. Specific techniques have been developed for different network types, and they can be grouped into two major categories of optimal and heuristic. Optimal solution is very complicated and it is only used when practicable. Network topology design problems are NP-Complete problems. NP is the class of problems solvable by nondeterministic algorithms operating in polynomial time. NP-Complete is the term used to describe problems that are the most difficult ones in the NP problem. That is any possible optimum seeking algorithm must be computationally too large to be applied in practice, because the time required to solve the NP-Complete problem increases exponentially as the problem size increases. It is unlikely there will be a polynomial bounded efficient algorithm for NP-Complete problems.

A topological graph G(N,L) consists of two associated sets, N {1,2, ..., n} nodes and L {1,2, ...,l} links, such that each link terminates on a node. A path through the network is the consecutive sequence of nodes and links that connects two specific nodes, which will often be the source (origin) and destination (sink) nodes. If a path starts and ends on the same node it forms a loop (circuit). A graph G(N,L) is connected if there is a path between every pair of nodes, and a component of G(N,L) is simply a connected subgraph. A graph is complete if there is a link between every pair of nodes. Completeness thus corresponds to a fully connected data communications network.

A topological tree of a graph G(N,L) is a connected subgraph that contains no loops. A network in general has nodes of a connected graph and thus must consist of precisely n nodes and n - 1 links. For any spanning tree there is exactly one path between any pair of nodes, and removal of any link will disconnect the corresponding graph.

In modeling data communication networks it is desirable to associate a numerical weight with the link between each node pair. If the weight of a graph corresponds to some generalized cost to minimize, then the least expensive subgraph that connects all nodes will be a tree. If it were not a tree, one branch of a loop could be removed to get a lower cost. any particular tree for which the cost is less than or equal to all other trees is called a MST. The MST ensures that each network node may communicate with each of the others with minimum cost.

When designing a tree network with one central site (headend), if traffic flow is so small that it is never constrained, then the solution is just the MST. The CMST is the lowest-cost tree meeting all constraints.

A network topology may be developed as a hierarchy. First, the required outlets (terminal) are divided into groups, with one terminal location in each group to serve as a connection point to a feeder cable. Next the connectivity within each terminal group is established. Finally, links between local central site are established using a trunk cable. These steps may also be viewed as partitioning the network into two levels of nodes, and establishing connectivity at each level. The lower level corresponds to all terminal locations, while the higher level represents the local central site.

3.2 Access to the Cable System

Access to the cable system is through taps installed in the distribution cable. There are several ways to decide the number and locations of taps.

- The cable system is designed as a utility. A connection to the cable system can be made at any point in the buildings like an electric utility. The distribution cable routing and the tap locations are dictated by the maximum length of the drop cable allowed.
- The requirement for the distribution of outlets for connection of terminal devices may be specified. Each office is usually provided one or more outlets. Each 200 square feet of laboratory or manufacturing space shall have an outlet.
- Specify the locations of all outlets and/or communication devices to be connected to the cable system.

In this research it is assumed that that the locations of all taps are already determined, and the distances between taps and the links between them are known.

A topology algorithm consists of two parts: the first part initializes the topology, and the second part interactively improves it. The optimization step is repeated until further improvement is not feasible. The resulting network design is the output of the algorithm.

3.3 Use of the Esau-Williams Algorithm

In the Esau-Williams paper, all nodes are first connected to the center. A trade-off function is then calculated for each pair of nodes representing the savings gained by removing the central connection and creating a link connection. The algorithm then maximizes the savings. In the notation used here the trade-off function is the negative of he Esau-Williams function, and one chooses to minimize it.

Step 0. Initialize by calculating all trade-off parameters

$$t_{ij} = c_{ij} - c_{i1} \text{ for all } i, j \tag{3-1}$$

Where c_{ij} is the cost of node i to node j, and c_{i1} is the cost to connect node i to node 1. The equation measures the difference in cost between connecting node i to node j, and node i directly to center.

Step 1. Select the minimum t_{ij} and consider connecting i to j.

Step 2. Check to see if there is objection to the link selected in step 1. if yes Goto Step 3. If not, set t_{ij} to large number (or infinity), go back to Step 1 and select again.

Step 3. Add link i - j. Reevaluate the constraints and update the trade-off functions. Then go back to Step 1.

Figure 3-1 shows a flow diagram of the topology design module used to generate an initial design for the purposes of this research.Inputs into this module are distances between nodes. The distances between nodes correspond to cost of each link. If there is an objection to a certain link, the user has an option to reject it. When user objects a certain link, the topology design module puts a flag into the trade-off matrix for no further consideration of that link. The resulting topology is then used by system design and system layout phases of a network design which will be described in the next chapters.

Thus, an input file is used in the read block in figure 3-1. The next block computes trade-off matrix given by equation 3-1. The next decision block checks whether all nodes are considered. If there is a node left to consider, then the next block selects the minimum element of the trade-off matrix and requests the user to either deny or approve the link.Depending upon the response of the user, the system updates the trade-off matrix and repeats the process until all nodes are assigned.

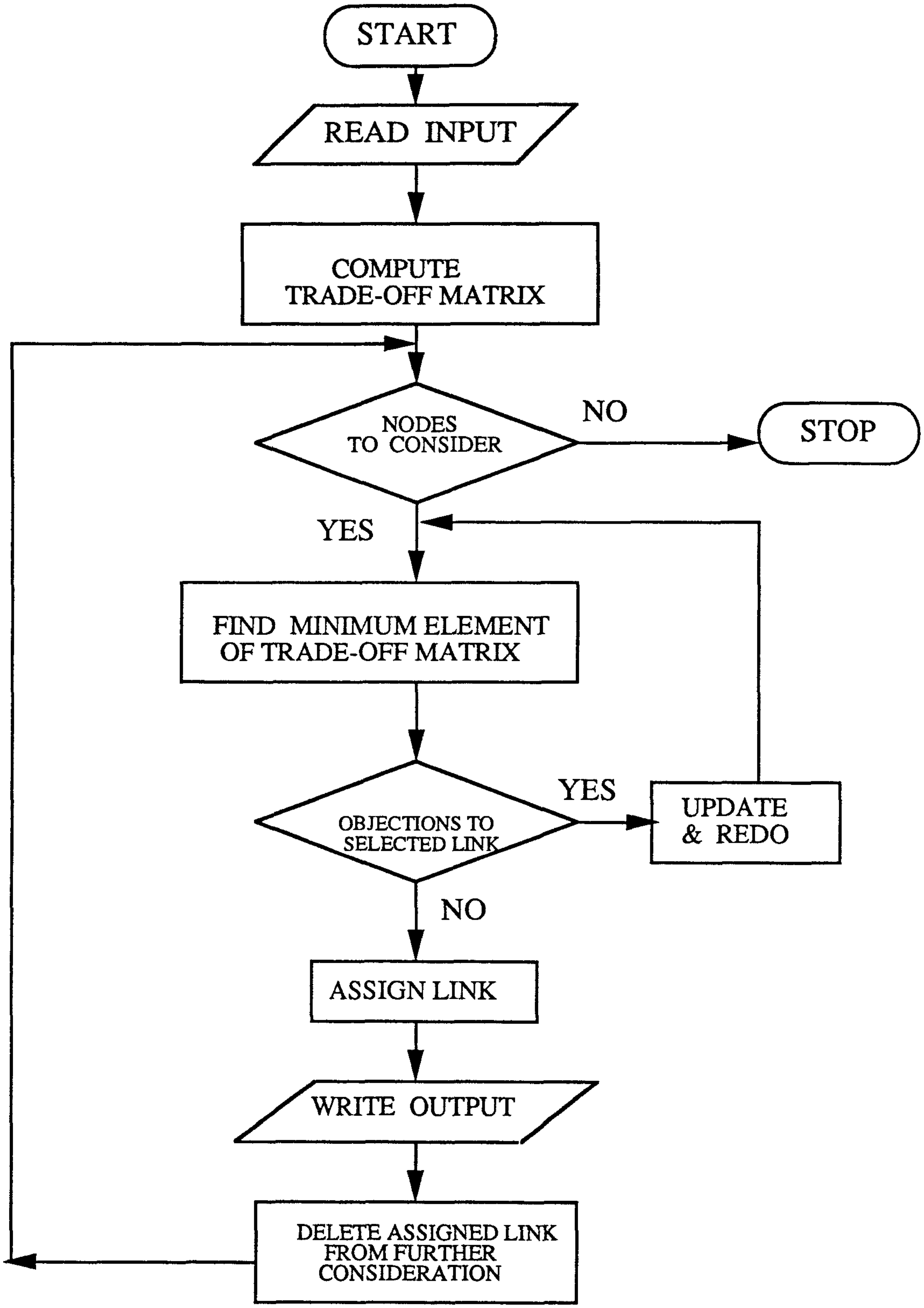


Figure 3-1. Flow diagram of the topology design.

CHAPTER 4

Design of the Broadband Cable System

The design of a broadband cable system depends to a large extent upon user requirements, such as the area covered by the network and the tap density of the network. In this research, the design of the trunk-plus-feeder concept is considered. However, this design concept can easily be extended if necessary. For example, If the area to be covered by a LAN is small, the trunk-plus-feeder concept may not be employed at all. In such a case, the feeder subsystem of trunk-plus-feeder system may be extended to provide both functions of trunk and feeder of the trunk and feeder of trunk-plus-feeder system. The logic behind the trunk-plus-feeder design philosophy is discussed in order to identify the system parameters to meet the specific requirements.

An important design goal for the CATV systems is to get a maximum reach of a system. However, in LAN systems which are limited in local geographic area, reach may not be an important issue, so a different approach from conventional CATV system design is discussed. Using maximum available gain of amplifiers used in the trunk system may be reduced. The application of this approach in a system design may provide increased reliability, ease of maintenance and reduced cost.

4.1 How to Get Acceptable Performance ?

In this system two different subsystems are designed and then combined to produce an acceptable, overall transmission performance.

Conventional trunk-plus-feeder systems have a cascade of trunk amplifiers intentionally limited in length. The trunk amplifiers employ relatively low gain, and operate with conservative low output levels. Trunk cables are usually of larger-size, lower-loss and relatively higher in cost. The trunk-plus-feeder system is utilized when tap requirements are heavy and evenly distributed throughout the service area. Under these conditions the efficiency of tapping can be substantially improved if operating signals are kept at a high level throughout the feeder cable plant. But maintaining high levels in the feeder cables requires high operating output levels in all feeder amplifiers. To make the high feeder plant distortion tolerable, the trunk plant is operated at low output levels, thus introducing relatively low distortion. Since the trunk plant operates with relatively low signal levels, the trunk plant is the major contributor of noise in the overall performance of the system.

The low gain of the trunk amplifiers and low output levels limit the trunk carrier to (C/N) ratio. At the most distant point of the trunk cable, a C/N ratio is expected to be nearly at the overall system specification. The intermodulation distortion at this same point will be significantly better than system specification requires. Thus, the system can accept relatively large intermodulation distortions from the feeder plant.

If a trunk subsystem is designed to distribute signals generally throughout the service area, this system can be designed for both sufficient "reach" to cover the basic area and deliberate distribution of noise and distortion contributions. This trunk subsystem may be operated at conservative low gain, low input and output levels with reduced amplifier spacing, but by using larger-size, lower-loss cables in the trunk system, the amplifier spacing can be improved. Using either shorter spacing or larger cable sizes in the trunk system will be more expensive. Since tapping efficiency is low when system transmission levels are low, the trunk cable will not be utilized for drop feed at all and no taps will be cut into trunk cables.

The second level subsystem is feeder cable. The feeder plant serves all service taps loads. The feeder plant can be characterized as distinctly, and intentionally, limited in the length and operating at high transmission levels throughout. Thus, the feeder plant will introduce a very nominal amount of noise but contribute substantially to system intermodulation distortion. This provides a much higher level of efficiency in tapping.

The bridging amplifiers are considered as an integral part of the feeder subsystem. It is through the use of bridging amplifiers that the transition in transmission levels, from low trunk levels to high feeder levels, is accomplished. Increasing the output levels of the amplifiers will substantially increase the distortions produced in each amplifier. In the design of a subsystem, some distortion tolerance is reserved to permit higher distortions from the feeder amplifiers. To limit the feeder distortions to acceptable levels, a strict limitation on the number of cascade of feeder amplifiers is imposed.

The overall system performance is a function of the trunk and feeder plant operating in tandem. Transmission is through the trunk system to a point where a bridging amplifier introduces higher transmission levels, and then through a limited number of line extender (feeder) amplifiers. The end-of-system performance quality is the combination of both noise and distortions produced in both the trunk and feeder systems.

Extensions of the trunk system are possible to some reasonable extent, if the original design anticipated such subsequent extensions. The extension of a feeder cable leg is limited, however, since the original design allows only a specific distortions from the feeder extensions. It is possible, during initial system layout to provide extension of selected feeder legs, But this requires a reduction in operating levels along the extended feeder to ensure that the distortions from the feeder do not exceed the original design allocation for feeder contributions.

Typical feeder limitations are one bridging amplifier followed by two line extenders. A three-line extender cascade is permitted during initial layout, but all line extender amplifier output levels must be reduced in such cases. In trunk-plus feeder system, it is not uncommon to utilize several varieties of amplifiers, and it is inherent in the design to introduce several transmission levels. Consequently, trunk-plus feeder systems are somewhat more complicated to maintain properly.

4.2 Determination of Noise and Distortion

The specifications for distribution cable plant alone cannot be established without some regard for overall system design. The modifications or changes in the cable plant specification may or may not be significant depending on the other system elements but they must be examined and considered.

The system performance specifications for both noise and distortion must be determined for the different sections of the distribution cable plant. It need not be constrained to one type of amplifier or one set of input/output (I/O) signal levels. The input signal levels to all amplifiers must be maintained at a sufficiently high level to protect the end-of-system C/N ratio. At the same time, the output levels must be held sufficiently low to ensure a tolerable end-of-system intermodulation distortion.

As a general rule, a lower-gain amplifier will always provide the longest possible cascade of amplifiers and produce the highest quality of transmission for a given length of system. It will always require more amplifiers, however, a cost penalty not only in initial system construction but in long term system operation and maintenance as well.

The trunk cable will be feeding signals into feeder cable plant. Since the trunk will be followed by a substantial contribution of both noise and distortion from the feeder cable plant, it must be designed conservatively. The noise and distortion from the trunk will be

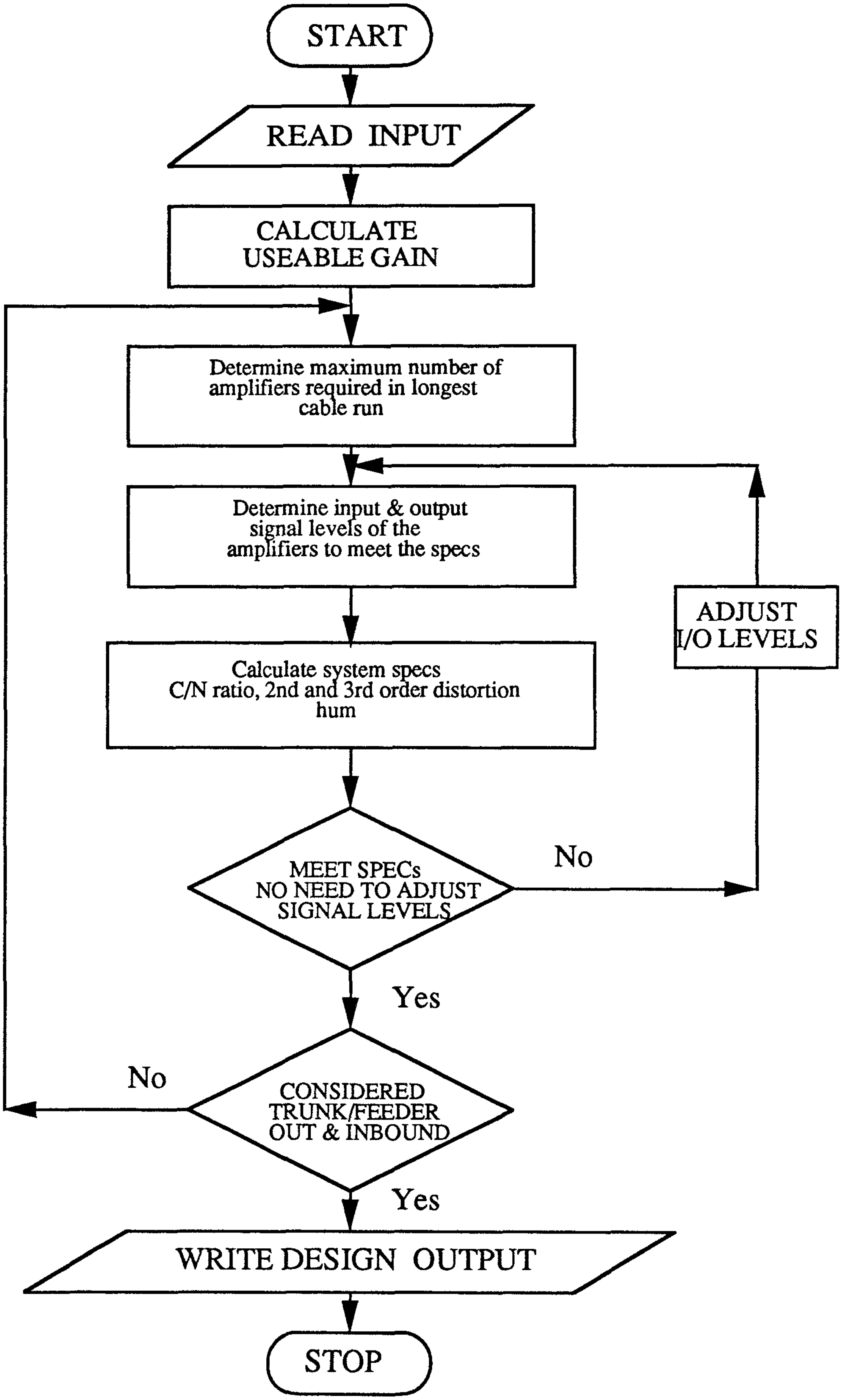


Figure 4-1. Flow diagram of the system design module.

combined with that from the feeder plant. Thus the trunk itself must produce usually high transmission quality.

