Optical Network Technology: Future Impact on CATV Networks

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Abstract

Future CATV networks may be able to transport video, data and voice services over large areas made possible by managing individual optical wavelengths within a single fiber, each wavelength carrying a different service type or going to a different location. The capability of optically routing, switching, provisioning and otherwise controlling various services without intermediate optical/electrical/optical conversion will enable creation of "All Optical Networks". This paper discusses the current state of optical technology required for these networks, where this technology is first appearing within existing CATV infrastructure, and how it may positively impact the capital, operations and maintenance costs of future CATV networks.

Introduction

Wave Division Multiplexing (WDM) is the ability to transmit two or more optical signals independently through the same fiber, utilizing different optical wavelengths. Although transmission of 1310 nm and 1550 nm wavelengths have been used for many years, it has been the advent of commercially available optical amplifiers which have made it is now technically feasible to transmit tens of optical signals simultaneously on the same fiber within a relatively narrow optical window of approximately 30 nm. This is referred to as Dense WDM Transmission, or simply dense WDM for short. Figure 1 illustrates a point to point dense WDM fiber link. Although the ability to transmit a dense WDM stream and amplify its multiple signals with a single optical amplifier is a key element of future All Optical Networks, commercial development of a number of new optical devices will be required in order to take full advantage of the potential benefits of All Optical Networks.

All Optical Networks may provide the following economic benefits to CATV service providers:

- Lower Fiber Plant Cost Through Significantly Reduced Fiber Counts
- Shared Signal Transmission and Switching Through Common Active Optical Components, Reducing Electronics Costs
- Improved System Reliability Through Reducing Overall Network Active Devices
- Faster Fiber Restoration After Cuts, Through Significantly Reduced Fiber Counts
- Reduced Future Costs For Network Capacity Expansion By Further Sharing Common Plant and Equipment

In addition to these benefits, technology improvements may allow each hub to economically serve significantly larger areas in terms of homes passed per hub, thereby allowing further consolidation and reducing operations costs.

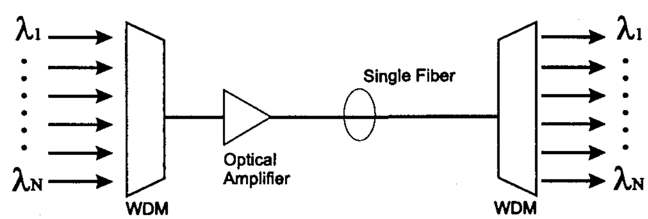

Figure 1. Dense WDM link. "N" can be 4-32 commercial applications today.

Elements of an All Optical Network

Dense WDM technology enables the creation of multiple optical circuit paths within a single fiber path (Figure 2). In relative terms, it is easy to compare an All Optical Network to a fiber network in the following way: An optical cable consisting of multiple fibers within a sheath becomes a "superset". An individual fiber within the cable can be thought of as a virtual fiber cable. An individual optical wavelength within the fiber can be thought of as a virtual fiber. Management, redundancy and routing can all be readily understood by translating requirements in conventional

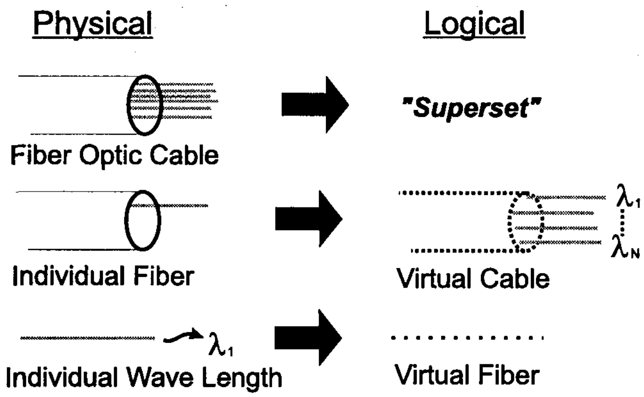

Figure 2. All optical network equivalents

networks between cables, fibers, and their virtual counterparts in an All Optical Network.

To attain the economic and operational benefits derived from implementing the future All Optical Network, a number of optical elements will be required which are currently not available in commercial quantities for wide scale deployment. Figure 3 is a compilation of these devices. From left to right shows progression in time of the anticipated evolution of these devices.

