

# AVAILABILITY CALCULATIONS AND CONSIDERATIONS IN A BROADBAND HYBRID FIBER COAX NETWORK FOR TELEPHONE SERVICES

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## 1.0 ABSTRACT

*There is a growing acceptance for Hybrid Fiber Coax architectures to serve the many requirements of a multi-media environment. Given this application of analog video and telecommunications services, there is a great desire to understand and predict the network availability for telephone-like services. This paper will address the various elements involved in the actual offering of telephone service and their resulting impact on the availability of the network services. Efforts will be made to characterize the individual contributions as well as methods to improve the overall availability by use of techniques such as electronic redundancy and/or diversity. Projections will be made on availability of POTS services in that environment, given the configuration of the optics, the number of amplifiers in cascade, powering alternatives and other contributing factors in the availability of the service.*

## 2.0 AVAILABILITY CALCULATIONS

Clearly the most important question involving any system reliability involves the up-time of the system. This has significant implications over the operational cost of the service provider. The failure rate of the various components of a network has direct impact over the size of the spare stock. The level of training, the size of the maintenance staff and their geographic spread are all dependent on the diagnostic capability of a system and the frequency and location of necessary maintenance actions. Also, the number of service interruptions affect the level of satisfaction of a subscriber. It is therefore clear that a service provider would view the

overall reliability and the up-time of the product as a key requirement.

The chance that the system will be up at any particular time, and the percentage of time the system is operating are two measures which reflect the up-time of the system. Availability of the system is defined as [2],

$$A = \lim_{t \rightarrow \infty} P(t),$$

where  $P(t)$  = "probability that system is operating at time  $t$ ".

The unavailability of the system will be denoted by  $U$ , and is given by

$$U = 1 - A \quad (1)$$

It can be shown that the long term availability performance of a replaceable system component is related to its long term Mean Time Between Failure (MTBF) and its Mean Time to Repair (MTTR) as

$$A = \text{MTBF} / (\text{MTBF} + \text{MTTR}) \quad (2)$$

It can be observed that as MTBF increases, representing a more reliable subsystem or component, the availability  $A$  approaches 1.0, regardless of any finite MTTR. Also, as MTTR approaches zero,  $A$  approaches 1.0, regardless of MTBF.

Another common term in reliability analysis is, Failure In Time (FIT). FIT is the average number of failures in  $10^9$  hours of operation. MTBF and FIT are inversely related as follows:

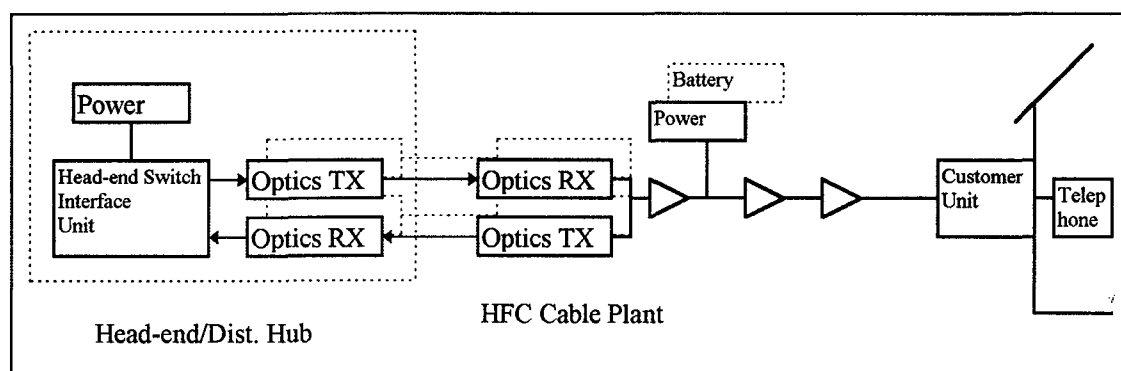
$$\text{MTBF} = 10^9 / \text{FIT} \quad (3)$$

## 2.1 SYSTEM RELIABILITY MODELING

System reliability analysis is a time consuming endeavor requiring a wide variety of technical skills. The steps involved are [2]:

**1. System Definition:** The first step in performing a reliability analysis is to obtain a complete and precise definition of the system architecture from both a functionality and a reliability point of view. A graphical

representation of the architecture such as reliability block diagrams or state transition diagrams is very helpful in providing a precise and usable description of the reliability architecture of the system. In the context herein, a system may be the Access network consisting of the end-to-end equipment from a class 5 switch to the home terminal equipment or could be a stand-alone rack of equipment, such as the Head-end Switch Interface Unit (HSIU); both are shown in figure 1.0.