Figure 4-1 shows flow diagram of the system design module implemented for purposes of this research. Inputs into the module are system specifications, distance of the longest cable run, maximum frequency, type of cable etc. The results from this module are I/O levels of amplifiers in the trunk and feeder subsystems. Both outbound and inbound amplifiers are considered. The signal levels determined in this module are used in the system layout process to properly place amplifiers.

4.3 Analysis of Equations

The underlying meanings of formulas used in system design are analyzed and the gain expression for an amplifier is derived. Understanding of these formulas will provide an insight on how C/N ratios and distortions affect the decisions on the I/O levels, and the gain of an amplifier.

The formula for computing the C/N for a single amplifier with 4.2 MHz bandwidth is

$$C/N_A = Sig_{in} + N_t - NF$$

$$C/N_A = Sig_{in} + 59 - NF \qquad (4\text{-}1)$$

where C/N_A = C/N ratio for an amplifier in dB

Sig_{in} = input signal level in dBmV,

N_t = 59, thermal noise in 4.2 Mhz, and

NF = amplifier noise figure in dB.

Given an NF of 9 dB, the noise present in a 4.2 MHz channel would be 9 dB above the -59 dBmV thermal noise.

To determine the C/N ratio of any number of amplifiers in cascade which all have the same NF and all receive the same input signals.

The formula for determining the C/N ratio of any number of amplifiers in cascade which have all same NF and all receive same level input signals is

$$C/N_m = C/N_A - 10 \log m \qquad (4\text{-}2)$$

Table 4-1. Specification of an amplifier from the Catalog, Scientific Atlanta Inc.

	Trunk	Bridger	Extender
Output (dBmV)	33	46	44
Main Full Gain	26	33	33
NF (dB)	9	7.5	7.5
X - Mod (dB)	89	67	67
CTB (dB)	84	64	62
2nd Order (dB)	>80	>80	>80
Hum (dB)	70	70	70
Return Loss (dB)	16	16	16

where C/N_m = C/N ratio for single amplifier in cascade
C/N_A = C/N ratio for single amplifier, and
m = number of amplifiers in cascade.

C/N ratio for cascaded amplifiers equals C/N ratio of single amplifier minus the increase of NF because of cascaded amplifiers.

Substituting the equation (4-1) into equation (4-2) and solving for Sig_{in},

$$Sig_{in} = NF - 59 + C/N_m + 10 \log m \qquad (4\text{-}3)$$

The formula for calculation of composite triple beat (CTB) ratio produced by a single amplifier is.

$$CTB_A = CTB_S + 2\,(Sig_{out} - Sig_S) \qquad (4\text{-}4)$$

Where CTB_A = amplifier CTB ratio in dB
CTB_S = manufacturer-specified CTB ratio in dB
Sig_{out} = operating output signal level in dBmV, and
Sig_S = manufacturer -specified reference output signal level in dBmV.

The formula for determining the CTB ratio of any number of amplifiers in cascade which all have the same CTB ratio is,

$$CTB_m = CTB_A + 20 \log m \qquad (4\text{-}5)$$

Where CTB_m = CTB ratio for the cascade in dB
CTB_A = CTB ratio per amplifier in dB, and
m = number of amplifiers in cascade.

Substituting equation (4-4) in equation (4-5) and solving for Sigout,

$$Sig_{out} = 1/2(CTB_m - CTB_S) + Sig_{out} - 10 \log m \qquad (4\text{-}6)$$

Since amplifier gain, G, is ($Sig_{in} - Sig_{out}$), Subtracting equation (4-3) from equation (4-6) will yield

$$G = 1/2(CTB_m - CTB_S) + Sig_S - 10 \log m - (NF - 59 + C/N_m + 10 \log m)$$

$$= 1/2(CTB_m - CTB_s) + Sig_s - NF + 59 - C/N_m - 20 \log m \qquad (4\text{-}7)$$

From the catalog Scientific Atlanta Inc., $CTB_s = -84$ dB, $NF = 9$, and $Sig_s = 33$ dBmV for trunk amplifiers as shown in Table 4-1. If $CTB_m = -59$ dB and $C/N_m = 45$ dB as system requirements, for example, then equations (4-3), (4-6) and (4-7) become;

$$Sign_{in} = -5 + \log m \qquad (4\text{-}8)$$
$$Sig_{out} = 45.5 - 10 \log m \qquad (4\text{-}9)$$
$$G = 50.5 - 20 \log m \qquad (4\text{-}10)$$

These equations are plotted in Figure 4-2. Theoretically, any input level equal to or greater than Equation (4-8), output level equal to or less than Equation (4-9) and amplifier gain equal to or less than equation (4-10) can be used and still meet requirements.

If the cross-modulation (X-Mod) distortion requirements are used with the data in Table 4-1, instead the CTB ratio, Equations (4-3), (4-6) and (4-7) become;

$$Sig_{in} = -5 - 10 \log m \qquad (4\text{-}11)$$
$$Sig_{out} = 48 - 10 \log m \qquad (4\text{-}12)$$
$$G = 53 - 20 \log m \qquad (4\text{-}13)$$

The results are plated in Figure 4-3. The difference between two plots (figures 4-2 and 4-2) arises because of the different values of the amplifier specifications for CTB and X-Mod. In this case CTB more is demanding requirement than the X-Mod.

According to Krabec and Sutherland, the total number of amplifiers allowed in a MAP network is 128 and not more than 18 amplifiers are allowed in cascade. If m = 18 in Equation (4-7), The gain of an amplifier is 25.39 dB in the above example. Theoretically, trunk amplifier gain of up to 25.39 dB can be used and the given requirements can still be met. Assuming the no loss except from the cable system and 0.5" cable with 1.65 dB loss per 100 feet is used, an amplifier can cover (25.39/1.65) x 100 feet = 1,538 feet. With 18 amplifiers in cascade, the total distance of 1,538 x 18 = 27,684 feet can be covered by the system.

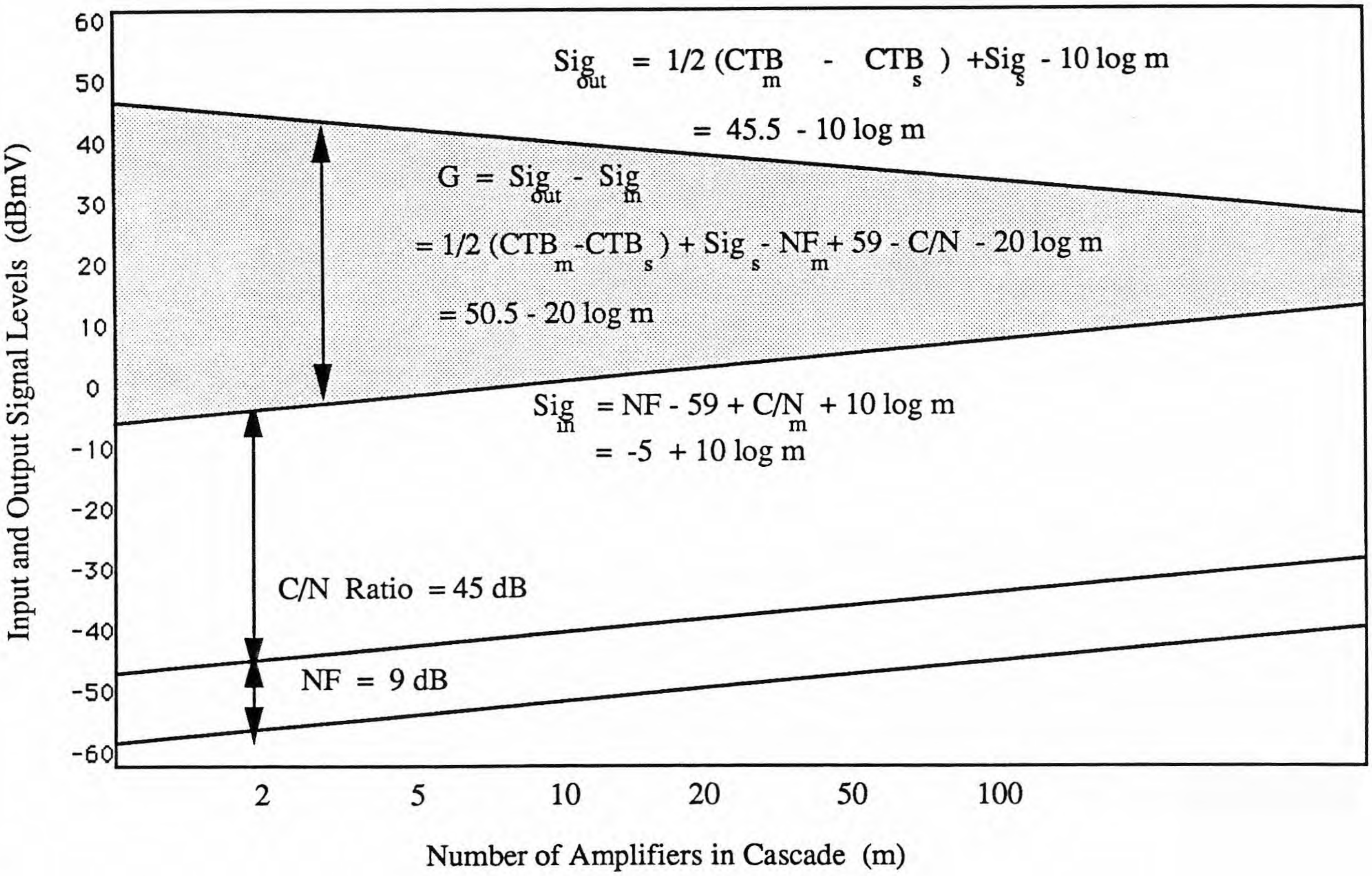


Figure 4-2. Available gain of amplifiers in cascade
(when CTB is a limiting factor).

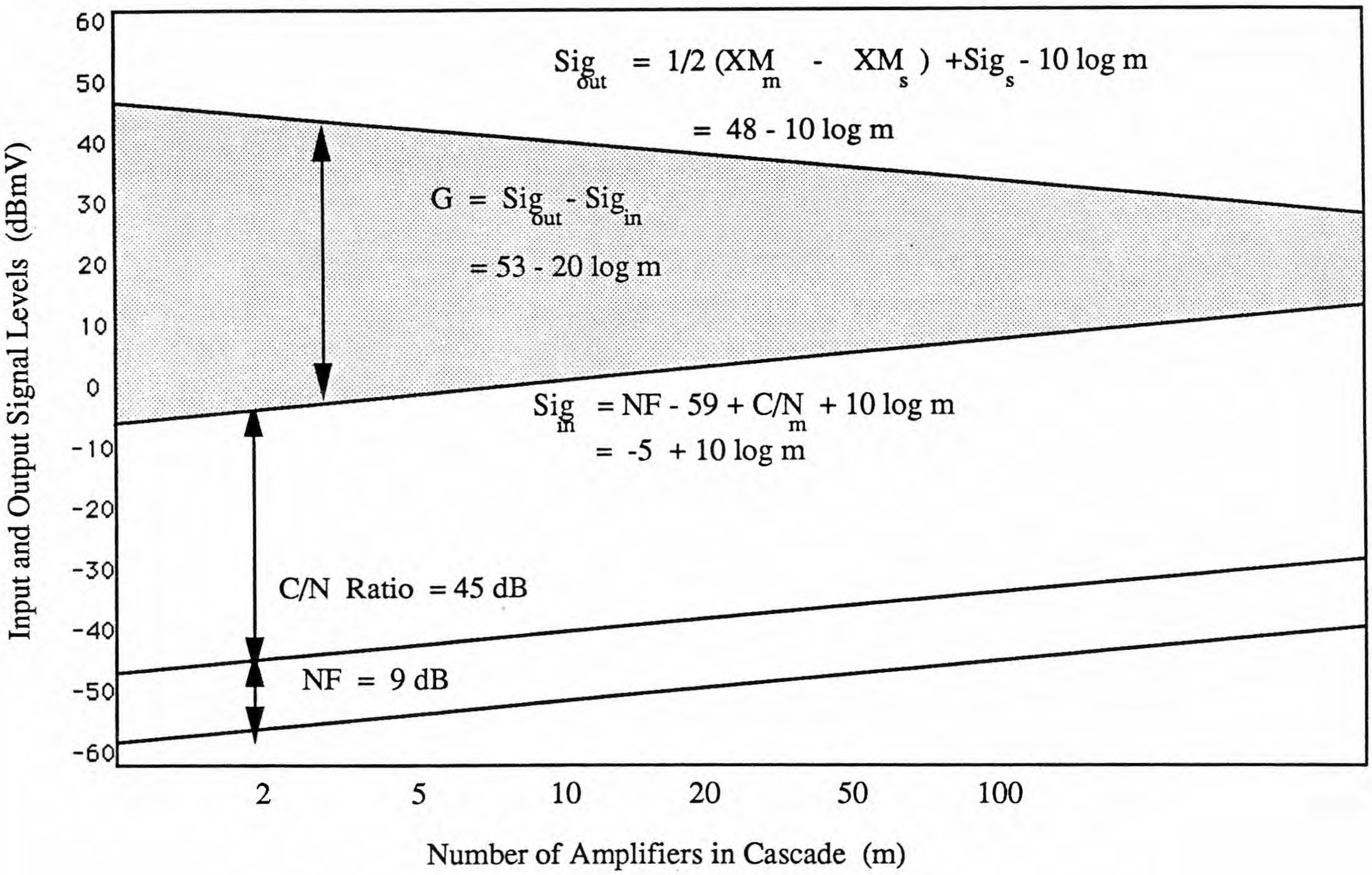


Figure 4-3. Available gain of amplifiers in cascade
(when X-Mod is a limiting factor).

4.4 Over All System Performance

With overall system performance specifications, the problem of allocating or distributing the acceptable noise and distortions between the trunk and feeder subsystems can be addressed. Let us establish the outbound and inbound C/N ratio to be 43 dB and 40 dB respectively, while -53 cross modulation (X-Mod) and composite triple beat (CTB) which are minimum requirements in the MAP/TOP signification. Now operating signal levels for the individual units of equipment in the trunk and the feeder subsystems for both outbound and inbound signal paths must be established.

4.4.1 Allocation of MAP/TOP Broadband Specification to subsystems

The allocation of a broadband system specification to different subsystems has significant effect on the overall system performance and cost. The following questions must be answered before proceeding with actual system design: How large a margin of variation should be provided for each system? What is a reasonable margin for a particular system specification? How much future expansion does the cable system expect to provide? How large is the area to be served by the cable system? Furthermore, the interactions of variables involved are such that there is no closed form equation for answering these questions. Thus an iterative trial and error approach is used.

To make this example simple, the allocations given by Tables, 4-2, 4-3, 4-4 are used.

4.4.2 Outbound Trunk System

The usable gain is the amount of amplification the device can supply. From the catalog of Scientific Atlanta Inc., One dB of equalizer insertion loss will be used in this example. Reverse gain is a small amount of amplifier gain set aside during the design process to accommodate signal level variation that can arise when implementing and using

Table 4-2.Allocation of system requirements to out/inbound systems.

	system	Outbound	Inbound
X - Mod (dB)	-53	-58	-60.2
CTB (dB)	-53	-58	-60.2
C/N (dB)	-	43	40

Table 4-3. Allocation of outbound system requirements to trunk and feeder subsystems.

	Outbound System	Trunk	Feeder
X-Mod (dB)	-58	-70	-60.5
CTB (dB)	-58	-70	-60.5
C/N (dB)	43	45	47.4

Table4-4. Allocation of inbound system requirements to trunk and feeder subsystems.

	Inbound System	Trunk	Feeder
X-Mod (dB)	-60.2	-70	-63.57
CTB (dB)	-60.2	-70	-63.57
C/N (dB)	40	42	44.33

the network. This gain can be used when the length of an installed cable run exceeds the estimated value used for design calculations. First find the usable amplifier gain.

Usable amplifier gain = Minimum full gain (catalog specification)
- Diplex filter loss - Equalizer loss
- Reverse gain
= 26 - 1.0 - 1.0 - 2.0 = 22 dB

The distribution system will be designed with an amplifier gain of 22 dB in the forward path (the return path needs less gain, but the calculation is similar.)

Next, determine the minimum number of amplifiers needed to compensate for the signal loss of the longest cable runoff a system. To determine the maximum number of amplifiers in the cascade, several factors must be considered such as, output level and usable gain of the amplifiers, system bandpass and the amount of cable loss between each amplifier. The amplifier cascade to use for designing the system (the design cascade) is then found by multiplying some number to this calculated minimum value as shown in figure 4-4.