Dense WDM transmission is not without technical challenges. Operating at the 1550 nm window, attention must be paid to issues such as the dispersion performance of the optical fiber, the flatness of amplifier gain in the optical bandpass, and the optical stability of fiber devices. Recognizing these challenges, this paper is primarily focused on the potential application of All Optical Networks in CATV systems.

Large urban/suburban CATV networks consist of a series of hubs/subheadends (or video end offices) connected to one or two master headends (or video serving offices) usually via a redundant fiber optic ring, commonly referred to as the fiber backbone system. While most large backbones are exclusively digital, medium sized rings may be a combination of digital and high powered linear systems. A hybrid fiber/coax distribution architecture is used to distribute signals bidirectionally between the hub and the serving areas via linear optical transmission between the hub and optical nodes, and linear RF transmission within each serving area between the node and subscribers. Figure 4 illustrates a typical backbone system architecture while Figure 5 illustrates the distribution system architecture.

Dense WDM systems offer potential economic advantages in both digital and broadband linear (aka: analog) CATV transmission. The first area of anticipated use

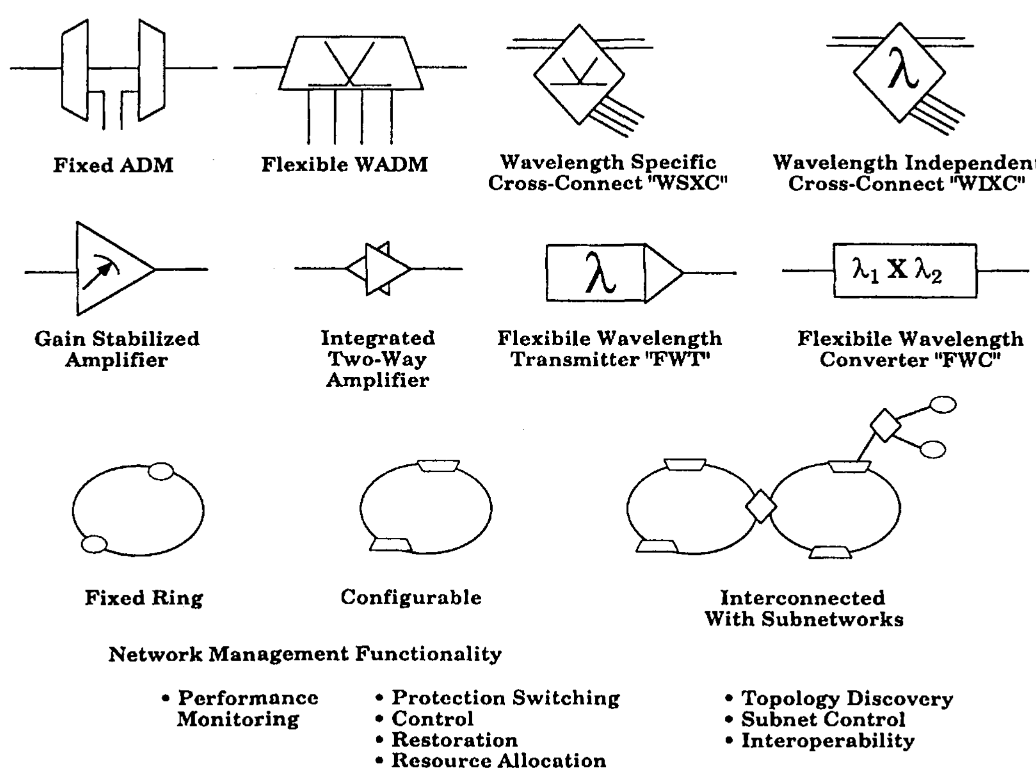

Figure 3. Current and future elements for All Optical Network: Source Bellcore

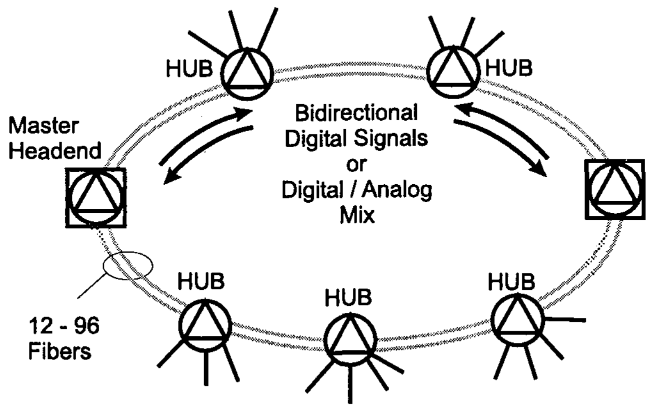

Figure 4. Backbone System. Fiber transmission is typically uncompressed digital for large networks, and a combination of digital and high power 1550 nm AM for smaller systems.