**Figure 1.0 Hybrid Fiber Coax Model for Telephony**

### 2. Reliability, Availability, and Maintainability (RAM) measures selection:

Before a reliability analysis can begin, it is necessary to determine what measures of reliability, availability and maintainability are to be predicted. Care should be taken that the measures reflect the features of the system that are of interest to the service provider. The right selection of MTTR is very key in making the results plausible. The MTTR chosen for various parts of the system must reflect the average performance of a maintenance organization for the various parts of the system. Bellcore TR909 [3] suggests the following MTTR values:

Location or Type of Equipment	MTTR (hours)
For Central Office or manned head-ends	2
For Host Digital Terminal (HSIU)	4
For Outside Plant equipment	6

**Table 1.0 Mean Time To Repair Values for Fiber-In-The-Loop**

### 3. Architecture Analysis and Decomposition:

To predict the appropriate reliability, availability, and maintainability measures for a complex system such as the HSIU, for which

there are a large number of subsystem modular components, a tremendous number of states may be required to appropriately model the system.

**4. Architecture Modeling:** Architecture modeling involves creating reliability model(s) that describe the behavior of a system. Features such as interactions between the hardware and software components, maintenance and operational characteristics, and fault detection and isolation characteristics must all be taken into account. It turns out that the end-to-end system or network can be modeled as a chain of complex system components. Each complex network component in this chain can be analyzed rigorously and individually. The results can then be used to compute the end-to-end availability with much simpler methods. This can be done as long as the components are statistically independent.

**5. System component parameter determination:** One of the most important (and often time consuming) tasks in system reliability modeling and analysis is the determination of the parameters of the reliability model such as circuit pack failure rate, maintenance and repair times, and detection and coverage probabilities.

There are three methods to calculate availability parameters as described by Bellcore TR-332 [1]. These will be discussed in section 2.2

**6. Model Solution and computation of RAM measures:** Once the reliability model(s) are created and the parameters have been determined the model(s) can be solved for the appropriate RAM measures

**7. Model Parameter Sensitivity Analysis:** One of the usages of reliability analysis is the optimization of system architecture. Often this task takes the form of determining the effect of changes in a parameter on the desired availability measure, then subsequently finding the value that optimizes the measure. In these cases also, the effect of the choice of parameter value on the resulting availability measure is of major importance. A parameter sensitivity analysis is the procedure that assesses the effects of changes in the parameter on the desired availability (RAM) measures. *This procedure is especially appropriate for finding the weak link in an architecture. Also, through this process a development organization can determine whether they are over-engineering or under-engineering redundancy in a system.*

### 2.1.1 RELIABILITY BLOCK DIAGRAM

(COMBINATORIAL METHOD)

Reliability Block Diagrams (RBDs) are commonly used to represent the reliability architecture of a system. RBDs consist of a simple pictorial method to represent the effects of all possible configurations of functioning and

failed components on the functioning of the system. RBDs are most useful when in analyzing the end-to-end availability of a transmission system such as the Hybrid Fiber Coax (HFC) architecture. This is due to the functional independence of the components of the end-to-end system. It will become clear that in a complex stand-alone system such as the HSIU, the State Space Method would be more appropriate. In the HFC architecture as shown in figure 1.0, there is no functional interdependence say, between the function of the Customer Interface Unit and the Fiber Optics, except for signal transmission processing. The Optics has to pass the broadband signal through, with some level of integrity. To demonstrate the point we assume that the optics either processes signal with no through degradation, or passes no signal at all and that is only upon unit failure. The CIU does not rely on the Optics to function properly. Because of the functional independence property, the failure analysis of the HFC architecture would most appropriately be analyzed using RBDs or using the academic terminology, the combinatorial method. To understand the availability of the HFC architecture, we must establish some simple combinatorial rules. It can be proven that the availability of a serial chain as shown in figure 2a, when the members are statistically independent, is the product of the availability of each chain member. Therefore the availability of the chain, when the availability of each component is known, and when they are statistically independent, is given by