After the design cascade is determined, the trunk amplifier C/N ratio and distortions can be found. CTB is used in this example for third order distortion to simplify the presentation. CTB is considered the most rigorous requirement when designing the 400 and 450 MHz networks. Other third-order distortions can be calculated the same way as the CTB. The system design module will check all the specifications including second-order and hum distortions. Assume that the C/N ratio for the trunk system is 45 dB and feeder system C/N ratio is 47.4 dB with total outbound C/N ratio of 43 dB. From the equation (4-2), the C/N ratio of an amplifier to be used can be determined.

$$\begin{aligned} C/N_{amp} &= C/N_{sys} + 10 \log m \\ &= 45 + 10 \log 6 \\ &= 52.78 \text{ dB} \end{aligned}$$

The C/N ratio of an amplifier should be equal to or greater than 52.78 dB. Assume that C/N ratio of an amplifier is 53 dB at each amplifier is from equation (4-1)

$$\begin{aligned} Sig_{in} &= NF - 59 + C/N_{amp} \\ &= 9 - 59 + 53 = 3 \text{ dBmV} \end{aligned}$$

Since an amplifier with 22 dB gain is used as calculated, a 3 dBmV input level establishes a 25 dBmV output level. Assume the manufacturer has specified CTB for this unit to be -84 dB at an output reference level of +33 dBmV with 35 channel loading. The CTB for this unit operating at 25 dBmV of output can be determined from equation (4-4):

$$\begin{aligned} CTB_{amp} &= -84 + 2(25 - 33) \\ &= -100 \text{ dB} \end{aligned}$$

The CTB distortion for a cascade of 6 such amplifiers may be established using equation (4-5):

$$\begin{aligned} CTB_{sys} &= -100 + 20 \log 6 \\ &= -84.44 \text{ dB} \end{aligned}$$

Longest cable run (estimated)	3,500 ft.
Cable loss (0.5-inch cable & 450 MHz) 3500 ft x 1.65 dB/100 ft	57.75 dB
Required cascade over longest run cable loss usable gain 57.75 dB/22 dB	2.625 amplifiers
Minimum required cascade	3 amplifiers
Design cascade two times Minimum required cascade	6 amplifiers

Figure 4-4. Number of amplifier cascade.

Then the trunk system transmission performance, through a cascade of 6 trunk amplifiers operating at 3 dBmV of input and 25 dBmV of output will be 45.22 dB C/N ratio and -84.44 dB CTB.

Since the overall outbound system performance specification is established to be equal to or greater than 43 dB C/N ratio and equal or less than -58 CTB, the acceptable noise and CTB for feeder system can be established. The trunk C/N ratio is determined to be 45 dB (C/N ratio of the amplifier is based on this figure), so any significant noise contribution from the feeder plant cannot be accepted at all.

The CTB for a feeder system can be determined as

$$\begin{array}{lll} 20 \log x = -88.44 & \Rightarrow & x = 5.9979\ E - 5 \text{ (Trunk)} \\ 20 \log z = -58 & \Rightarrow & z = 1.259\ E - 3 \text{ (Outbound system)} \\ y = z - x = 1.2\ E - 3 & \Rightarrow & 20 \log y = -58.42 \approx -58.5 \text{ (Feeder)} \end{array}$$

Values less than or equal to -58.42 can be chosen to satisfy the requirements. Suppose -58.5 is chosen for the feeder system CTB of -88.44 dB. When combined with trunk CTB of -88.44 dB, The overall system CTB is -58.07 dB. The feeder system (select output levels) will be designed to produce a -58.5 dB CTB.

If the I/O levels determined above are examined with regard to equations 4-3 and 4-6, these signals levels are based on the minimum input level allowed as can be seen in figure 4-5. Depending on the design problem, a designer may choose I/O values somewhere in the middle between the two extreme values with more margins for output levels as shown in figure 4-6. With input level of 7 dB the CTB is -76.4 dB, which are also well within the allocation determined (Table 4-3).

4.4.3 Outbound Feeder System

Bridger and feeder amplifiers are available with CTB specifications of -64 dB and -62 dB, respectively at a + 46 dBmV reference output level with 35-channel loading. From Table 5-1, amplifiers in the feeder system have noise figure (NF) of 7.5 dB it is assumed that all feeder legs to one bridger amplifier followed by two line extender amplifiers, a total feeder cascade of three amplifiers as shown in figure 4-7.

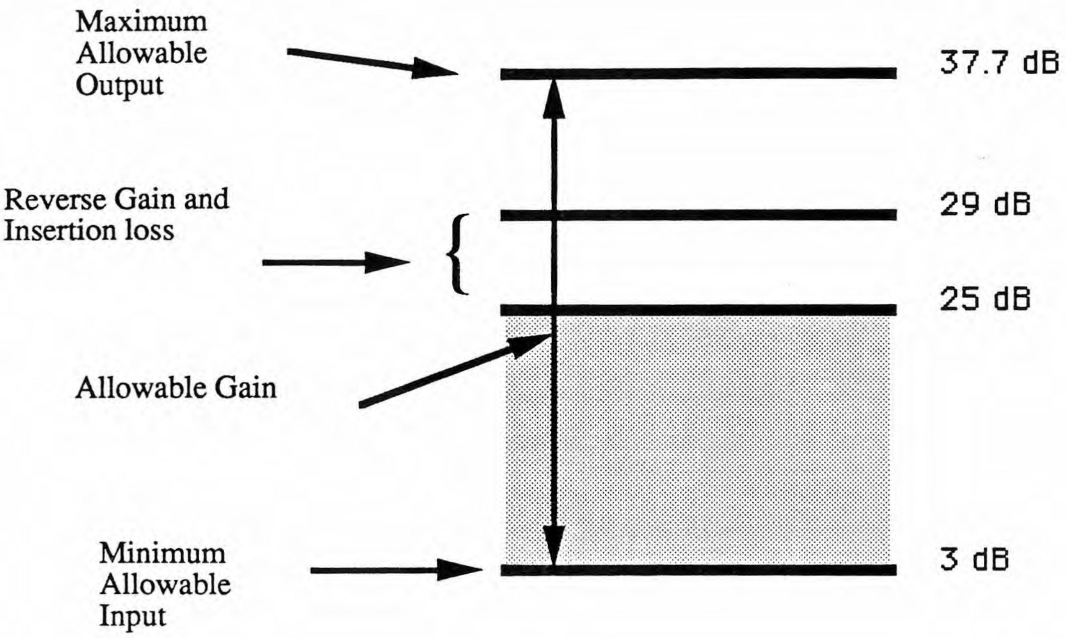


Figure 4-5. Input/Output levels compared with theoratical values.

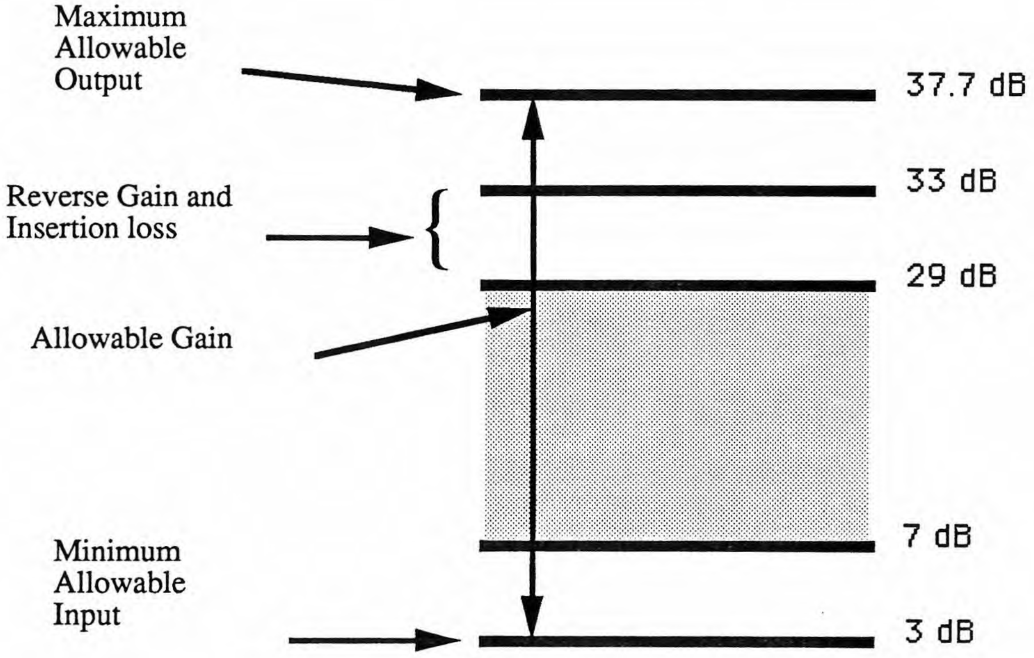


Figure 4-6. Input/Output levels suggested.

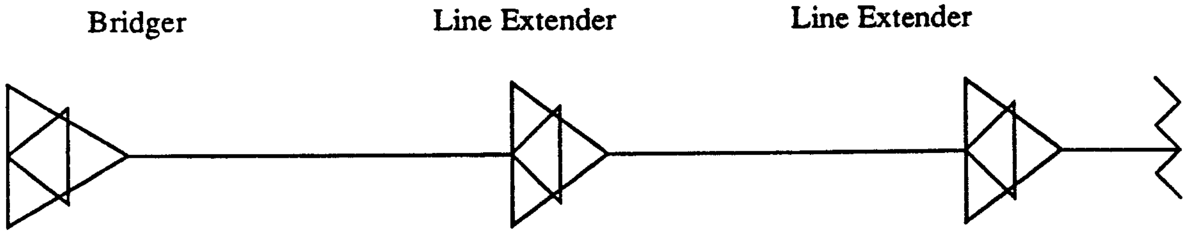


Figure 4-7. Bridger followed by two line extenders.

If the total feeder CTB cannot exceed -58.5 dB, the allowable CTB from each amplifier is from equation (4-5)

$$\begin{aligned} CTB_{amp} &= CTB_{sys} - 20 \log m \\ &= -58.5 - 20 \log 3 \\ &= -68.04 \text{ dB} \end{aligned}$$

According to the specifications, the bridger amplifiers produces -64 dB CTB at +46 dBmV output. The output level of bridger amplifier can be increased or decreased within the CTB specification. For every 1 dB increase in output level, CTB will increase 2 dB. Likewise , for every 1 dB decrease in output level, CTB will decrease 2 dB. Therefore, the bridger output level can be decreased by 2.02 dB (to 43.98 dBmV) in order to satisfy given requirements. Similarly, for line extenders, the output level can be decreased by 3.02 dB (42.98 dBmV).

The input level of amplifiers will be a function of the gain of the units selected. If 28 dB and 30 dB usable gains are used for the bridger and the extender respectively, then the input levels will be 15.98 dBmV for bridger and 12.98 dBmV for extenders. From the equations (4-1) and (4-2), the C/N ratio of the feeder subsystem is 60.4 dB. When combined with the trunk C/N ratio of 45 dB.

If one more line extender amplifier is added into the existing cascade of three units, each producing -68.04 dB CTB, the total CTB from the feeder system is,

$$
\begin{aligned}
CTB_{sys} &= CTB_{amp} + 20 \log 4 \\
&= -55.99 \approx -56 \text{ dB}
\end{aligned}
$$

This performance is out of specification for the feeder system, which was chosen to be equal or better than -58.5 dB.

4.4.4 Inbound Trunk System

Usable amplifier gain for inbound trunk is, from equation (4-8)

$$
\begin{aligned}
\text{Usable amplifier gain} &= 24 - 1.0 - 1.0 - 2.0 \\
&= 20 \text{ dB}
\end{aligned}
$$

For all inbound calculations, an equivalent amplifier cascade must established that will reflect the noise contribution from both the cascade of amplifiers passed through and the noise from the total number of return amplifiers. The following formula is used to find the equivalent cascade of amplifiers:

$$C_{eq} = (NM)^{1/2}$$

where C_{eq} = equivalent cascade of amplifiers,

N = total number of amplifiers in system, and

M = number of amplifiers actually in cascade.

Given the noise figure of a single inbound trunk amplifier and the input signal applied to the amplifier, the C/N ratio of this cascade can be established at the end of the input transmission system (trunk only), which will be at the headend.

If the total number of the inbound trunk amplifiers are established to be 6 and the number of amplifiers in cascade to be 4, the equivalent cascade of inbound trunk amplifiers is, from above equation

$$C_{eq} = (6 \times 4)^{1/2} = 4.8 \approx 5 \text{ amplifiers}$$

A total inbound C/N ratio of 40 dB or better can be accepted. A C/N ratio of 42 dB will be arbitrarily allocated to the inbound trunk plant and a 45 dB C/N ratio to the inbound feeder plant. The C/N ratio of an amplifier necessary to all inbound trunk amplifiers to produce a C/N ratio of 42 dB is calculated using equation (4-2),

$$\begin{aligned} C/N_{amp} &= C/N_{sys} + 10 \log m \\ &= 42 + 10 \log 5 = 48.989 \text{ dB} \end{aligned}$$

The C/N ratio of an amplifier should be equal or greater than 48.98 dB. Assume that the C/N ratio of an amplifier is 49 dB. The input signal level necessary to maintain a C/N ratio of 49 dB at each amplifier is, from equation (4-1)

$$\begin{aligned} Sig_{in} &= NF - 59 + C/N_{amp} \\ &= 8 - 59 + 49 = -2 \text{ dBmV} \end{aligned}$$

Since an amplifier with 20 dB gain is used as calculated, a -2 dBmV of input level will be established a 18 dBmV output level. Assume the manufacturer has specified CTB for this unit to be -84 dB at input reference level of + 17 dBmV. The CTB for this unit operating at -2 dBmV of input can be determined from equation (4-4)

$$\begin{aligned} CTB_{amp} &= -84 + 2(-2 - 17) \\ &= -122 \text{ dB} \end{aligned}$$

The CTB distortion for a cascade of 4 such amplifiers may be established using equation (4-5):

$$\begin{aligned} CTB_{sys} &= -122 + 20 \log 4 \\ &= -109.958 \text{ dB} \end{aligned}$$

Then the trunk system transmission performance, operating at -2 dBmV of input and 18 dBmV of output ,will be 42.01 dB C/N ratio and -109.95 dB CTB.

As for the outbound trunk system, if I/O levels determined above are examined with regard to equations 4-3 and 4-6, these signal levels are based on the minimum input level allowed. With input level of 4 dBmV and output level of 24 dBmV, the inbound system C/N ratio of 48 dB and CTB of -97.95 dB are found which are also well within the allocation determined (Table 4-4).

4.4.5 Inbound Feeder System

Since the C/N ratio of 45 dB is allocated arbitrarily to the inbound feeder plant, the input and output signal levels of an amplifier must be found which will satisfy the requirement. From the catalog, the feeder specifications are: NF = 7.5 dB, Reference input = 17 dBmV, CTB = 69 dB, X-Mod = 69 dB, minimum full gain = 32 dB. The bridger specifications are: NF = 7.5 dB, Reference input = 17 dBmV, CTB = 84 dB, X-Mod = 83 dB, minimum full gain = 24 dB. To simplify the presentations, it is assumed three feeder amplifiers are used instead of one bridger followed by two feeder amplifiers. The equivalent cascade of inbound feeder amplifier is, if the total number of feeder amplifiers is estimated to be 40 and the longest cascade is 3 including bridger, by putting values that will give,

$$C_{eq} = (40 \times 3)^{1/2} = 10.95 \approx 11 \text{ amplifiers}$$

The input signal necessary to all inbound feeder amplifiers to produce a C/N ratio of 45 dB with 11 amplifiers in equivalent cascade is, from equations (4-1) and (4-2),

$$\begin{aligned} Sig_{in} &= NF - 59 + C/N_{sys} + 10 \log m \\ &= 7.5 - 59 + 45 + 10 \log 11 \\ &= 3.91 \approx 4 \text{ dBmV} \end{aligned}$$

Using 22 dB gain , a 4 dBmV of input will produce an output of 26 dBmV at all inbound feeder amplifiers. The CTB performance through a cascade of three such units is from equations (4-4) and (4-5):

$$\begin{aligned} CTB_{feeder} &= -69 = 2(4 - 17) + 20 \log 3 \\ &= -85.46 \text{ dB} \end{aligned}$$

The inbound system CTB with -109.96 dB trunk CTB and -85.46 dB feeder CTB, -84.95 dB which is well within the specification of -53 dB.

Chapter 5

Layout of the System

System layout is the process of overlying on the pole lines of strand maps the actual cable routing and the specifics of location, type etc., of all equipment and devices required. However, in this research, "System Layout" means the determination of all the necessary information so that devices can be laid out on the strand map. All transmission losses, such as cable side lead feeds and tap insertion losses, must be calculated, and as required, offsetting gain must be provided by inserting amplifiers. Although the methodology of layout is not sophisticated, the actual layout will have a significant impact on system cost and long-term maintenance expense.

The product of the layout process is a system design transposed to drawings. A bill of materials can be generated, from which actual cable placement, splicing, and equipment installation can proceed. In addition, functions such as system powering, location of power supplies, and the selection of amplifier equalizers and attenuator pads can be completed.

Various aspects of the devices and the signal levels along the cable must be considered for the system layout. These include cable attenuation, selecting tap values, tilted system operation and equalizer value calculations.

