HFC Access Plant

This lecture describes a modern Hybrid Fibre-Co-ax (HFC) cable TV access network. After this lecture you should be able to: distinguish between trunk, distribution and drop cables, explain the location and role of an optical node and distribution amplifier, convert signal levels between mV, dBm and dBmV, compute the output noise power and C/N for an RF amplifier, identify the source of CTB, CSO, gain flatness and group delay distortions and their units, and identify the frequency ranges used in upstream and downstream directions.

Importance

In 2011 Statistics Canada reported about 8 million cable TV, 6 million cable Internet and 4 million cable telephony subscribers in Canada. Since there are about 13 million households, this represents about 60% adoption of a telecommunication service using cable TV access technology.

In 2011 Canadian cable companies had revenue of about $10 billion and a profit margin of about 27%. Approximately half of the revenue was from Internet and phone services.

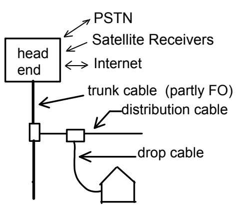
Exercise 1: Assuming 10 million subscribers, what was the ARPU per year? Per month?

The cost of deployment is about $20–$40 per meter (aerial vs buried). For a house frontage of 10m-50m, that's $200–$2000 per "house passed." The cost of headend equipment is relatively low because it is shared by many subscribers.

Exercise 2: How does the deployment cost per user compare to the annual revenue per user?

HFC Cable System Architecture

The cable plant network is arranged as a hierarchical tree:



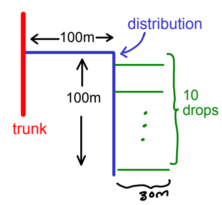
The headend contains links to other service providers: satellite receivers for broadcast services and fiber optic (FO) links to Internet and PSTN gateways.

The signal is distributed first over trunk cables. Their main purpose is to extend the range of the system by distributing the signal as far as possible with minimum degradation in quality. In co-ax-only system low-loss 1" or 3/4" diameter co-ax is used. The co-ax trunk requires an amplifier approximately every 1 km to boost the signal.

Distribution cables are co-ax cables that run down each street and past each house or building. It allows individual subscribers to access the cable system. The distribution cable is typically 1/2" co-ax. Each distribution cable will have many taps and distribution amplifiers to make up for the loss of signal power.

Each subscriber connects to a tap in the distribution cable with a "drop" cable. This cable is typically flexible co-ax less than 50 m long.

Exercise 3: Assume city blocks are 100m long and there are 10 houses per block as shown in the following diagram. What length of distribution cable is required per house? If the distribution cable must run an average of 100 m to reach the trunk and each drop is 30m long, what is the ratio of distribution cable to drop cable length?



Modern cable systems have replaced much of the trunk cabling with single-mode fiber optic cables. In such a Hybrid Fiber-Co-ax (HFC) system the signal is initially distributed over a bidirectional FO link to an optical node. FO cables have much lower loss than co-ax (about 0.3 dB/km) and are smaller and lighter than rigid co-ax.

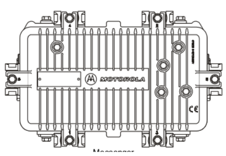
To transmit the signal over fiber, the RF signal amplitude modulates a laser-generated optical signal at 1550 or 1310 nm. At the receiver a photodiode recovers the RF signal. Note that the modulating signal has a bandwidth of up to 1 GHz. Note that even though the RF signal itself contains many modulated carriers, from the point of view of the optical modulator/demodulator this RF signal is the baseband signal.

The hardware component that converts between the RF and optical signals (in both directions) is called an optical node. An optical node may serve several hundred subscribers and cost about $2000.

Components

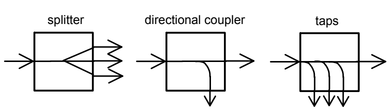
The most expensive component of the CATV plant is the 75 ohm co-ax cable. Trunk and distribution cables are typically semi-rigid cable while drops are typically flexible cable. The loss of co-ax cable depends on the dimensions and type of dielectric and and conductors used. The loss in dB is proportional to distance. Manufacturer's data sheets need to be consulted to obtain the loss per unit distance (x dB/100m) at various frequencies.

Probably the second most expensive component of the system is the distribution amplifiers and optical nodes. Distribution amplifiers and optical nodes are mounted in sealed enclosures with external heat sinks that look like this when mounted on cables:



Power supplies, often with battery backup, are used to inject power, typically 90VAC, into different places in the cable system to supply the amplifiers and optical nodes. Power for the amplifiers and optical nodes is usually distributed over a co-ax cable center conductor.

Three types of passive devices, directional couplers, taps and splitters are used divide up the RF signal:



These devices often need to be rated to pass significant amounts of current (up to 15A) to supply downstream optical nodes and distribution amplifiers.

Signal and Noise Levels

Powers in cable TV systems are usually measured in dB relative to 1mV at 75Ω impedance. This is a convenient unit because the input to a TV receiver is typically 0 dBmV.

Exercise 4: What is power in mW of 1 mV signal if the cable impedance is 75 ohms? What is the power in dBm?

The thermal noise level at the output of an amplifier is given by $N = G \cdot kTBF$ where G is the amplifier gain, k is Boltzman's constant, T is the temperature (typically assumed to be 290K), B is the bandwidth in Hz and F is the amplifier noise figure. When this value is computed in dB, kT is -174 dBm-Hz.

Exercise 5: A 0 dBmV signal is applied to the input of a distribution amplifier with a gain of 20 dB and a 2 dB noise figure. What are the output signal and noise powers? What is the output C/N measured over a 6 MHz bandwidth?

Distortion

Non-linear amplification in amplifiers causes distortion that introduces additional frequency components. These distortion products cause interference to other signals.

The most significant distortion products are due to second- and third-order products. Cable measure the amount of second- and third- order distortion power using measures called "composite second order" (CSO) and "composite tripe beat" (CTB). We will not go into detail on how these are measured.

Linear distortion must also be controlled. Gain flatness (maximum loss difference in dB) is usually specified over the upstream or downstream frequency range and maximum group delay (ns) is specified over a 6 MHz channel bandwidth.

Frequencies

Almost all cable systems today are bidirectional. Signals above a certain frequency (54 or 108 MHz) propagate from the head end to the subscriber. This is called the forward or downstream (D) direction. Frequencies from 5 to 30 MHz (or 42 or 85 MHz) propagate from the subscriber toward the head end. This is called the reverse, return or upstream (U) direction.

The actual frequency ranges in each direction are chosen by the cable company and depend on cost considerations. Systems with larger bandwidths require more and/or better amplifiers and are thus more costly. The maximum downstream frequency may be between 300 and 1002 MHz.

In a bidirectional system all of the distribution amplifiers need to be bi-directional. A pair of analog filters called a diplexer (diplex filter) is used on each end of the amplifier to separate the two directions based on frequency.