$$A_{eq} = A_M * A_N \quad (4)$$

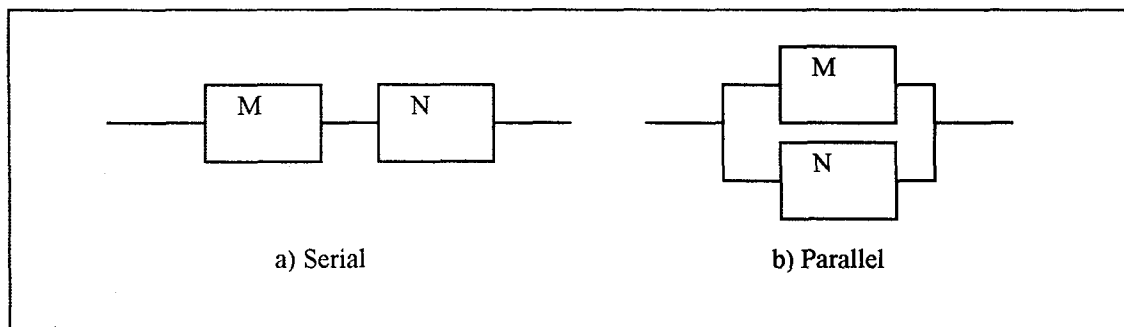


Figure 2.0 Reliability Block Diagrams

For the parallel blocks of figure 2b, the equivalent availability of the chain is given by,

$$A_{eq} = A_M + A_N - A_M * A_N \quad (5)$$

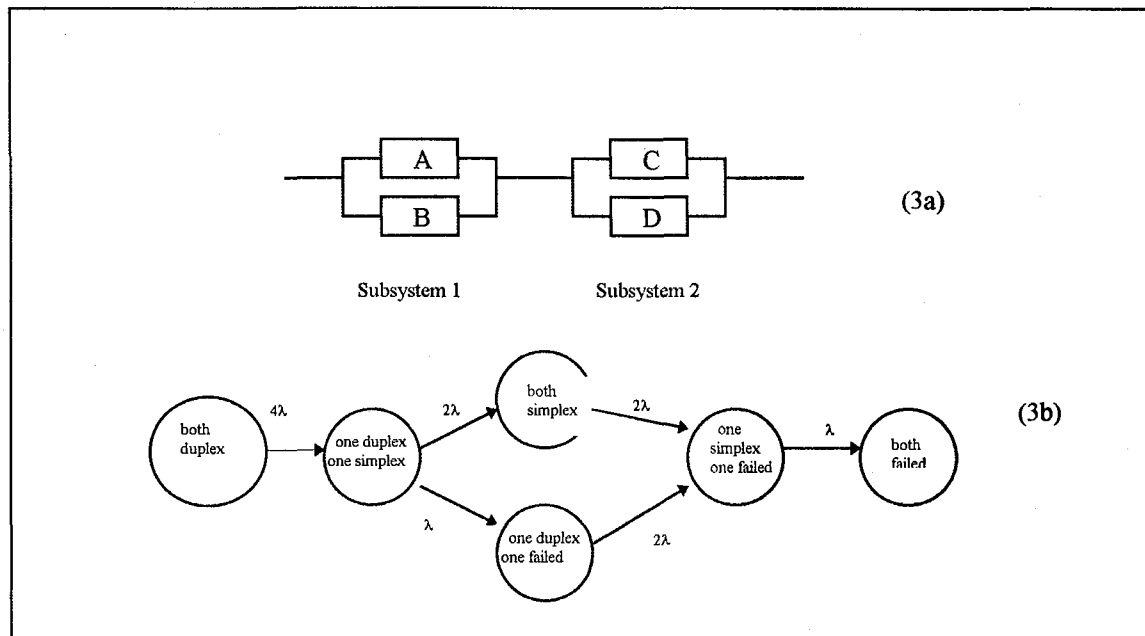
The relations of (2), (4) and (5) are sufficient to analyze any RBD availability. In section 3 we will apply these equations to the reference model of figure 1.0 to derive the availability of a typical HFC architecture, for the delivery of telephony services.