5.1 Cable Attenuation

The attenuation characteristics of a certain length of cable and their effects on a band of signals presented to the cable at equal levels are shown in figure 5-1. The input signals to the cable are "flat" and the output signals from the cable/equalizer combination are also "flat." The signal levels are titled by the sections of the cable and equalizers are used to restore them to equal amplitude. Each cable section will be compensated for its own "tilt." This is done for gain and loss within each cable section. Every amplifier is intended to offset the loss of the cable section immediately preceding it. Thus a cable section, consisting of the coaxial cable and an amplifier is operated at unity gain (no difference in signal levels between the input and the output of the section). This is shown in figure 5-2.

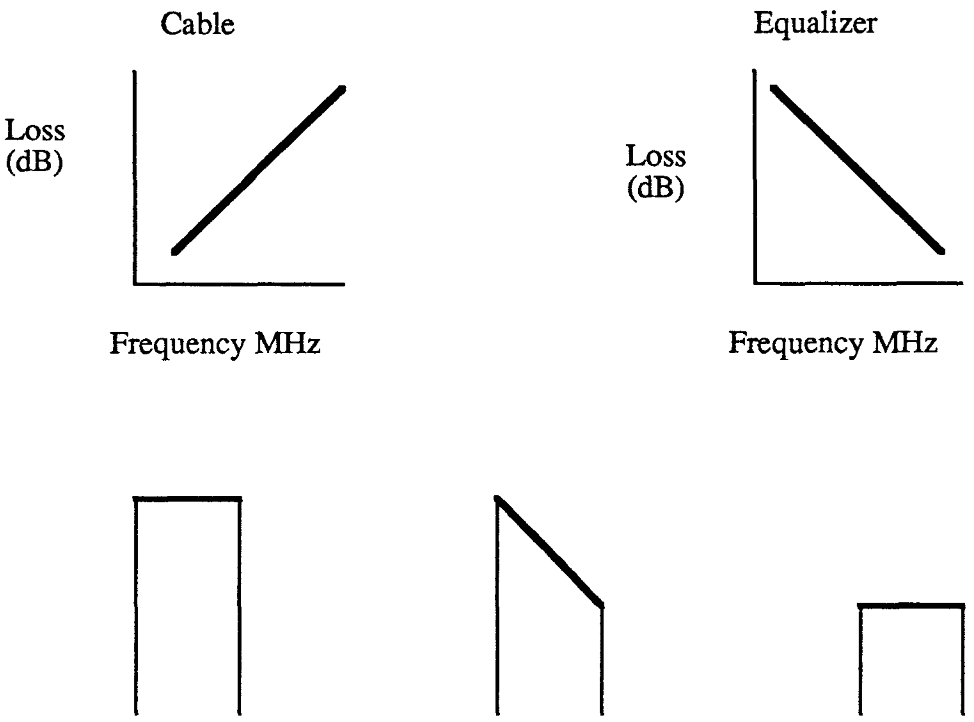


Figure 5-1. Effect of equilization on signal amplitude.

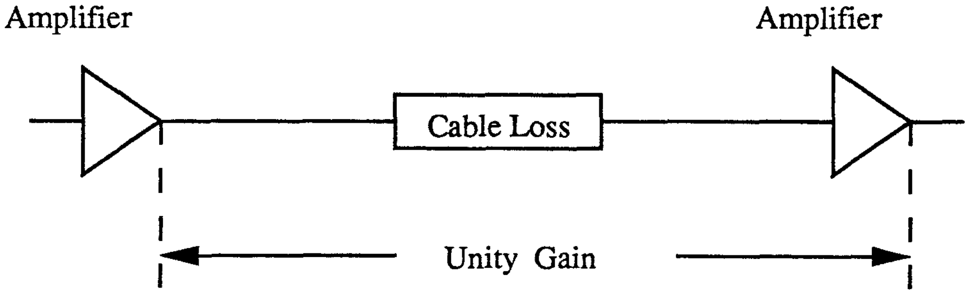


Figure 5-2. Unity Gain.

Devices such as splitters, directional couplers, and taps will be inserted into the cable section. These devices will affect the physical spacing between amplifiers and introduce the same loss to all frequencies within their passband. They do not introduce tilt and are thus referred to as "flat" losses and must consider only the length of the interconnecting cable.

Most manufacturers specify equalizers simply as being equivalent to a specific length of cable. For example, a 16.5 dB equalizer, for a 450 MHz system, will be the equal length of cable having 16.5 dB of loss at 450 MHz. This will be approximately 1,000 feet of half inch cable. Such a length cable will have 11.45 dB of loss at 234 MHz. The equalizer will actually have insertion loss of perhaps 0.5 dB to 5.55 dB (16.5 - 11.45 + 0.5) at 234 MHz.

The MAP/TOP specification requires all signals to be within a 3 dB range. This may be called the "window" for variation.

5.2 Selecting Passive Devices

The Tap value selections are directed by the transmission level at the tap location and the service drop input specification in every case. The layout proceeds until the signal level in the through cable becomes too low to tap or until this level is reduced to the system design input requirement for line extender amplifiers, which ever comes first. At this point an amplifier must be inserted to produce further with the feeder cable.

5.2.1 Frequency Response and Equalization

Any transmission must be concerned with the frequency response across the bandwidth that it presents for use. If the response for different sections of bandwidth is not the same, the fidelity with which the system output reproduces the input information will suffer.

With the bandwidth provided in broadband cable systems, typically from 5 to 400 or 450 MHz, it is anticipated that such systems will present frequency response problems. With a large number of RF carriers distributed across the spectrum provided, variation in the response means variations in the amplitude of the signals themselves.

The many devices employed in a broadband system (taps, amplifiers, splitters etc.) will each contribute some distortion to the overall system frequency response. Since these devices are mass produced, similar units introduce similar distortion, sometimes referred to as "response signature." A particular value tap, for example, may have roll off of response at one end of the transmission bandpass.

Amplifiers are produced in quantity, and not only does each individual unit have a characteristic response "ripple," but a cascade of identical units will also exaggerate the condition. Amplifiers sometimes have minor adjustments in order to correct the e response, and although the range of such adjustment is limited, it can often rectify some response distortion which preceding passive units may have introduced.

5.2.2 Peak-to-Valley Response

Peak-to-Valley is defined to denote the most extreme deviations of frequency in the pass band of the device or system. Peak-to-Valley means the highest and lowest variation anywhere within the pass band.

The MAP/TOP broadband specifications specifies the following two peak-to-valley requirements:

- Peak-to-Valley gain versus frequency response across the inbound and outbound frequencies and due to the cable system only, shall be less than or equal to 3 dB or m/10 + 1.5 dB, whichever is greater, where m is the number of amplifiers in cascade.
- Peak-to-Valley gain versus frequency response across any specific channel due to the cable system only, and separately measured for in bound and out bound paths should be less than or equal to:

1.5 dB across a 6 MHz channel
2.0 dB across a 12 MHz channel
2.0 dB across a 18 MHz channel

Compliance with the frequency response specification is required for all channels except within 6 Mhz of each edge of the inbound and outbound frequency bands.

When many components are combined together, to construct a usable system, it is anticipated that distortion of the overall frequency response will occur. Some small incremental corrective adjustments can be made in each system amplifier.

5.2.3 Tilted System Operation

How much pretilt should be introduced into the system will be a consideration of the tap output "window" specification. A 500-feet cable section 90.5 inch diameter with all signals at identical amplitude (flat input) of 40 dBmV is shown in figure 5-3. Five taps at 100-feet intervals are shown with each tap feeding at 100-feet (which, according to MAP/TOP specification, is the maximum recommended drop length with RG-6) service drop of RG-6 cable and 15 feet of RG-59 cable. The transmission levels are shown for input to each tap at both 234 and 450 MHz. The difference in signal levels between 234-MHz and 450 MHz at both service drop input and output are also shown.

The first two taps are well within our "window" specification of 3 dB , but the other three taps are out of specification. A compensating equalizer can be simply selected. In figure 5-4, the same conditions exist as in the figure 5-3, except the input signals are tilted to the cable section by 3.38 dB. The 234 Mhz carrier is at 36.62 dBmV, but 450 MHz carrier remains at 40 dBmV as before.
All five drops are now in full compliance with the "window" specifications.

In some very long, tapped cable sections it may be advantageous to insert an in-line equalizer somewhere between amplifiers to tighten up on the tap output port "window."

Examine figure 5-4 again. A 1.65 dB loss at 450 MHz (per 100 feet of cable) for the main cable run is used in calculation. Each 100-feet cable span introduces 1.65 dB of loss at 450 MHz and 1.145 dB of loss at 234 MHz. The input to the cable section was 40-dBmV at 450 MHz and 36.62 dBmV at 234 MHz. The input levels to the first tap are calculated as 40 - 1.65 = 38.35 at 450 MHz and 36.62 - 1.145 = 35.475 at 234 MHz.

To provide a 12.11 dBmV input to the service drop, a 23.5 dB tap is used. From the tap specifications, a eight-port 23.5 dB tap has insertion loss of 0.8 dB at 234 MHz and 1.0 dB insertion loss at 450 MHz in the main cable. The outputs from this location on the main cable are 37.35 dBmV at 450 MHz and 34.675 dBmV at 234 MHz.

At the service drop input, the signal levels will be lower than the main cable level since tap value is 23.5 dB. This will be 14.85 dBmV at 450 MHz and 11.975 dBmV at 234 MHz. This is a difference of 2.875 dB.

The service drop cable with 100 feet of RG-6 and 15 feet of RG-59 introduces a 3.645 dB loss at 234 MHz and 5.11 dB loss at 450 MHz. The signal levels at the service drop are 9.74 dBmV at 450 MHz and 8.33 dBmV at 234 MHz. The level difference at this point is 1.41 dB. The process continues in this fashion.

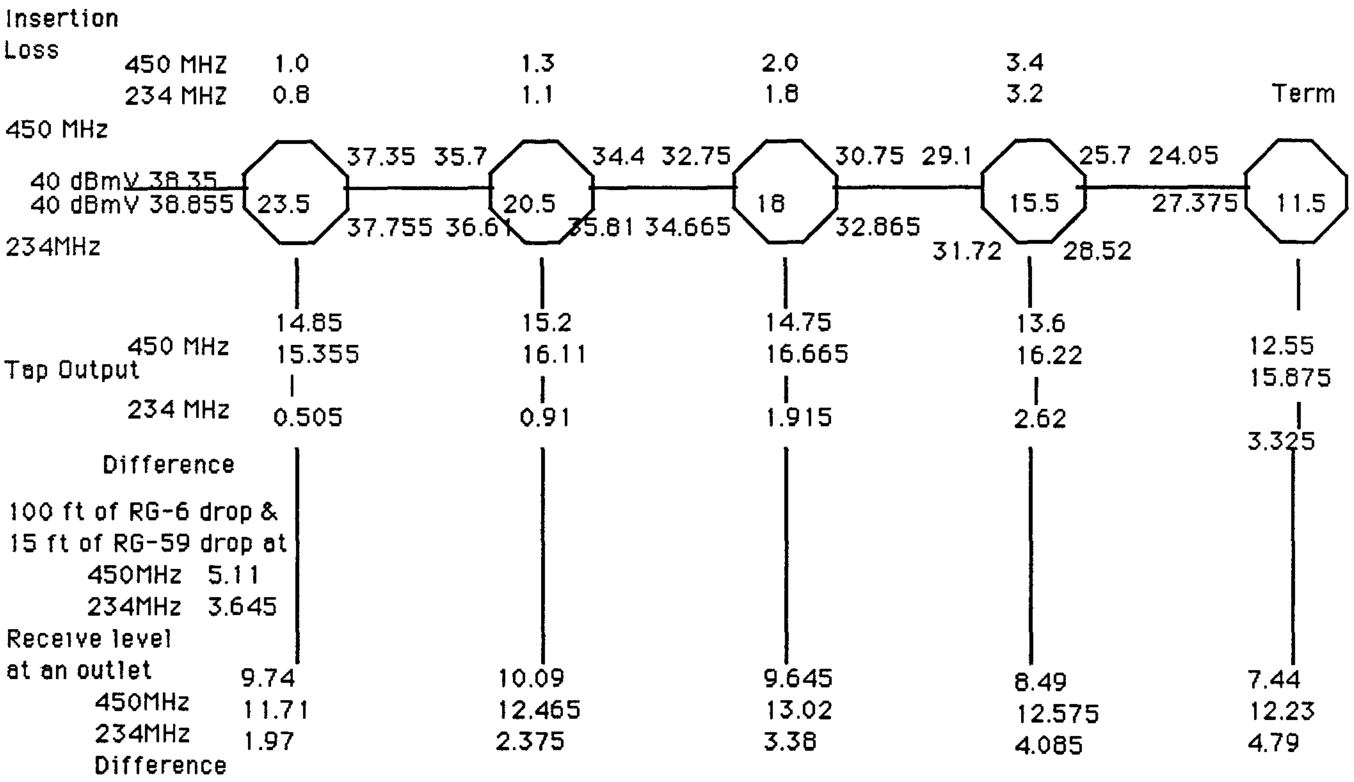


Figure 5-3. Frequency response "window" (flat input).

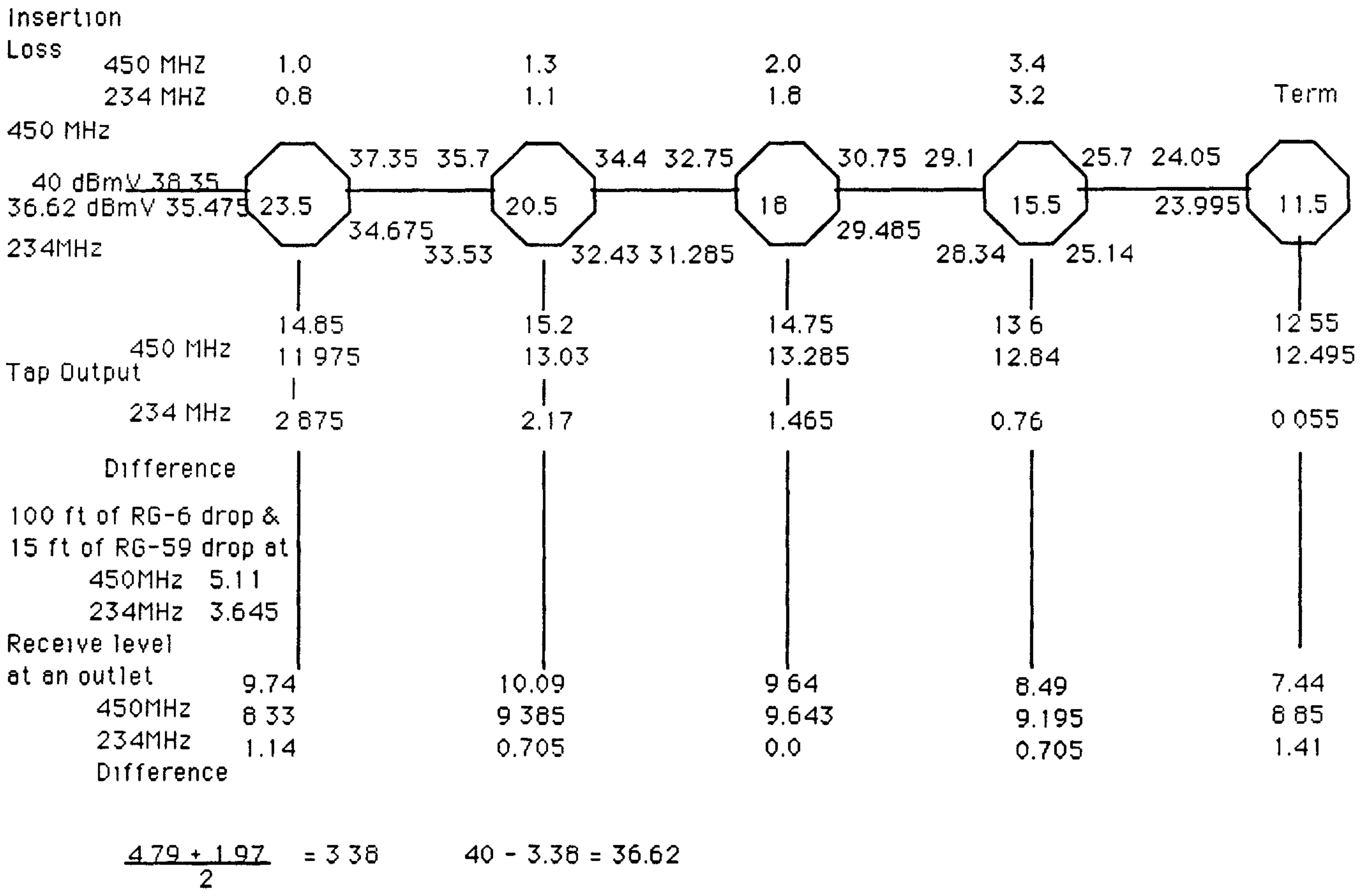


Figure 5-4. Frequency response "window" (tilted input).

5.2.4 Equalizer Calculations

Plug-in equalizers at the input of all forward trunk, bridger and feeder amplifiers. They are also required at the output of all reverse trunk , feeder amplifiers. Equalizer values are expressed in terms of cable attenuation in dB at the upper frequency. All forward equalizers are selected according to the upper frequency attenuation of the cable on the input side of the forward amplifier. Reverse equalizers are selected according to the upper frequency attenuation of the cable on the output side of the reverse amplifier.

Forward equalizer values are calculated as follows:

450 MHz Trunk amplifier (and Bridger): 450 MHz cable attenuation
450 MHz Feeder amplifier: Upper frequency cable attenuation + 1 dB

Reverse Equalizers are calculated as follows:

174 MHz Trunk amplifier (and Bridger): 174 MHz cable attenuation
174 MHz Feeder amplifier: 174 MHz cable attenuation + 1 dB

Plug-in pads are required in all bridger amplifiers, at the input of all forward amplifiers, and the output of all reverse amplifiers.

Plug-in pad equalizers are calculated as follows:

All Forward Amplifier: Pad = Amplifier Gain - Upper frequency loss input side of amplifier (include cable & flat loss)
All Reverse Amplifier: Pad = Amplifier Gain - Upper frequency loss output side of amplifier (include cable & flat loss).

5.3 Signal Level Requirements along the Feeder Cable

The design path loss is 44 dB ± 3 dB and the system transmit signal level should be equal to or less than 54 dBmV. Therefore the range of path loss is from 47 dB to 41 dB. Subtracting these path losses from the maximum transmit signal level of 54 dBmV result in 7 dBmV to 13 dBmV. This means that if the headend remodulator sends signal with 54-dBmV level, the minimum signal level required at any outlet in the network is 7 dBmV and maximum signal level allowed is 13 dBmV. According to IEEE 802.4, the minimum and maximum of received signal levels are -10 and +10 dBmV, respectively. Hence the following assumptions are made for the discussion:

- The minimum receive level at an outlet is 7 dBmV.
- Distance between taps is 100 feet and 0.5" feeder cable is used. Feeder cable loss is 1.65 dB at 450 MHz and 1.145 dB at 234 MHz.
- 100 feet of RG-6 and 15 feet of RG-59 are used for the drop cable. Total cable loss of a drop cable is 5.11 dB at 450 MHz and 3.645 dB at 234 MHz.

CHAPTER 6

DESIGN AND KNOWLEDGE - BASED SYSTEMS

In this chapter, a knowledge-based approach is developed for the layout of broadband cable systems. Components of the developed knowledge-based systems are described. The frame structure for the knowledge representation scheme is described. The frame structure is used as the database system.

6.1 The Nature of Design

The tree representation of the sample problem presented in the chapter 2 (Figure 2-4) is shown in figure 6-1. In figure 6-2, one branch (or link) between the root node (Node - 0) and node-2 is shown. For illustration purposes, assume that the necessary information at Node-0 and Node-2 is known. It is assumed that cable loss is 1.65 dB per 100 feet, minimum input signal level at Node-2 is 10 dBmV, and output signal level at Node-0 is 32 dBmV. However, Node-0 has three children nodes. A device to split signal power to feed all three children is needed. Inserting a device means that there will be an insertion loss associated with the device. Now output signal level at Node-0 depends on the decision of the designer. Since the cable loss between Node-0 and Node-2 is 22.11 dB and the output level at the Node-0 will be less than 32 dBmV, an amplifier is needed to compensate the cable loss between Node-0 and Node-2. There may be various constraints in placing the node X. The same kind of problem but with different environments exist for every branch of the tree.

Decision on one node affects the value of the parameters on the other nodes. Unlike the other problems where the given size of the problem is fixed, the number of nodes (of problem size) may increase as the layout problem in this research. The information on node X is completely unknown at the time when design started but should be created and the signal levels on that node must be determined during the process of design.

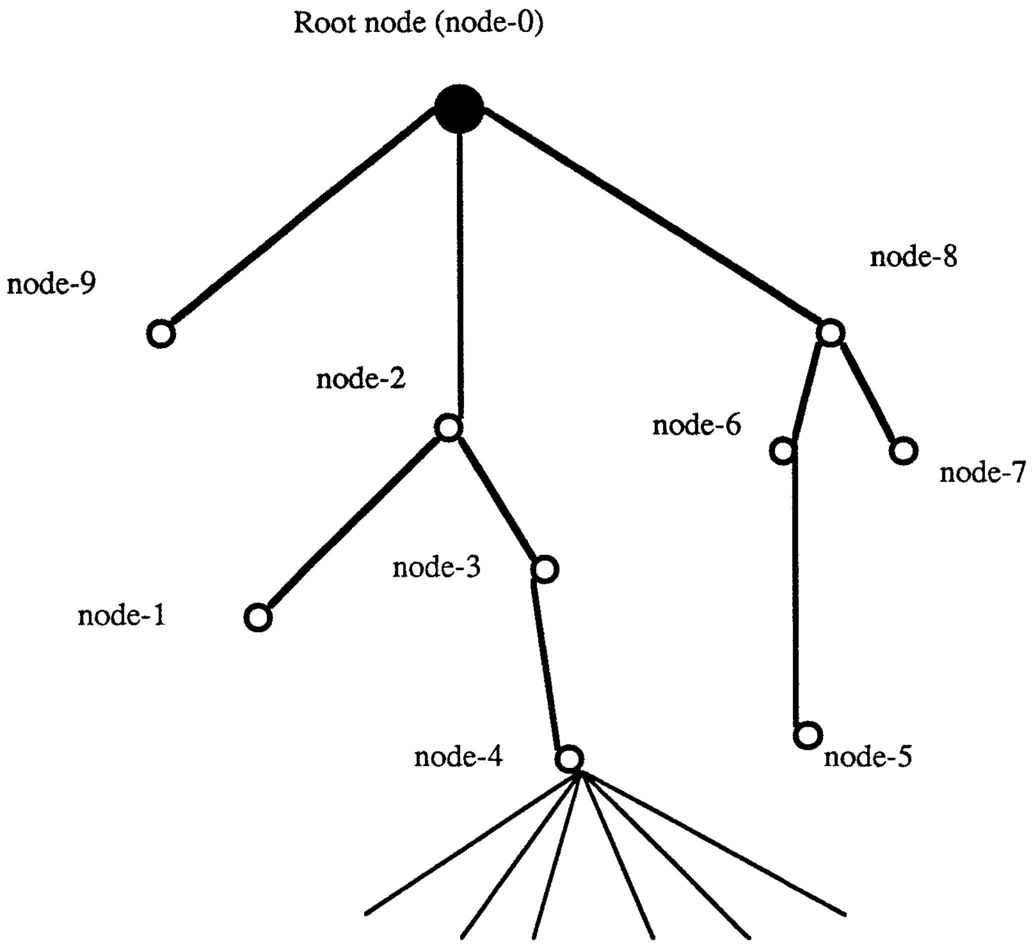


Figure 6-1. Tree representation of the problem in chapter 2 (Figure 2-4.).

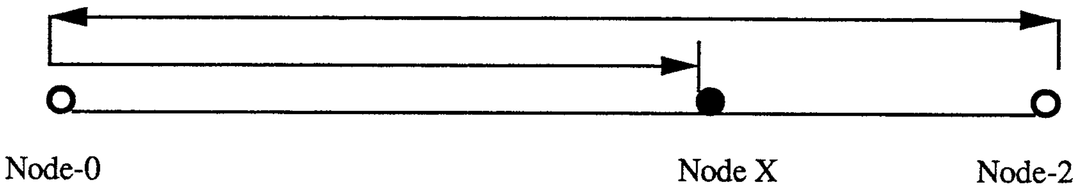


Figure 6-2. Problems inherent in broadband cable network design.

6.2 Design Methodology

The strategy taken in this research is to consider two nodes at a time. The information regarding the two nodes is copied from the database into the working memory according to its position in the stack. A stack stores branches of a tree (or network). The stack may be regarded as a "plan" in cable layout. The longest branch from the root of a tree is placed on the bottom of a stack. Two nodes from the longest branch starting with the root (headend) of a tree are considered first. After completing the longest branch, the design proceeds to any branching node closest to the leaf (terminal) node. If there are no branching nodes or all branching nodes have been considered, then the design proceeds to the next longest branch which is stored in the plan.

Data of signal levels are propagated from the parent node to child node and constraints violations are being checked during this process. With this approach, the interactions can be dealt with effectively that arise when the design problem is decomposed.

6.2.1 Computer Aided Design

Computer design aids began as programs performing the task of book keeping storing design data in data bases. Routine tasks which involved the manipulation of large sets of data were automated. The design is computer aided in the sense that the computer is used as work environment with some nice features. It does not forget, it does not make mistakes in checklist tasks or data conversion tasks etc. This can be useful for analysis and verification phases in the design. There is however very little support for the synthesis phases of design.

6.3 Expert Systems

Expert systems can be categorized into a few distinct types including interpretation systems, prediction systems, diagnosis systems, monitoring systems, configuration systems, planning systems and design systems. Experimental systems have been built for most of these types in different domains.

Expert systems to perform design-type tasks have been very few in number, reflecting the greater difficulty and complexity of building such systems. An expert system is defined as a program that relies on the body of knowledge to perform a difficult task usually only performed by a human expert. Two major lessons learned from successful expert systems are:

(1) The limitations of general purpose reasoning were discovered and the importance of explicit knowledge in problem solving and reasoning was realized. Since the use of highly specific domain and knowledge led to successful reasoning, it was beneficial to deal with problems that have a narrow focus,

(2) simple and straightforward reasoning techniques could be used to solve or assist in the solution of important problems.

KB systems have been developed to help solve problems whose structures do not lend themselves to recipe-like solutions. These systems are effectively coping with enormous search spaces of alternatives found in real world problems. The key to success of KB systems is the ability to use domain-rich knowledge to recognize familiar patterns in the current problem state and act appropriately.

6.4 Components of the Knowledge-Based Systems

The problem domains and features of the existing KB systems differ widely, but many have three components in common: a working memory — facts on the domain and the problem, knowledge-base — methodological guidelines of heuristics, and an inference engine — methods of inference.

Components of a KB system developed in this research are as follows.

6.4.1 The Working Memory

The working memory is a collection of attribute-value pairs that describe the current situation of network nodes. The attribute-value pairs are copied from the database according to the plan which dictates with nodes to consider next. The format to represent facts in the working memory is:

```
((attribute-1 value-1)
   ...
(attribute-n value-n))
```

As an example, the following may be used as facts:

```
((INPUT-LEVEL-TRUNK-OUTBOUND 10)
(OUTPUT-LEVEL-TRUNK-OUTBOUND 32)
(USABLE-GAIN-OUTBOUND-TRUNK 22.0)
(OUTB-HIGH-TRUNK -CABLE-LOSS 1.65)
(OUTB-LOW-TRUNK-CABLE-LOSS 1.145)
(OUTB-HIGH-FEEDER-CABLE-LOSS 1.65)
(OUTB-LOW-FEEDER-CABLE-LOSS 1.145)
(ROOT-INP-HIGH-OUTB 32)
(DIRECTION OUTBOUND)
(CURRENT-NODE |node-2|)
(PARENT-NODE |node-0|)
(TYPE-OF-CABLE TRUNK)
(CURRENT-NODE-TERMINAL NO)
(PARENT-TRUNK-CHILDREN (|node-9||node-8||node-2|)
(PARENT-FEEDER-CHILDREN |node-0-F|)
(CURRENT-NODE-TRUNK-CHILDREN (|node-1||node-3|)
(CURRENT-NODE-FEEDER-CHILDREN |node-2-F|)
(DIST-TO-PARENT 1340))
```

6.4.2 The Knowledge-Base

The part of an expert system that stores knowledge about domains of expertise is called the knowledge-base. The knowledge base is the collection of conditional statements that operate on elements stored in the working memory. The knowledge in a KB system may include general problem solving knowledge as well as specific domain knowledge. In general, the domain knowledge is contained in the knowledge-base and the general problem solving knowledge is mostly built into the way the inference engine operates.

The process of using the knowledge-base and inference is a logical reasoning process. In knowledge representations, facts and rules are represented in terms of predictions. Rules become readable and easy to understand when a suitable syntax for defining predicates is chosen.

The form (P x y) is used to represent facts and rules, where P is predicate and x and y are arguments. The number of arguments in a form can be one or more. For example, the form, (Input-signal 7), means Input-signal is equal to 7 dBmV. The combination of a predicate and its arguments is "clause." A clause is logical statement with a truth value. A clause with only one predicate is a simple clause. A compound clause consists of a number of simple clauses linked by logical connectives (and, or, not). The basic syntax for a rule is any predicate-like structure. The format of a rule is:

```
(defrule <rule-name>
  if
        <antecedent-1>
              ....
        <antecedent-n>
  then
        <consequent-1>
              ....
        <consequent-n>
```

As an example, the following rule can be used:

```
(defrule count ch-parent-node outb
  if
        (type of cable ?trunk (equal ?trunk trunk))
        (direction ?direction (equal ?direction outbound)
        (current-node ?current-node)
        (parent-node ?parent-node)
        (Parent-trunk-children ?parent-trunk-children
                                 (listp ?parent-trunk-children))
        (<- ?temp1 (length ?parent-trunk-children))
        (<- ?temp2 (print-message "parent-node has " ?temp1 "children."))
        (<- ?temp3 (prompt-user 2-way-splitter 4-way-splitter 8-way-splitter))
```

```
    then
            (parent-children ?temp1)
            (need ?temp3))
```

Characters in bold must be typed exactly as shown except blank spaces. At least one blank space is required between symbols, variables or constants. <rule-name> is a user defined name to identify the rule. A rule is proved when the antecedent or premise ("If" part) of the rule matches known facts. I the all antecedents are proved, then the consequent are either new facts or actions to be executed. With variables, rules serve as predicates to express universal formulas. In rule "directives" are used to perform a procedural task.

A variable in a clause is said to be "instantiated" when there exists a fact in the working memory with identical structure to that of the clause from which the variable can take its value. All variables in a rule need first be instantiated in order for the rule to fire.

Variables are specified by the prefix "?." There are two ways to instantiate the a variable. First, by pattern matching with any fact asserted in the working memory. Second, with the directive "<-" which assigns the value(s) of an expression to the variable(s).

Filters are used to perform logical tests on the value of instantiated variables. This can be regarded as constraints for the variable. Any form can be evaluated provided that it returns either a rule or a false flag.

Two types of general procedural calls can be incorporated in a rule. First, functions can be called by reference to perform some action on the right-hand side of a rule. Second, functions can be called by a value to evaluate an expression within an antecedent or consequent. A function is treated as a predicate and it is simply called by a LISP expression.

6.4.3 The Inference Engine

The part of an expert system that carries out reasoning that uses knowledge to solve problems is called interface engine. The interface engine matches patterns within working-memory elements against the knowledge-base to decide what rules apply to the given situation. It carries out the consequences and antecedents are present in the working memory.

An inference engine combines facts and rules to arrive at conclusions. In cases when a large number of facts and rules are matched, the system needs methods of inference that can select what rule should be applied at each step in the reasoning process. The approach taken in this research is to associate priority indicators to the rules. Thus, the rules will be fired in a given sequence as ordered.

There are two broad strategies for controlling a reasoning process. The first strategy is to reason forward from the available facts and hope that the deduction of new facts will eventually lead to the deduction of the goal. This type of reasoning is known as a forward chaining or antecedent reasoning strategy. The alternative of forward chaining inference is backward chaining or consequent reasoning, where the inference process works backward from the goal. Backward chaining inference takes the goal as a hypotheses and then tries to prove a series of subgoals working backward from the goal. Each subgoal, in turn, becomes hypotheses during the reasoning process.

In forward chaining production systems the inference engine cycles through the rules until one is found whose premise matches a fact. This rule is then proved or fired, and the conclusion is added to the fact base. In this research, a forward chaining inference strategy is used.

In backword chaining inference, the system accepts a goal or hypotheses and tries to determine which other goal need to be proven in order to prove the initial goal. If these goals are not immediately available, they serve as new hypotheses that require further inference and so on. This type of reasoning is referred to as "backward chaining" because of the reasoning backward from the hypotheses to the data.

In addition to inference control, several other control schemes are implemented to (1) execute functions (or programs), (2) retrieve data from data base, (3) store newly created data into a data base, (4) backtrack if constraints are violated, (5) create a plan in which nodes of a network are ordered according to the distance to the root node.

6.4.4 The Database

The database is a collection of frames. Frames are used to represent the nodes in a network. Information regarding nodes to be considered is retrieved from the database and stored in the working memory. After these nodes are evaluated, the newly created information is copied from the working memory into the database.

6.4.5 The Control Module

One of the difficulties in implementing a KB system for system layout is how to divide a tree network (as shown in figure 6-1) into manageable pieces and feed them to the KB layout system.

The control module oversees overall execution of the network layout. It executes outbound trunk, inbound trunk, outbound feeder and inbound feeder layouts in that order. During the layout process of each branch of subsystems, it writes not only facts but also tries to feed relevant information into the working memory. Once a layout process for a branch is done, the control module clears the working memory and writes new facts and information for the next branch into the working momory. This process continues until all branches are considered, then the next branch of the subsystem begins.

Selection of parameters for one branch affect the parameters of the next branch. Because parameters are interrelated, it is desirable not to backtrack while layout is being carried out by the KB system. However, when a new node is created during layout process, this fact (new node) has not been considered before. In this case, backtracking is needed to redo the layout.

6.5 Knowledge Representation

Frames are a way of packaging knowledge within a well defined structure. A procedural function, called "demon," can be attached to a frame, when data are added into the slot of a frame ("if-added"). The if-added demon is used to check the signal level requirements when a new designed value is added to the frame.

Each frame has a higher-level frame (parent frame) to which it belongs. A slot is used to hold the value of an attribute. A frame may contain a number of slots that can be filled with specific instances or data. Frames can be used to handle default reasoning. In the absence of external information, a slot in a frame can be filled with a default value that will be assumed until new information is obtained.