### 2.1.2 STATE TRANSITION DIAGRAM

(STATE SPACE METHOD: MARKOV MODELING)

For most complex systems, there are more modes of operation than simply just working or failed. There are a variety of different working

modes where certain components have failed but are being covered due to redundancy, a variety of different failed modes where different components have failed and brought down the system, and other modes of degraded operation which cannot be conveniently labeled as working or failed. Each possible mode of operation for a system, and the set of states of the system is called the "State Space". It is customary to assign the list of possible states of the system the numbers 1,2,...,n and refer to the model as an n-state model. A "State Transition Diagram" is a pictorial view of all of the possible operational states of the system, with arrows representing possible transfers (called state transitions) in the mode of operation of the system. In Figure 3.0 the two reliability modeling methods for the same system are illustrated.



The numbers shown on the lines are failure rates (commonly expressed in FITs). It is also assumed that the times between the occurrence of events are exponentially distributed. Exponential distributions have many useful properties. It turns out that an exponentially distributed process, call it X, of (failure) rate  $\lambda$ , is defined as

$$P(X > t) = e^{-\lambda t} \quad \text{for } t \geq 0.$$

An exponential distribution, is fully defined once the rate  $\lambda$  is known.

In figure (3a) a system is shown using RBDs. The system consists of two identical subsystems in series with each subsystem having two identical components in parallel, labeled, A, B, C, and D. It is assumed that all components have exponential distributions with common failure rate  $\lambda$ . The same system is shown in figure (3b) using the state transition diagrams.

Some of the properties of exponential distributions have been used to go from the RBDs to the State Transition Diagram. For example  $P(X_A \cup X_B > t) = e^{-2\lambda t}$ , where  $P(X_A > t)$ , represents the "time before failure" distribution for the component A. The  $4\lambda$  rate shown on the line moving from "both duplex" to "one duplex, one simplex" state represents the equivalent rate for the union of the four processes A, B, C and D, since any singular failure in a both duplex state will result in a transition.

Once the repair statistics are incorporated into the model, then many Availability calculations can be done. For the sake of time, we will not get into this method any further, however, we will state the only proper way to understand a certain availability measure of a system or a

subsystem with inter-dependencies is via the State Space Method or the Markov modeling method. Care must be taken that the behavior of the system has been properly modeled. It is very easy to overlook the fault detection and diagnostic portion of a system. Most fault tolerant complex systems utilize rather sophisticated fault detection, diagnostic and recovery schemes. The more complex these schemes are the higher will be the probability of fault recovery malfunction. This fault recovery scheme is handled through some hand-shaking between hardware and software. This complex interaction between software and hardware can only be modeled through Markov models. To apply combinatorial methods (RBDs) to these complex schemes will result in oversimplification and illusive conclusions.

## 2.2 SYSTEM ELECTRONIC COMPONENT RELIABILITY PREDICTION

The majority of the failures in the field are due to a hardware component failure. Therefore, there is a need to predict beforehand or assess the field reliability performance of replaceable hardware assemblies.

The three methods in Bellcore TR-332 for calculating the MTBF of a system's replaceable components (plug-in, power converter module, etc.) are given in the following subsection. Method I, is basically a parts count method. Method II combines results of lab testing with Method I. Method III allows for incorporating field return data into the long term predictions.

In this paper we will only look at Method I in some detail.

### 2.2.1 Method I

This is basically the parts count method. This method provides a starting point when no lab test results or field failure information are available. Bellcore defines the steady-state failure prediction of a replaceable system component, circuit pack, or assembly, as  $\lambda_{SS}$ , where,

$$\lambda_{SS} = \pi_E \sum N_i \lambda_{SSi}, \quad \text{with the summation done over } i=1, \dots, n, \text{ and} \quad (6)$$

where

$n$  = the number of devices in the assembly

$N_i$  = quantity of the  $i^{\text{th}}$  device type

$\pi_E$  = unit environmental factor as explained in Table 2

$$\lambda_{SSi} = \lambda_{Gi} \pi_{Qi} \pi_{Si} \pi_{Ti}, \quad \text{steady-state failure prediction rate for the } i^{\text{th}} \text{ device} \quad (7)$$

$\lambda_{Gi}$  = Generic failure rate for the  $i^{\text{th}}$  device, given in Table 3

$\pi_{Qi}$  = Quality factor for the  $i^{\text{th}}$  device, given in Table 4

$\pi_{Si}$  = Stress factor for the  $i^{\text{th}}$  device, given in Table 5

$\pi_{Ti}$  = Temperature factor for the  $i^{\text{th}}$  device, given in Table 7