In the frame structure, the topmost frame represents general concepts and the lower frames more specific instances of those concepts. This is done by connecting the frames in the series of "ISA": or parent-child relationships.

```
(FRAME :NAME frame-name
       :ISA frame-of-upper-hierarchy
       :WITH ((slot-1 aspect-1 value-1)
              (slot-2 aspect-2 value-2)

              (slot-n aspect-n value-n)))
```

Figure 6-3. Basic structure of frame.

```
(frame :name trunk-node
       :with ((cable size = 0.5)
              (cable-loss-high-outb = 1.65)
              (cable-loss-low-outb = 1.145)
              (cable-loss-high-inb = 1.015)
              (kind -of-cable = trunk)
              (cable-loss-low-inb = 0.172)))
```

Figure 6-4. A frame with default cable loss can be used in lower hierarchy frames.

If information from a frame is needed, and that information is not in the frame itself, that information can be obtained from its parent using the process of inheritance. Inheritance is a consequence of using knowledge structures organized in hierarchies. One uses a hierarchy by placing information at the highest level where it can reasonably be expressed. It can then be shared by all the nodes that are children or descendents of the node that contains the information.

The frame utilized in this research has the structure shown in figure 6-3. The :NAME keyword assigns a name to the frame in order to identify the frame, and it is used to access the frame. The :ISA keyword shows the hierarchy of a frame. The frame defined in figure 6-3, is a subclass of a "frame-of-upper-hierarchy." The various properties of a frame are expressed with the :WITH keyword. The ordering of the properties following :WITH is not significant. At present time, the "PRESUMED" and "=" aspects are utilized. For example, links in the trunk system has the same cable loss if the same cable trunk is used. If the frame is defined with the name of TRUNK-NODE with the cable loss at various frequencies as shown in figure 6-3, the frame |node-0| inherit these cable loss characteristics using :ISA TRUNK-NODE as shown in figure 6-5. Since these cable loss values are inherited from upper hierarchy frame, it is preceded by :PRESUMED aspect keyword. If a value is added directly to the specific frame, the aspect = is used.

```
#<frame :NAME |node-0|
        :ISA TRUNK-NODE
        :WITH CABLE-LOSS-LOW-INB :PRESUMED 0.172
             CABLE-LOSS-LOW-OUTB :PRESUMED 1.145
             CABLE-SIZE :PRESUMED 0.5
             CABLE-LOSS-HIGH-INB :PRESUMED 1.015
             CABLE-LOSS-HIGH-OUTB :PRESUMED 1.65
             DESIGN-CHECKED = NO
             TYPE-OF-CABLE = TRUNK
             SIGNAL-OUT-LEVEL = 50
             TERMINAL NODE = NO
             CHILDREN = (|node-9| |node-8| |node-2|)
             >
```

Figure 6-5. Frames inherit default cable loss.

CHAPTER 7

EXAMINATION OF DESIGNED NETWORK

Several experiments are conducted in this chapter to examine the designed network and determine whether it meets the MAP/TOP Broadband specification. If the input levels of the design comply with the required system performance parameters, the resulting network design will comply with the MAP/TOP Broadband specification.

7.1 Topology Design Module

Since the distance matrix is symmetric, either upper or lower diagonal elements of the symmetric matrix are needed. In order to input the data shown in figures 2-2 and 2-3, the input file has the format shown in figure 7-1. The number 10 in the first line is the dimension of the distance matrix.

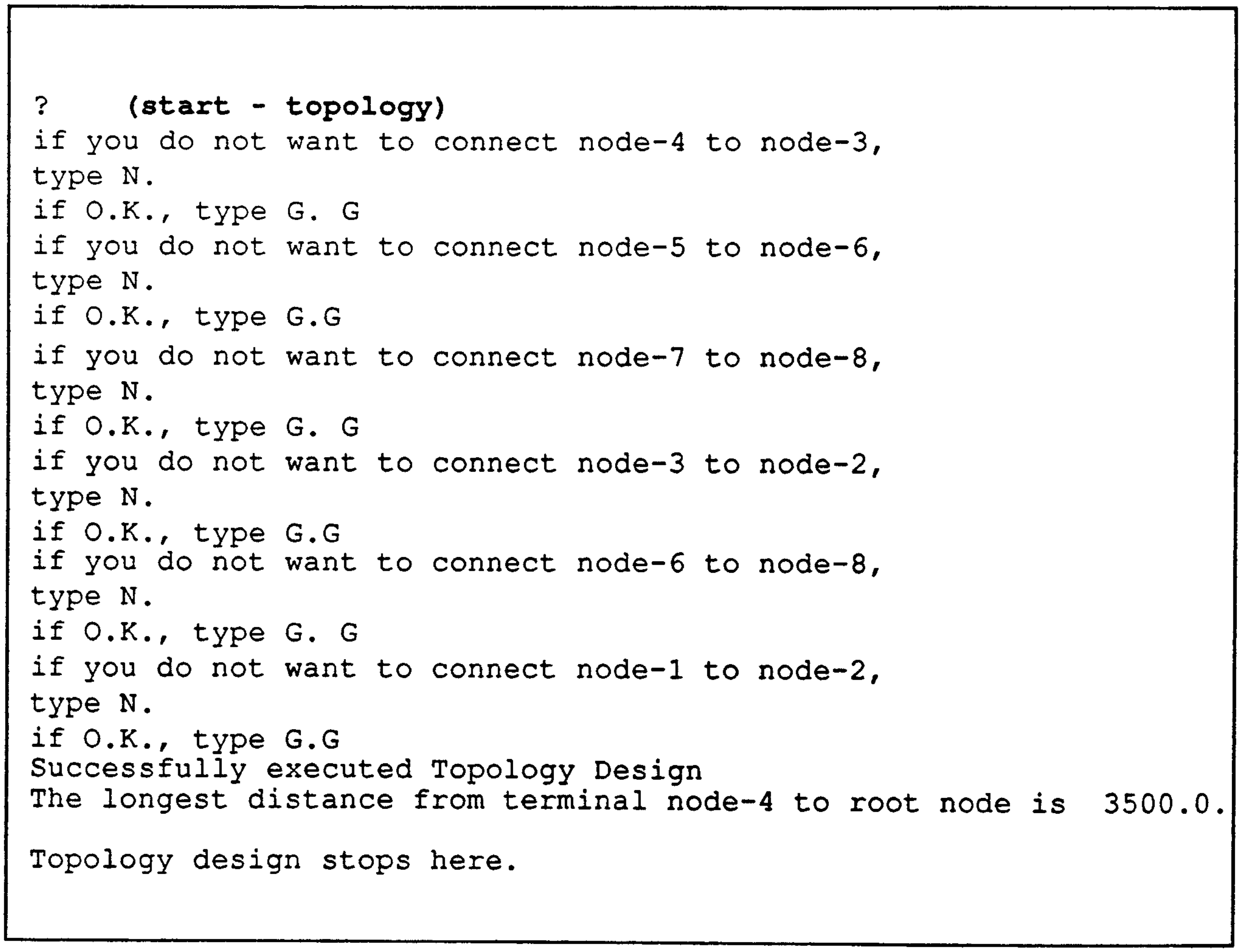
The basic format for inputting data is the number of children nodes followed by the distances between the parent node and children nodes. Blank spaces between numbers can be added for ease of inputting data. The four zeros after the dimension of the matrix indicate that the root node (node-0), node-1, node-2, node-3, in figure 2-1 do not have feeder children. The next line (#15) indicates that node-4 has 5 feeder branches as shown in figure 2-3. The number following "5" are distances between node-4 and its five children nodes. The next line (#16) indicates the first branch among the five branches has 6 feeder children and further indicates the distance between the parent node and its children nodes. The following six lines (#17 - #22) are for each feeder children specified above and represent tap strings. The next four lines (#23 - #26) of zero indicate there are no feeder children from that node. Finally five lines (#27 - #31) of zero indicate that node 6 through node 10 do not have children nodes.

Figure 7-2 shows a sample trace of the topology design process. The results are internally stored for the next phase of network design. For purposes of verifying the

```
10                                            ; dimension of matrix           #1

2100 1340 2400 3140 2460 1960 1940 1420 740   ; first row of matrix           #2
1240 1340 2460 2880 2800 3360 2860 2840                                       #3
1060 1960 1780 1620 2160 1640 2000                                            #4
1100 1800 2000 2800 2400 3040                                                 #5
1500 2000 2860 2660 3700                                                      #6
640 1460 1420 2760                                                            #7
880 780 2180                                                                  #8
460 1820                                                                      #9
1440                                          ; 9th row of distance matrix    #10

0                                             ; number of feeder children     #11
0                                                                             #12
0                                                                             #13
0                                                                             #14

5 490 680 550 380 580                         ; number of feeder children     #15
6 150 240 70 150 240 70                       ; and distances between         #16
1 100 1 100 1 100 1 100 1 100 0               ; parent and its children       #17
1 100 1 100 1 100 1 100 1 100 0                                               #18
1 100 1 100 1 100 1 100 1 100 0                                               #19
1 100 1 100 1 100 1 100 1 100 0                                               #20
1 100 1 100 1 100 1 100 1 100 0                                               #21
1 100 1 100 1 100 1 100 1 100 0                                               #22

0                                             ; number of feeder children     #23
0                                                                             #24
0                                                                             #25
0                                                                             #26

0                                                                             #27
0                                                                             #28
0                                                                             #29
0                                                                             #30
0                                                                             #31
```

Figure7-1. Input file for the topology module.

results, frames are shown in figure 7-3. Each frame has information on parent-children relationships. For example, node-0 has three children nodes and node-2 has two children nodes and its parent node is node-0. From the information contained in these frames, the topology of a network can be determined. Consider terminal node-4 first. The parent is node-3 and the distance between them is 1,100 feet while the parent node of node-3 is node-2 with a distance of 1,060 feet and the parent node of node-2 is node-0 with a distance of 1,240 feet. Note that nod -0 has no parent node since it is a root node. Repeating this process with other terminal nodes, the topology of the network shown in figure 2-4 is constructed.



```
?    (start - topology)
if you do not want to connect node-4 to node-3,
type N.
if O.K., type G. G
if you do not want to connect node-5 to node-6,
type N.
if O.K., type G.G
if you do not want to connect node-7 to node-8,
type N.
if O.K., type G. G
if you do not want to connect node-3 to node-2,
type N.
if O.K., type G.G
if you do not want to connect node-6 to node-8,
type N.
if O.K., type G. G
if you do not want to connect node-1 to node-2,
type N.
if O.K., type G.G
Successfully executed Topology Design
The longest distance from terminal node-4 to root node is  3500.0.

Topology design stops here.
```

Figure 7-2. Sample trace of the example topology design.

```
#<frame :NAME   |node-0|
  :ISA TRUNK NODE
  :WITH CABLE-LOSS-LOW-INB :PRESUMED 0.172
        CABLE-LOSS-LOW-OUTB :PRESUMED 1.145
        CABLE-SIZE :PRESUMED 0.5
        CABLE-LOSS-HIGH-INB :PRESUMED 1.015
        CABLE-LOSS-HIGH-OUTB :PRESUMED 1.65
        DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        SIGNAL-OUT-LEVEL  =  50
        TERMINAL-NODE  =  NO
        CHILDREN = (|node-9| |node-8| |node-2|)
        >

#<frame :NAME  |node-1|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1240
        PARENT  =  |node-2|
        TERMINAL-NODE  =  YES
        >

#<frame :NAME  |node-2|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1340
        PARENT  =  |node-0|
        TERMINAL-NODE  =  NO
        CHILDREN  =  (|node-1| |node-3|)
        >

#<frame :NAME  |node-3|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1060
        PARENT  =  |node-0|
        TERMINAL-NODE  =  NO
        CHILDREN  =  |node-4|
        >

#<frame :NAME  |node-4|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1100
        PARENT  =  |node-3|
        TERMINAL-NODE  =  YES
        >
```

```
#<frame :NAME  |node-5|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  640
        PARENT  =  |node-6|
        TERMINAL-NODE  =  YES
        >

#<frame :NAME  |node-6|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  780
        PARENT  =  |node-8|
        TERMINAL-NODE  =  NO
        CHILDREN  =  |node-5|
        >

#<frame :NAME  |node-7|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  460
        PARENT  =  |node-8|
        TERMINAL-NODE  =  YES
        >

#<frame :NAME  |node-8|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1420
        PARENT  =  |node-0|
        TERMINAL-NODE  =  NO
        CHILDREN  =  (|node-6| |node-7|)
        >

#<frame :NAME  |node-9|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  240
        PARENT  =  |node-0|
        TERMINAL-NODE  =  YES
        >
```

Figure 7-3. Results of topology design.

Along with the decision on network topology, a sequence of longest branches of the network tree is required and is passed on to later phases of network design. To find the longest branch of the network, programs for growing a tree, given a root node, are developed as shown in figure 7-4. The end result is a stack with the longest branch on the top and the shortest one on the bottom.

7.2 System Design Module

The example presented in section 5 of chapter 4 is used to verify and validate the system design module.

7.2.1 Distortion and C/N Ratio Allocations

The allocations of distortions and C/N ratios to various subsystems presented in Tables 4-2 and 4-4 are used to verify the results from the system design module as shown in figures 7-5 and 7-6. The system prompts the user to repeat the allocation process until satisfied with the values. The values chosen with the last iteration are used in subsequent calculations of system design parameters.

The MAP/TOP Broadband specification specify the overall network system CTB equal to or better than 53 dB, and the outbound and inbound C/N ratios equal to or better than 43 dB and 40 dB, respectively. The system performance parameters are allocated to various subsystems in the network so that overall system performance is within specifications. After allocating these system performance parameters to each subsystem of a network, the system layout parameters for each subsystem can be determined.

7.2.2 Trunk System Design

Sample traces of trunk system design, presented in sections 4.2 and 4.4 of chapter 4, are shown in figures 7-7 and 7-8 for outbound and inbound, respectively. The design

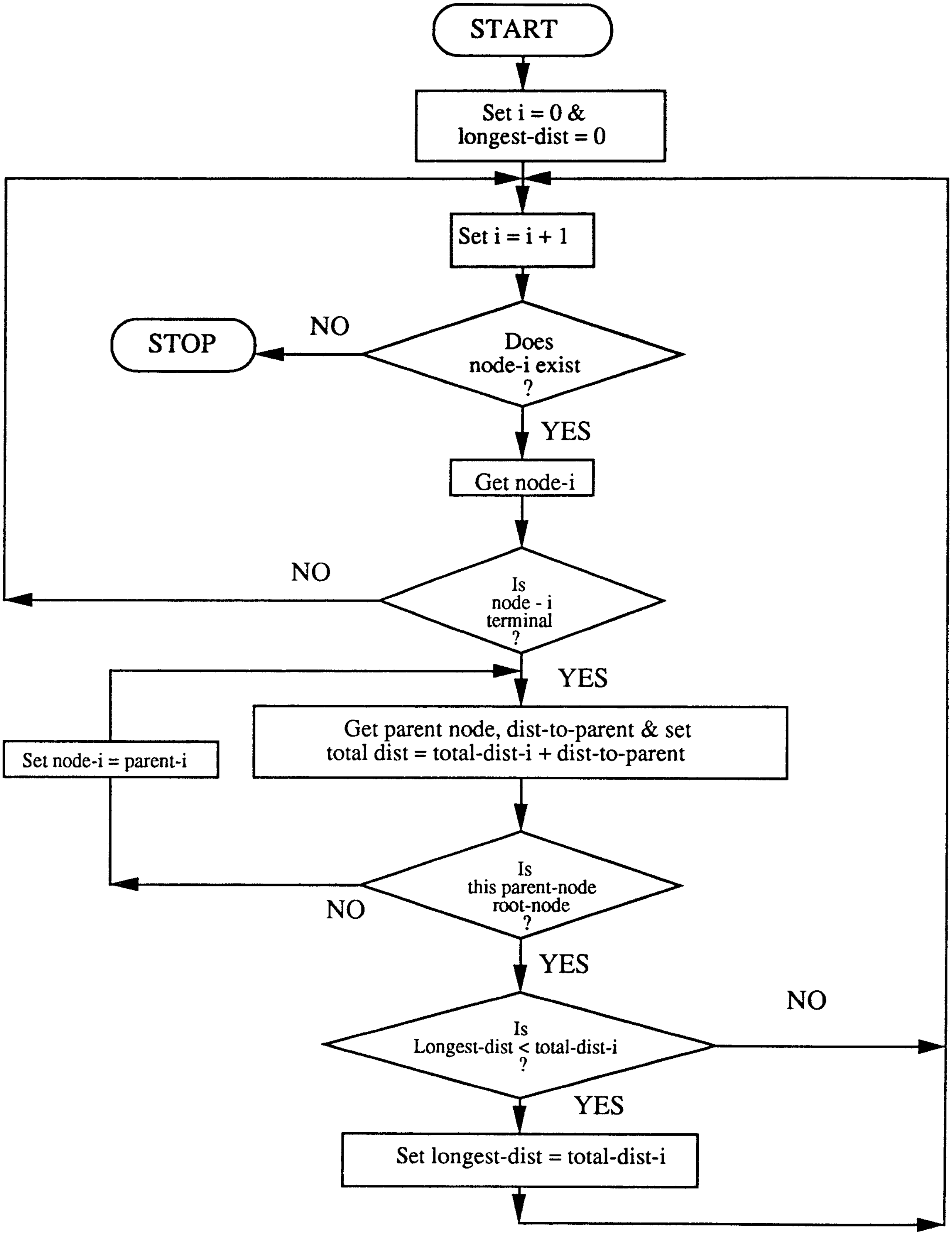


Figure 7-4. Longest distance from terminal node to root node.

```
? (dist-allocate)

The required system CTB is 53.0 dB.  How do you want to
allocate between outbound and inbound? Type outbound CTB.
Inbound will be calculated.  58

The calculated ctb for inbound is -60.17728917966038.
If you want to repeat, type REDO, if not, type any character.  no

The allocated outbound CTB is 58.  How do you want to
allocate between trunk and feeder? Type in trunk
CTB.  Feeder CTB will be calculated.  70

The calculated ctb for outbound feeder is -60.5125515498363.
If you want to repeat, type REDO, if not, type any character.  no

The allocated inbound CTB -60.17728917966038.  How do you
want to allocate between trunk and feeder? Type in trunk
CTB.  Feeder CTB will be calculated.  70

The calculated ctb for inbound feeder is -63.56229182613637.
If you want to repeat, type REDO, if not, type any character. no
```

Figure 7-5. Sample trace of CTB allocation in subsystems.

```
? (cn-allocate)

The required outbound C/N ratio is 43.0.  How do you want to
allocate between trunk and feeder? Type in trunk
C/N ratio.  Feeder C/N ratio will be calculated.  45

The calculated C/N ratio for outbound feeder is 47.32923433336247
If you want to repeat, type REDO, if not, type any character.  no

The reauired outbound C/N ratio is 40.0.  How do you want to
allocate between trunk and feeder? Type in trunk
C/N ratio.  Feeder C/N ratio will be calculated.  42

The calculated C/N ratio for inbound feeder is 44.32923433336248.
If you want to repeat, type REDO, if not, type any character.  no
```

Figure 7-6. Sample trace of C/N allocation to subsystems.

parameters for the outbound trunk subsystem include I/O levels of an amplifier, usable gain of an amplifier, number of amplifiers in cascade, C/N ratio, CTB, X-Mod, second order distortion and hum modulation distortions. From figures 7-7 and 7-8, it can be seen that resulting design parameters are the same as manually calculated values in chapter 4.

The design parameters for the inbound trunk subsystem are similar to those of the outbound trunk subsystem. However, during the process of inbound trunk system design, the number of amplifiers that used in the network should be estimated as well as the number of amplifiers in cascade.

The input level of the inbound trunk amplifier shown in figure 7-8 is based on the minimum allowable input level within the specification.

7.2.3 Feeder System Design

Sample traces of feeder system design, presented in sections 4.3 and 4.5 of chapter 4, are shown in figures 7-9 and 7-10 for outbound and inbound, respectively. the design parameters for the outbound feeder subsystem include I/O levels of bridger and feeder amplifiers, usable gain of bridger and feeder amplifiers, number of amplifiers in cascade, C/N ratio, CTB, X-Mod, second order distortions and hum modulation distortions. The results are same as presented in chapter 4.

The design parameters for inbound feeder subsystems are similar to those of outbound feeder subsystems. As in the case of trunk system design, the number of amplifiers should be estimated that are needed to be used in the feeder subsystem as well as the number of amplifiers in cascade. The reason for doing this is because all amplifiers in the network are considered as noise generators when designing inbound systems.

7.3 Supporting Functions for Layout

One of the major problems in applying the KB systems is interconnection between subproblems,such as a node that has multiple children. In such cases satisfying constraints in one link of parent-child nodes may violate the constraints in other links of parent-child nodes. In order to avoid this situation, the approach taken in this research is to provide as much information as possible so that there is no need of backtracking. The only exception to this rule is when a new node is created during the system layout process and necessary

```
? (trunk-outbound)

please type anumber for future expansion factor.  2.0

Minimum required amplifier cascade for the longest cable run is 6.
If you want to change this number please type the number of cascade you decide.
If you do not want to change this value, type NO.
Calculated value will be used in subsequent calculations.  no

NO.

Calculated C/N ratio of an outbound trunk amplifier is 52.78151 dB
with input signal level of 2.78151 dBmV.  If you want to adjust C/N ratio
and input signal level of an outbound trunk amplifier, please type desired
input signal level.  One dB increase (decrease) in input signal raises (lowers)
C/N ratio by 1 dB.  If not, type NO.  Calculated value will be
used in subsequent calculations.  3.0

3.0

The default value for outbound channel loading is 35.
Please type the desired number of channel loading.
If not, type NO.  Default value will be used in subsequent calculations.  no

OUTBOUND TRUNK INPUT SIGNAL LEVEL :3.00000 dBmV
          OUTPUT SIGNAL LEVEL: 25.00000 dBmV
          USABLE GAIN: 22.00000 dB
          C/N RATIO:  45.21849 dB
          CTB: -84.43697 dB
          X-MOD: -89.43697 dB
          SECOND ORDER DISTORTION: -72.43697 dB
          HUM MODULATION DISTORTION: -54.43697 dB

If you want to change output signal level and usable gain of the trunk amplifier
and see the resulting system parameters, type REDO.  If not, type STOP.
System parameters determined will be used for subsequent calculations.  stop

The number of iterations for outbound trunk design is 0.
```

Figure 7-7. Sample trace outbound trunk design.

information of that node is not available. In that case backtracking to the previous node is needed to gather information to the newly created node. Signal level requirements along the feeder are found as discussed in chapter 5 and implemented as shown in figure 7-11. Since the calculation is based on the signal level requirements of terminal nodes, these signal levels represent the minimum required signal levels.

7.4 Knowledge_Based System for System Layout

The approach to layout in all four subsystems is essentially the same. The only differences lie in the rule-bases, facts and different values of design parameters.

Any tree network can be represented with parent-children relationships as shown in figure 7-12. A parent node may have one or more children; however a child node has only one parent. For the purpose of discussion, various signal levels are referred to as follows:

parent-node-in-outbound — input signal level to the parent node for outbound
parent-node-out-outbound — output level signal from the parent node for outbound
child-node-in-outbound — input level signal to the child node for outbound
child-node-out-outbound — output level signal from the child node for outbound
child-node-in-inbound — input level signal to the child node for inbound
child-node-out-inbound — output level signal from the child node for inbound
parent-node-in-inbound — input level signal to the parent node for inbound
parent-node-out-inbound — output level signal from the parent node for inbound

The outbound system will be discussed first. The same logic applies to both trunk and feeder subsystems. Starting with the root node (node-0) where the headend is located, a child node is found along the longest branch of the network tree. The known facts are copied in into the working memory (WM) of the KB system. These include output signal level from the headend (parent-node-in-outbound), distances between nodes, cable attenuation per 100 feet, cable type, direction of design, input level of an amplifier for the given cable type and direction, number of direction nodes for each parent node, etc. By applying a knowledge base to these facts, the interference engine deduces new facts and places it into WM. If the signal level (child-node-in-outbound) at a child node is within the range of system design parameters, design of this link is completed and the control module

```
? (trunk-inbound)

please type an estimateto the total number of inbound trunk amplifiers. 6

Please type the number of inbound trunk amplifiers in cascade. 4

 The equivalent cascade of inbound trunk amplifiers are 5.
If you want to change, please type desired equivalant cascade of inbound
trunk amplifiers. If you do not want to change this value, type NO.
Calculated value will be used in subsequent calculations. no

NO.

Calculated C/N ratio of an inbound trunk amplifier is 48.98970 dB
with input signal level of -2.01030 dBmV.
 If you want to adjust C/N ratio and input signal level of an inbound
trunk amplifier, please type desired input signal level.
 One dB increase (decrease) in input signal raises (lowers)C/N ratio by 1 dB.
If not, type NO. Calculated value will be used in subsequent calculations. -2.0

-2.0

The default value for outbound channel loading is 28.0.
Please type the desired number of channel loading.
If not, type NO. Default value will be used in subsequent calculations. no

 INBOUND TRUNK INPUT SIGNAL LEVEL : -2.00000 dBmV
          OUTPUT SIGNAL LEVEL: 18.00000 dBmV
          USABLE GAIN: 20.00000 dB
          CASCADE: 5
          C/N RATIO: 42.01030 dB
          CTB: -109.95880 dB
          X-MOD: -103.95880 dB
          SECOND ORDER DISTORTION: -89.95880 dB
          HUM MODULATION DISTORTION: -57.95880 dB

If you want to change input signal level and usable gain of the trunk
amplifier and see the resulting system parameters, type REDO.
If not, type STOP.
System parameters determined will be used for subsequent calculations. stop

The number of iterations for outbound trunk design is 0.
```

Figure 7-8. Sample trace inbound trunk design.

```
? (feeder-outbound)

Calculated feeder system CTB is -58.42416 dB
With outbound trunk CTB of -84.43697 dB.
If you want to adjust this CTB of the feeder system,
please type desired CTB of outbound feeder system. If not, type NO,
and the calculated value will be used in subsequent calculations.  no

NO.

Bridger input level is 16.01671 dBmV, and output level is 44.01671 dBmV
with usable gain of 28.00000 dB.
OUTBOUND FEEDER INPUT SIGNAL LEVEL : 13.01671 dBmV
          OUTPUT SIGNAL LEVEL: 43.01671dBmV
          USABLE GAIN: 30.00000 dB
          CASCADE: 3
          C/N RATIO:  60.53525 dB
          CTB: -58.42416 dB
          X-MOD: -61.42070 dB
          SECOND ORDER DISTORTION: -73.44087 dB
          HUM MODULATION DISTORTION: -6045757 dB

If you want to change INput signal level and usable gain of the bridger and
feeder amplifiers and see the resulting system parameters, type REDO.
If not, type STOP.
System parameters determined will be used for subsequent calculations.  stop

The number of iterations for outbound trunk design is 0.
```

Figure 7-9. Sample trace outbound feeder design.

```
? (feeder-inbound)

please type an estimateto the total number of inbound feeder amplifiers. 40

Please type the number of amplifiers in inbound feeder cascade. 3

The equivalent cascade of inbound feeder amplifiers are 11.
If you want to change, please type desired equivalant cascade of inbound feeder
amplifiers. If you do not want to change this value, type NO.
Calculated value will be used in subsequent calculations. no

NO.

Allocated C/N ratio for inbound feeder system is 45.00000 dB.
If you want to adjust the C/N ratio of the feeder system,
please type the desired C/N ratio. If not, type NO. no

NO.

Calculated C/N ratio of an inbound trunk amplifier is 55.41393 dB
with input signal level of 3.9139 dBmV. If you want to adjust
 C/N ratio and input signal level of an inbound feeder amplifier,
please type desired input signal level.
 One dB increase (decrease) in input signal raises (lowers)C/N ratio by 1 dB.
If not, type NO. Calculated value will be used in subsequent calculations. 4.0

4.0.

INBOUND TRUNK INPUT SIGNAL LEVEL : 4.00000 dBmV
          OUTPUT SIGNAL LEVEL: 26.00000 dBmV
          USABLE GAIN: 22.00000 dB
          CASCADE: 11
          C/N RATIO: 45.08607 dB
          CTB: -85.45757 dB
          X-MOD: -94.45757 dB
          SECOND ORDER DISTORTION: -86.45757 dB
          HUM MODULATION DISTORTION: -60.45757 dB

If you want to change input signal level and usable gain of the feeder amplifier and
 see the resulting system parameters, type REDO.
If not, type STOP.
System parameters determined will be used for subsequent calculations. stop

The number of iterations for outbound trunk design is 0.
```

Figure 7-10. Sample trace inbound feeder design.

clears the WM and places the new facts into the WM for design of the next node in the branch. Now, a current child node becomes a parent node. This process continued for all branches of the network tree until all nodes are considered.

Once outbound layout is done, the control module places new facts regarding the terminal node and its parent node into the WM and loads the rule base for inbound system layout. This process is similar to the outbound system layout.

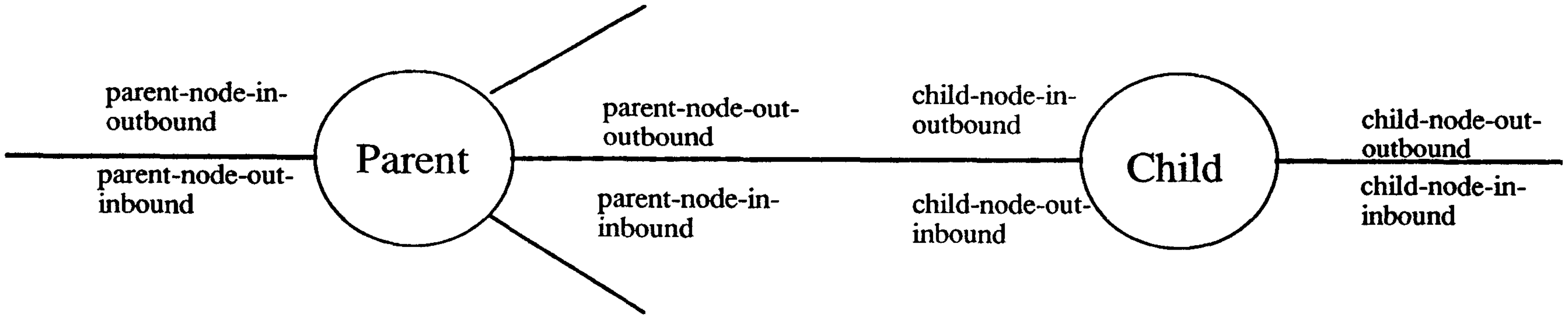


Figure 7-11. Representation of a network with parent children relationship.

CHAPTER 8

CONCLUSIONS

8.1 The Topology Design

The topology module has been implemented to determine near-optimum topology of a broadband cable network based on Esau and Williams algorithm. The module produces either a minimum spanning tree, star or a combination of the two depending on the requirements. Consequently, this module provides the network topology that is required by the MAP/TOP Broadband specification.

8.2 The System Design

The system design module has been developed and it allocates system performance parameters to each subsystem of a trunk-plus-feeder cable system based on the MAP/TOP Broadband specification. Next, the module determines usable gains and input/output levels of amplifiers for each subsystem within the allocated system performance parameters. A printout of system parameters is produced at each stage of design the so that it could be determined whether to repeat the system design process.

8.3 The Knowledge-based System

The objective of this research was to build a knowledge-based system for broadband cable LANs. Because of the uniqueness of a broadband cable LAN design, it is difficult to apply not only existing KB systems to broadband LAN design but also the developed KB systems to other design problems. The results in chapter 7 showed that the developed KB system produced designs which comply with the MAP/TP Broadband specifications. Thus the objective of this research has been achieved. The main aspects of prototype KB system are:

1. Network design problem representation:

   One of the difficulties in applying the KB systems to design concerns how best to represent design problems. The method developed in this research is to decompose the tree structure of a network into a parent-child relationship. Thus, any tree network can be represented with this approach. Without this general representation scheme, it is difficult to apply a KB system to the network design problem because there is an infinite variety of tree networks.

2. Novel features of the knowledge based system used in this research:

   The problem of applying an existing KB system to the system layout of the broadband cable network design is made difficult by the fact that an inference engine must be applied repeatedly to each link of a network. In order to do this, a control program is required which is outside the scope of a KB system. In other words the execution of a KB system is guided by a higher-level control program. Depending on the plan which was created when the topology of a network was designed, the control block in figure 8-1 loads the appropriate rule database and writes facts into the working memory. For example, for the trunk outbond layout shown in figure 7-13, the trunk outbound rule base was loaded once and new facts were written six times (facts on parent-child nodes, i.e., |node-0| - |node-2| and new node-1 - ||node-2||, |node-2| - |node-3|, new node-2 - |node-3|, |node-3| - |node-4|, new node-3 - |node-4|) into the working memory.

   When a new node is created, there must be ways to handle this situation because information regarding this new node is not readily available but must be calculated or obtained. In this research, when a new node is created, information on parent child node is updated and the current child node becomes the parent node of the newly created node. A particular rule in the rule base detects this situation, places the current child node into the top of the plan and stops the inference process. Detecting the situation, the control block clears the working memory and writes new facts into it. The working memory now contains facts on the newly created parent node and child node which was put on the top of the plan.

   In order to save computing time for matching rules to facts, four separate rule databases (trunk-outbound, trunk-inbound, feeder-outbound and feeder-inbound) are used in this research as shown in figure 8-1.