Environment	$\pi_E$	Nominal Environmental Conditions
Ground, Benign	1.0	Nearly zero environmental stress, e.g. Central Office, CEV
Ground, Fixed	1.5	Conditions less than ideal, some environmental stress, e.g. manholes, remote terminal, customer premises subject to shock, vibration, or temperature variation
Ground, Mobile	5.0	Conditions more severe than previous row. Mobile telephones, test equipment

**Table 2, Environmental Factor**

Device Type	Failure Rate (in 10E9 hours)	Temp Stress Curve	Electric Stress Curve, or Multiplier
Digital Integrated Circuits	CMOS		
101-500 Gates	52	8	1.0
1001-2000 Gates	70	8	1.0
10001-15000 Gates	110	8	1.0
Microprocessors	CMOS		
1001-2000 Gates	50	8	1.0
10001-15000 Gates	71	8	1.0
Random Access Memory	CMOS, Static		
64Kbits	170	8	1.0
256Kbits	300	8	1.0
Random Access Memory	NMOS, Dynamic		
64Kbits	120	8	1.0
256Kbits	180	8	1.0
1024Kbits	270	8	1.0
ROMS, PROMS, EPROMS	CMOS		
64Kbits	55	10	1.0
256Kbits	81	10	1.0
1024Kbits	120	10	1.0
850nm Laser Diode	15000	10	1.0
1550nm Laser Diode	5000	10	1.0
Discrete Resistor Fixed, Film	2	3	C
Discrete Capacitor Fixed, Al, Axial lead < 400 $\mu$ f	30	7	E
Relays, contactor	560	3	C

**Table 3, Typical Device Failure Rates**

	Integrated Circuits		Discrete Semiconductor Devices		All Other Devices
Quality Level	Hermetic	Non-hermetic	Hermetic	Plastic	
I, Some Device Quality Control	1.5	1.8	1.5	1.8	1.5
II, Average Device Quality Control	1.0	1.0	1.0	1.0	1.0
III, Tight Quality Control	0.5	0.5	0.5	0.5	0.5

**Table 4, Quality Level Multiplier**

	Electrical	Stress Curve
% Stress	C	E
10	0.6	0.4
50	1.0	1.0
90	1.7	2.6

**Table 5, Electrical Stress Multiplier,  $\pi_s$**

Definition of Electrical Stress	
% Electrical Stress For Resistor	applied power/rated power
% Electrical Stress For Capacitor	Sum of applied dc voltage plus ac peak/ rated voltage

**Table 6, Electrical Stress Definition**

Operating Temp, °C	Temperature Stress Curve			
	<b>3</b>	<b>7</b>	<b>8</b>	<b>10</b>
30	0.9	0.6	0.6	0.4
40	1.0	1.0	1.0	1.0
65	1.4	2.6	3.0	6.8

**Table 7, Temperature Stress Multiplier,  $\pi_T$**

#### Observations:

As it can be inferred from the above formulas and tables, there are many factors that affect the reliability or potential lifetime of a device. Some devices are more sensitive to electrical stress, such as capacitors, resistors and diodes (not given). Laser diodes, ROMS, PROMS are very sensitive to high temperature operating environments. For example for these devices at 65°C, the expected lifetime will be almost 4 times worse than that operating at 40 °C. Quality control of incoming devices also has significant implications over their long term reliability. Activities such as burn-in or screening through temperature cycling, lot to lot

control of components and periodic requalification are characteristic of Quality Level III (as given in Table 4), representing the tightest level of Quality Control. A product designed for high reliability performance would have all of these factors incorporated. The designer should be very cognizant of the steady-state operating temperature of the devices used in his design and should take measures to ensure that temperature sensitive devices are not heat stressed and discretes such as diodes, capacitors or resistors are not electrically stressed. Furthermore, an attempt should be made to minimize the number of high failure rate devices, and in general, keep component count to a minimum.

### 3.0 Hybrid Fiber Coax Availability Modeling

#### 3.1 Model used for Telephony services:

The average availability (up-time) goal for Plain Old Telephone Service (POTS) subscriber loop has been set to be 99.99% or no more than 53 minute average unavailable time per year. There are many reasons for this high level of reliability and availability, but one simple one is public reliance on telephone access for emergency 911 services. This objective, incorporating all

network equipment between the local switch and the network interface (excluding the local switch and the customer premises terminal equipment), refers to the long-term average service to a typical customer.

Telephony-like services over HFC should therefore strive to achieve this goal if they are to

be the only means of providing telephone service in the area. In our discussion herein, we will attempt to assess the challenges in meeting this goal and highlight some additional measures that need to be considered in order to achieve this goal.

According to the above definition, the "subscriber loop", consists of: Head-end Switch Interface Unit (HSIU), Head-end Power, Head-end Optics TX, Head-end Optics RX, Fiber-Node Optics RX, Fiber-Node Optics TX, Plant Power, Up to 3 cascade amplifiers and the Customer Interface Unit. (Figure 1)

Using (2), (4) and (5), the end-to-end availability measure of the above model can be expressed as follows:

$$A = A_{HEP} * A_{HSIU} * A_{FOptics} * A_{ROptics} * A_{PP} * (A_{Amp})^m * A_{CIU} \quad (8)$$

$A_{HEP}$  = Availability of the Head-End Powering equipment

$A_{HSIU}$  = Availability of the Head-end Switch Interface Unit

$A_{FOptics}$  = Availability of the forward optics  
 $A_{ROptics}$  = Availability of the reverse optics  
 $A_{PP}$  = Availability of the plant power  
 $A_{Amp}$  = Availability of Amplifier  
 $m$  = Number of amplifiers in cascade, we will use  $m = 6$ , to account for reverse amplifiers too  
 $A_{CIU}$  = Availability of Customer Interface Unit

$A_{FOptics}$  and  $A_{ROptics}$  are further broken down into,

$$A_{FOptics} = A_{Flaser} * A_{Freceiver} \quad , \text{ If no redundancy is used}$$

$$A_{ROptics} = A_{Rlaser} * A_{Rreceiver} \quad , \text{ If no redundancy is used}$$

If redundancy in the optics is used, then equation (5) can be applied.

In order to calculate the individual availability measures, knowledge of the MTBF and MTTR is necessary. The MTTR's were given in Table 1.

### 3.2 Analysis of the Model

In order to get some idea about the expected availability measure of the end-to-end telephony model, we have to use some actual experienced numbers. In the above model, there is not much experience with the HSIU and CIU components, simply because these are products in the early phases of deployment.

To get an idea of the availability, we will create a hypothetical Customer Interface Unit. Here is the Bill Of Material for this hypothetical CIU (Table 8):

Device Description	Quantity **	Device FIT
100k Gate Digital IC	2	150
Microprocessor	2	100
256k DRAM	2	180
Relay	4	560
256k PROM	2	81
<b>TOTAL CIU FIT</b>		<b>3262</b>

**Table 8, Hypothetical Customer Interface Unit Bill Of Material**

\*\* - For purposes of illustration, we are oversimplifying the CIU construction. We are assuming that the quantities and types of devices in the above table are a most likely representative of the reliability of the real CIU.

Using the following coefficients and assumptions

$$\pi_E = 1.5 \text{ (Outside Plant)}$$

$$\pi_Q = 1.0 \text{ (Quality level II, average)}$$

$$\pi_S = 1.0 \text{ (Designed, such that devices are not electrically stressed)}$$

$$\pi_T = 1.3 \text{ (All devices fall in temperature curve 8, assume 45 °C operating temperature)}$$

$$\lambda_{SSCIU} = 6361 \text{ FIT} \longrightarrow \text{MTBF} = 157,208 \text{ (hours)}$$

$$A_{CIU} = 0.9999618$$

One significant difference between the design of the CIU and the HSIU, is that there is great incentive in keeping the cost of the CIU as low as possible. This prohibits the use of redundancy in the design of the CIU. On the other hand, the HSIU can afford to employ equipment duplication and protection, since its cost is shared by many hundreds of potential subscribers.



To estimate  $A_{\text{HSIU}}$  we assume that the FIT is ten times better than that of the CIU. This is not an unrealistic expectation, since the HSIU equipment will provide a much higher level of equipment protection, plus the operating environment will much more benign and stable. Therefore

$$A_{\text{HSIU}} = \frac{1572080}{1572080 + 4} = 0.99999745$$

To further continue the analysis we will consider 4 cases: (See Tables 9 -12)

Case I: Trunk and feeder with 20 trunk, 1 bridger and 2 line extender amplifiers. The annual return rate of the amplifiers are assumed to be 2%. For two-way telephony service the reverse path should be turned on. This results in an equivalent of 46 amplifiers in cascade in our reliability model. We see from Table 8 that the end-to-end availability is 99.93%. This number would further be aggravated if the dependence on commercial power were to be incorporated. It is common to see power outage in one segment of a cascade and not at the neighborhood. Taking all of these factors into account, it is easy to understand why so many people have a distaste for CATV service. Regardless of the power issue, we see that the Trunk and Feeder architecture is really not suitable for telephone services.