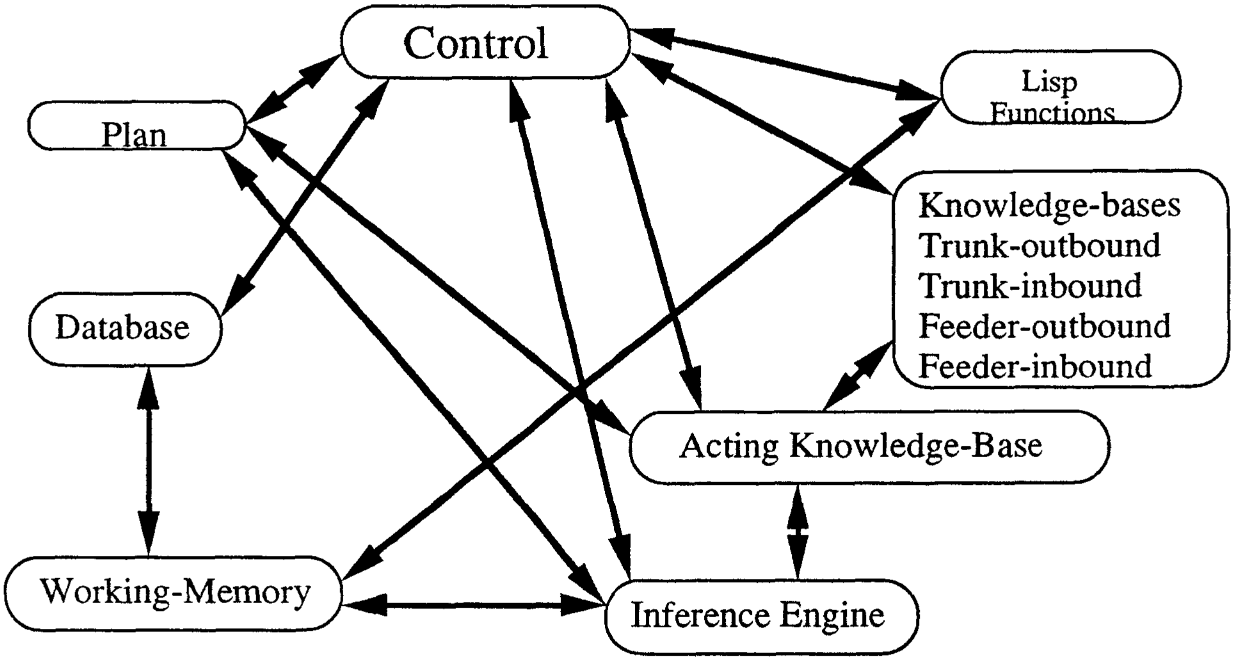


Figure 8-1. Structure of knowledge-based system.

3. Use of symbolic and numerical computing in the knowledge base:

   The inference engine is built to handle both symbolic and numerical computing so that rules can be written with flexibility. For instance, when an amplifier is needed based on numerical calculations, new facts, such as (an-amplifier-is needed yes) can be written into working memory.

8.4 Contributions

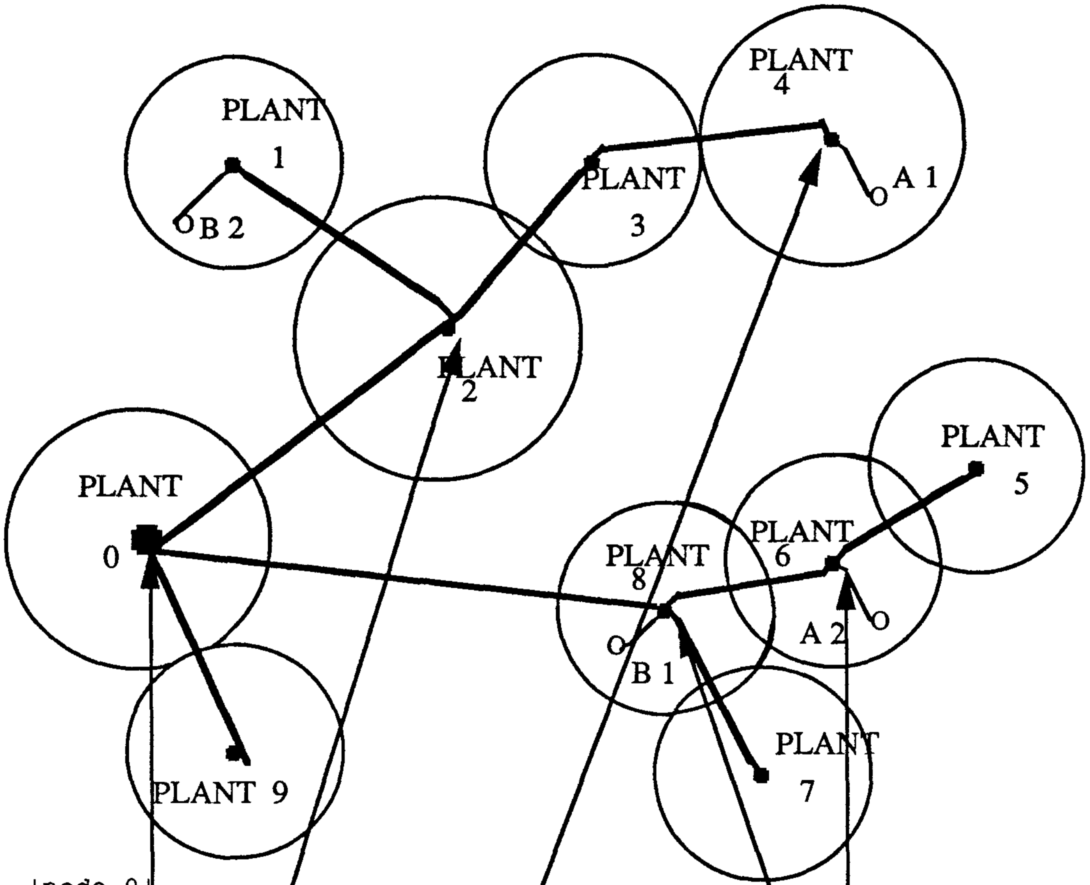
1. An analysis of the of the fundamental design problem structure was made and an examination of the potential application of a KB system to these problems was carried out.

2. An actual KB system was implemented to address the broadband cable layout problem. Thus, feasibility of a KB system was established for broadband cable network design.

3. An actual system was implemented which integrates the topology design with the system design and layout of a broadband network. The topology of a broadband network is important because it affects the performance of the network.

4. Development of a control structure to handle system layout problems: an application of KB system to a network layout problem is difficult because the number of nodes in the network is not fixed. During the system layout process new nodes are created and a methodology to handle these newly created nodes is needed so that a KB system can be applied to every node in the network. A control scheme was developed which allows the developed KB system to follow the broadband design.

5. Analysis was performed of the relationship among inputs and outputs of amplifiers, number of amplifiers in cascade and system specifications.



```
#<frame :NAME   |node-0|
  :ISA TRUNK NODE
  :WITH CABLE-LOSS-LOW-INB :PRESUMED 0.172
        CABLE-LOSS-LOW-OUTB :PRESUMED 1.145
        CABLE-SIZE :PRESUMED 0.5
        CABLE-LOSS-HIGH-INB :PRESUMED 1.015
        CABLE-LOSS-HIGH-OUTB :PRESUMED 1.65
        DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        SIGNAL-OUT-LEVEL  =  50
        TERMINAL-NODE  =  NO
        CHILDREN = (|node-9| |node-8| |node-2|)
        >

#<frame :NAME  |node-2|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1340
        PARENT  =  |node-0|
        TERMINAL-NODE  =  NO
        CHILDREN  =  (|node-1| |node-3|)
        >

#<frame :NAME  |node-4|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1100
        PARENT  =  |node-3|
        TERMINAL-NODE  =  YES
        >
```

```
#<frame :NAME  |node-6|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  780
        PARENT  =  |node-8|
        TERMINAL-NODE  =  NO
        CHILDREN  =  |node-5|
        >

#<frame :NAME  |node-8|
  :ISA TRUNK-NODE
  :WITH DESIGN-CHECKED  =  NO
        TYPE-OF-CABLE  =  TRUNK
        DIST-TO-PARENT  =  1420
        PARENT  =  |node-0|
        TERMINAL-NODE  =  NO
        CHILDREN  =  (|node-6| |node-7|)
        >
```

Figure 8-2. Results of network design and frames created during system layout.

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APPENDIX

Broadband networks, advantages and applications.

Broadband in the context of communication links, refers to a technique that multiplexes radio frequency signals onto a single network cable. It provides the most cost-effective means of supporting communications.

Industrial broadband local area networks (LANs) have been on the scene for some 15 years. When they were first introduced, and for some years after that, there were some equipment problems. These were due to a combination of the newness of technology and inexperience and incomplete training of the installers and users. Newer network designs get around many of these problems by using preengineered/preassembled modules that contain the various network component. The preengineered/preassembled aspect of these modules goes a long way towards increasing system reliability. To begin with, it assures users that all component connections and cable terminations are done properly. Another fringe benefit is that the final assembly can be tested as a complete unit before installation is complete. Modules allow a very straight forward network approach to be used, following a simple set of design rules

Broadband components as signal amplifiers, frequency division multiplexers (FDMs), cabling systems, network adapters, media access control (MAC) level bridges and communications processors are arriving from a growing number of vendors. In addition, more network managers in large offices and factories perceive broadband "backbones" as the best solution for interconnecting discrete LANs, scattered workstations and computers. Not only that, the eventual acceptance of Manufacturing Automation Protocol (MAP), sponsored by such players as General Motors Corp., should ensure the installation of broadband network backbones in large manufacturing operations. it's ideal for use in high-speed, high-bandwidth systems that links LANs, workstations and mainframes into a unified network.

Typical materials used in the construction of broadband coaxial cable provide lower I R loss in the distribution of power to amplifiers, they provide adequate conduction for RF signals. It is available for economical access to personal computers at data rates much higher than RS-232 allows and more advanced network services can be employed on large scale. Broadband equipment is highly standardized. Cables and fittings from different vendors can be mixed and matched. In some cases, even amplifiers and more complicated equipment is interchangeable. There are only two alternatives to broadband. The first is carrier band, a network carrying a single channel of information modulated onto a carrier. the problem with this method is that it can support only short cable runs.It is fine for small local area networks (LANs). The second alternative is fiber-optic LANs. These networks are acceptable for large installations because light signals travel through the cables essentially without loss. However the fiber connections are expensive enough to make campus like networks uneconomical. Broadband networks, on the other hand are relatively inexpensive. One reason is that they are based on the technology used in cable TV cables, connectors and signal sources for broadband factory networks are identical to those found in CATV installations. High volume use of these devices has already lowered the costs. In addition, the large number of suppliers and intense competition tend to keep prices low.

Two type of broadband systems are in wide use, single cable and dual cable. Single-cable systems allow stations to transmit and receive on the same cable but different frequencies. In dual-cable systems, all stations transmit and receive at the same frequency, but on different cables. The end of transmit cable. The end of the transmit cable connects to the beginning of the receive cable, forming the double loop through the plant.

In this research, single cable installations are used. In MAP, a station transmits at frequencies between about 60 and 90 MHz. The signals travel down to the so-called headend or central retransmission facility. this centrally located equipment area is fortified with safeguards such as lightening protection and fail-safe power supplies. Such safeguards are needed because a failure at the headend takes down the entire network. The headend contains signal generating equipment that includes remodulators or translators. Translators are analog devices and remodulators are digital instruments that perform the same function. A major advantage of a remodulator is that it eliminates the electrical noise present in the inbound signal before it rebroadcasts the outbound frequency, therefore remodulator is used in this research.

The headend may also contain signal processors, which retransmit video sent in the form of network. In addition, the facility contains the test equipment for system maintenance. Most systems broadcast a sniffer signal on the network to watch for RF leaks. the sniffer is an FM signal with a specific tone that is put in unused frequency range. The network is then patrolled with an FM receiver,which looks for the tone. If cable damage allows the signal to escape into the atmosphere, sniffer equipment helps track down the location of the problem.

Broadband networks are generally designed to what is called unity gain. This means that the gain of the given amplifier is just equal to the sum of the cable losses and the power dissipated by stations in that section of link. Systems are also generally designed so that all amplifiers are set for the same amount of gain. This can degrade carrier-to noise margins. For example, in the circuit depicted, boosting the gain of one modem could bring the level of signal A high enough to impinge on the envelope of signal B on the adjacent channel of the system. Thus, B become noise to A, reducing the carrier-to-noise ratio. Amplifier gains and signal margins are calculated using results of path loss measurements. Forward path loss is measured by inserting a signal generator at the headend and using an RF meter at various taps to gage signal strength. To measure reverse path loss, the generator would be placed at various taps, and the RF meter would be placed at the output of a splitter at the headend.

Amplifiers commonly used by broadband systems are trunk and bridging types. Trunk amplifiers are used to maintain a given signal level throughout the trunk line. The amplifiers are characterized as high-quality equipment having extremely low distortion. Typical output levels are 45 dBmV for a single amplifier. As these amplifiers are cascaded in the system, distortion introduced by each amplifier adds up, so in order to offset this effect , the output of each amplifier should be reduced by 3 dB every time the number of amplifiers in the system doubles. Thus, the cascading of twenty 45 dB amplifiers means that each amplifier in the cascade is set to a 32 dBmV output level. The reduction of the output is normally done by introducing pads, or signal attenuators, at the amplifiers input or output. In systems where the signals travel in both directions on the trunk, bidirectional amplifiers are needed. Pads are required in both directions in this case.

Bridging amplifiers are used to bring signals of the trunk to distribution legs. The amplifiers receive their input from taps made into the trunk cable. Bridging amplifiers are less expensive than trunk amplifiers, but of lower quality. Their outputs are considerably higher as well, these type of amplifiers are not designed to be cascaded. The alternative to bridging amplifiers is splitters.

Broadband technology has been the technology of choice for wide area networks. One LAN project involved a network with 1500 nodes, covering 90 buildings within three mile radios. Three host computers and 1500 PCs were interconnected with Ethernet, baseband and twisted-pair media. Moreover, each workstation required three different terminals to access the three hosts. The underground twisted-pair cabling was also susceptible to failure from flooding and cave-ins. Weather conditions also affected infrared communications between some of the buildings and network caused interference on telephone lines.

After consulting Navel Aviation Depot (NAVAVN), Almada, Calif., Allied Data Communication Group, Atlanta, upgraded the LAN with broadband system, which was completed three years ago. Though the new design is primarily broadband, parts of the depot's prior interconnections with Ethernet and baseband are bridged onto it. The remaining twisted-pair interconnections are phased out. The 1500, 80286 PC-ATs use terminal emulation software to eliminate the need for separate terminals to access the network hosts: two DEC VAX machines, the Tandem TXP and a Univac 1100 mainframe. The LAN also connects 90 buildings through RF modems.

The fundamental difference between broadband and baseband is in the manner in which data is transmitted over the network cable. A baseband network such as Eathernet (IEEE 802.3) uses the entire cable bandwidth as one channel. Only one signal is transmitted at any given instant and the signal is sent in its original form and frequency, rather than modulating an RF carrier. Baseband technology is preferred technology for digital data-only LANs because the absence of signal conversion makes possible the use of readily available and inexpensive line drivers and receivers.

Broadband signaling uses amplitude, frequency or phase modulation of an RF carrier. Modulation and demodulation are handled by circuitry much like that used in CATV systems. Moreover, such broadband components as coaxial cable, couplers, repeaters, splitters and taps are same as those used in CATV systems. Networks implemented with broadband coaxial cable can have bus or tree topologies, through a bus configuration with a headend node behaves as a star topology. A broadband coaxial cable can support up to about 25,000 nodes and has an aggregate data-handling capability of over 100 M bits/s. This network medium also has better immunity to noise and electromagnetic interference than twisted-pair cables used in baseband networks.

The major design advance for broadband network has been the advent of fully featured network status monitoring systems, which report on such parameters as signal levels and component currents and voltages. They can make a day to day operation of a broadband network more cost effective, and help in the areas of diagnostics and problem solving. The main elements of these status monitoring systems are a PC-based host running the system software, a master controller, remote transponders that relay signal levels and other information, amplifiers and power supply monitors, and line switches.

The master controller serves as the polling engine for the system. It communicates with the remote transponders via a dedicated frequency on the monitored broadband systems. The controller processes the PC's request for information, communicates that request to the appropriate transponders, and distills the response into a form that the PC will accept.

The technology of broadband coaxial networks has always offered a potential unsurpassed by any other media. This technology has recently benefited from design improvements and new products that will allow users to obtain these advantages with much higher reliability then previously available. The improvements have also lowered the cost of installing, operating and maintaining these networks, and shortened the time it takes to move a system to operations status. All of these advantages are achieved simplifying the installed equipment and tightening the management of network operations.

According to Eric Lundgren (Industrial Broadband Networking Comes of Age), The cost savings can be derived from increasing the reliability and maintainability of a broadband network through the use of preengineered/preassembled modules

1. Problem avoidance – A majority of the problems with a conventionally installed network, at least in the first few years, results from the improper installation. Because the modular approach is pretested, leaving less than 1/8 the number of field splices, these types of failures are reduced 75% to 95%. The cost savings can be determined as follows:

   2 Techs. x 2 h (total diag. & total time) x 3 times/week
   @ 75/h x 75% reduction = $17,550/Yr Savings

2. Diagnostic time – using status monitoring systems, diagnostic time for the remaining service calls can be reduced by an average of 40% to 60%.

   2 Techs. x 1 h Diag. Time x 2 times/week
   @ $75/hr x 40% reduction = $6240/yr Savings.

3. Outside services – The status monitoring system can perform its own system sweep (and it does it on a continuing bases), precluding the need to go outside, typically once a year, for this service.

   System Sweep = $10,000/Yr Savings

4. Test equipment – sophisticated status monitoring systems can act as a complete set of test equipment,thus saving this capital purchase.

   Sweep Generator & test set = $14,000
   Spectrum analyzer = $12,00
   Total = $26,000
   5 Year amortization = $5,100/Yr Savings

5. System downtime – This is too variable to even estimate an average. Many production lines that depend on network data can cost thousand of dollars per hour in lost production.

Both the modular design approach and the inclusion of status monitoring will minimize downtime, and therefore avoid this major expense.

Based on the information above, the annual savings can be calculated as follows:

1. Problem avoidance = $17,550
2. Diagnostic time = $6,240
3. Outside services = $10,000
4. Test equipment = $5,100
5. System downtime = $?

Total = $38,390 + ?.

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