Case II: Hybrid Fiber Coax, no Optical Redundancy. Even though in this example the optics perform less reliably than the amplifiers, the end-to-end availability has improved to 99.97%

Case III: Same as Case II, with Optical Redundancy. Using redundant optical equipment, despite their relatively low reliability, improves the end-to-end availability to 99.987%

Case IV: Same as Case III, with more reliable amplifiers. Deploying 6 times more reliable amplifiers results in 99.995% end-to-end prediction.

Therefore, using the hypothetical CIU and HSIU, applying redundancy in the optics and assuming that

$A_{\text{PP}} = A_{\text{HEP}} \cong 1.0$ , we were able to meet the Bellcore requirement of 99.99% long term availability. It is important to note that the only way that  $A_{\text{PP}}$  and  $A_{\text{HEP}}$  will be relatively high is through use of power back-up (i.e. batteries). Even then, the availability of emergency generators and emergency crews are essential in preventing extended power outages and in meeting the above requirement. The cable plant power has historically not been backed-up, therefore a cable plant being designed for telephone services must take all of the above into consideration

### 3.3 Other issues in consideration of availability:

- **Ingress:** The Cable plant reverse path suffers from a phenomenon called ingress. Ingress is the infiltration of 5-40 MHz energy off air (or through other means of energy coupling) from the various openings (primarily in the soft coax drop) into the plant. It is important to understand the effects of ingress on channel availability. All the considerations so far concentrated on electronic equipment reliability and up-time. Interference due to ingress can

conceivably jam the upstream transmission, effectively making the service unavailable to the subscriber. Analysis of ingress and quantifying channel availability as a function of interferer characteristics and CIU characteristics is not the focus of our discussion. However, we will mention that how a vendors' product treats ingress can have significant bearing over the availability of the channel to the point that electronic equipment reliability could be over-

shadowed. For example, through the use of frequency agility, rugged modulation, and narrow carriers, a higher immunity to ingress can be expected. Given this, it is easy to compute  $A_{channel}$  based on experimental information available on the plant ingress. Once  $A_{channel}$  is computed, it can be treated as another serial link in the reliability block diagram analysis to provide the real service availability measure.

The ability to shut off or attenuate various parts of the return system will be critical to problem isolation and detection.

- **Proactive system tests:** This is simply finding faulty units before the customer does. An important feature that will differentiate various cable telephony products, is their background and foreground diagnostic capability. As an example, a CIU in concert with the HSIU and while the service is not being used, could be running background tests. If failures are encountered, the results are transmitted to a central location, whereby maintenance staff are dispatched. The fact that the CIU is primarily going to be located at the side of the house, makes maintenance activities quite non-intrusive. The maintenance crew can service the fault, long before the subscriber becomes aware of the problem. This is a major departure from the traditional entertainment cable and is one of the major advantages of the "demarcation point" concept. Bit-error-rate tests conducted in this manner at various frequencies can be utilized to "qualify" potential segments of return spectrum, before assignment.

- **Cables and Connectors:** These are other unknown sources that can and will cause service interruptions. Intermittent connections are a major source of ingress and signal degradation that can adversely affect channel availability. Intermittent connections are likely to result in very long outages since the trouble will most likely be in the house cabling. Access and troubleshooting become quite a problem.

- **Plant Power:** It was mentioned earlier that power reliability and availability must be taken into consideration and cannot be overlooked in providing telephone-like services. Batteries must in fact be in place and in good condition to

be utilized under commercial outage situations. Status Monitoring may be well justified to verify this on a routine basis.

- **Software Reliability:** It will be critical in advanced systems to be able to diagnose problems before they occur, for preventive maintenance reasons. In the event of an unexpected failure, there is a high value attached to the ability of the product to automatically and correctly reconfigure redundant signal paths and raise appropriate notification. Since this intelligence is primarily realized through software its reliability becomes of paramount importance.

- **Return Spectrum Management:** There will be a high value placed on the ability to manage and control the various signals present on the return spectrum. Without this capability, many new and existing products and systems which utilize the return band for communication will overlap, contend and collide with high priority signals resulting in unpredictable communication and sub-optimal spectrum utilization.

- **Fiber Path Diversity:** Considering the extensive deployment of fiber, failures due to cable cuts could become a primary constraint. Optical cable path diversity may be well justified.

- **Return Power Sensitivity:** It has been shown that the return path can be overpowered if signals of arbitrary amplitude are permitted. The return amplifiers (just like forward amplifiers) will become non-linear if signal input power is too high. There is no effective gain control technique in the return path today and the return laser may be particularly susceptible to high power inputs.

## 4.0 Conclusion

This paper introduced the reader to some of the concepts of reliability analysis and some of the real world problems encountered in the Hybrid Fiber Coax plant. Quantifying service and channel availability to a subscriber is not a trivial task and requires a great deal of information gathering and analysis. Complex systems, in particular, where a great deal of

module inter-dependency exists, cannot be easily analyzed. It was stated that electronic equipment up-time will not be the only factor in ensuring channel availability: issues such as connections and ingress must also be considered. We also concluded that optics redundancy and power back-up are very important in meeting telephone service availability requirements. It is possible to meet the availability requirement of 99.99% with proper network design, planning, and routine monitoring. Care must be taken in the selection of network components and their associated modulation and spectrum formats.

OSS for these networks will be complex and necessary.

## 5.0 References

- [1] "Reliability Prediction Procedure for Electronic Equipment" Bellcore TR-NWT-000332 Issue 3, September 1990
- [2] "Methods and Procedures for System Reliability Analysis" Bellcore Special Report SR-TSY-001171 Issue 1, January 1989
- [3] "Generic Requirements and Objectives for Fiber In the Loop Systems" Bellcore TR-NWT-000909, Issue 1, December 1991

	Annual Return Rate%	Calculated MTBF (hours)	MTTR (hours)	Calculated Availability
Forward Laser	N/A		4	
Forward Receiver	N/A		6	
CoAxial Amplifiers	2	438000	6	0.999986302
2-way Cascade Length	46			0.999370066
Reverse Laser	N/A		6	
Reverse Receiver	N/A		4	
CIU	5.6	156429	6	0.999961645
HSIU	0.56	1564286	4	0.999997443
<b>System</b>				<b>0.99932918</b>

**Table 9, Case I Trunk & Feeder 20 + 3 in cascade**

	Annual Return Rate%	Calculated MTBF (hours)	MTTR (hours)	Calculated Availability
Forward Laser	9	97333	4	0.999958906
Forward Receiver	9	97333	6	0.99993836
CoAxial Amplifiers	2	438000	6	0.999986302
2-way Cascade Length	6			0.999917812
Reverse Laser	9	97333	6	0.99993836
Reverse Receiver	9	97333	4	0.999958906
CIU	5.6	156429	6	0.999961645
HSIU	0.56	1564286	4	0.999997443
<b>System</b>				<b>0.999671476</b>

**Table 10, Case II HFC w/ no optical redundancy**

	Annual Return Rate%	Calculated MTBF (hours)	MTTR (hours)	Calculated Availability
Forward Laser	9	97333	4	0.999958906
Forward Receiver	9	97333	6	0.99993836
CoAxial Amplifiers	2	438000	6	0.999986302
2-way Cascade Length	6			0.999917812
Reverse Laser	9	97333	6	0.99993836
Reverse Receiver	9	97333	4	0.999958906
CIU	5.6	156429	6	0.999961645
HSIU	0.56	1564286	4	0.999997443
<b>System</b>				<b>0.999876883</b>

**Table 11, Case III HFC w/ optical redundancy**

	Annual Return Rate%	Calculated MTBF (hours)	MTTR (hours)	Calculated Availability
Forward Laser	9	97333	4	0.999958906
Forward Receiver	9	97333	6	0.99993836
CoAxial Amplifiers	0.3	2920000	6	0.999997945
2-way Cascade Length	6			0.999987671
Reverse Laser	9	97333	6	0.99993836
Reverse Receiver	9	97333	4	0.999958906
CIU	5.6	156429	6	0.999961645
HSIU	0.56	1564286	4	0.999997443
<b>System</b>				<b>0.999946739</b>

**Table 12, Case IV HFC w/ optical redundancy & improved reliability**