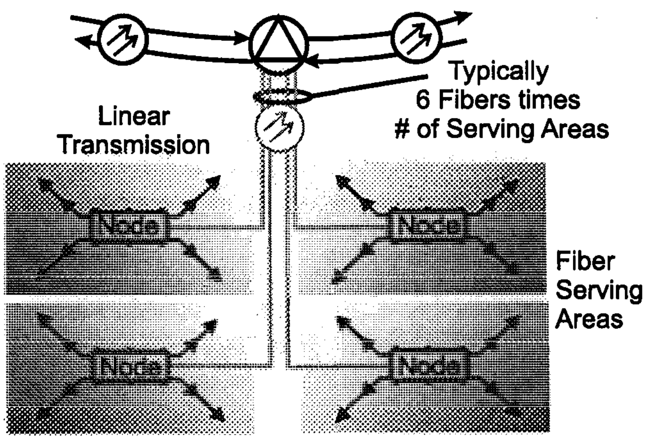

Figure 5. Distribution System. Fiber transmission is broadband linear between the hub and the optical nodes in the serving area.

of dense WDM technology in CATV networks is in fiber backbones, followed by potential implementation in the HFC distribution system.

Dense WDM in Backbone Systems

Fiber backbone systems generally cover long distances. The longest systems in the United States now cover over 500 kilometers. Given the expansion of CATV networks into the delivery of high speed data, telephony and other digital services, these systems usually employ uncompressed digital fiber systems to transport all video, data and voice services, or a combination of uncompressed digital and conventional telecommunications digital systems to transport and remultiplex various combinations of channels to create custom service delivery configurations at each sub-headend. Shorter systems sometimes employ a combination of digital transmission systems (for voice and data services), and 1550 nm high power linear transmission systems (for broadcast video services) on separate fibers, which are then combined at the hubs.

Each fiber in backbone systems represents a significant capital cost because of the long distances traversed. The initial system may be even more expensive if requirements dictate leasing fiber(s) over a limited right of way such as a long bridge spanning a body of water. The ability of combining multiple digital signals using many optical wavelengths has already been demonstrated and commercial products are already available. For example, ADC Telecommunications demonstrated eight wavelengths of its DV6000 uncompressed digital system at the 1996 SCTE Expo as shown in Figure 6.

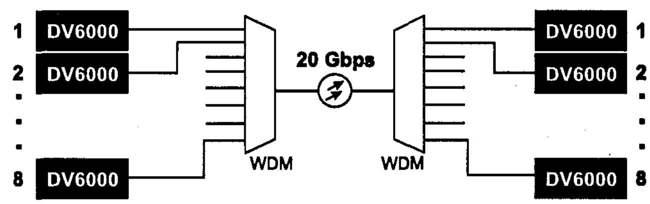

Figure 6. ADC Telecommunications' DV6000 Uncompressed Digital Transmission System employing DWDM for 20 Gbps transport.

This provides a single fiber capacity of 20 Gb/s, which translates to 128 analog CATV channels, 256 DS3 channels, 128 MPEG2 QAM multiplex signal streams (with up to 20 MPEG multiplex channels per stream) or a combination of these signal types. Other vendors currently provide systems which can transmit eight or more simultaneous wavelengths containing digital information, over the same fiber. A counter rotating ring can be implemented with no loss of capacity on 2 fibers, as shown in Figure 7. Alternatively, it is technically possible to implement a bidirectional WDM system with redundancy on a single fiber at 10 Gb/s.

Today, the application of WDM is primarily limited to point to point transmission between hubs on the ring. This is due to the fact that only "hard wired" fixed wavelength optical splitters are available. This provides the benefit of reduced fiber count, but not full optical add/drop capability. In order to dynamically drop or add a wavelength at any hub, a dynamically

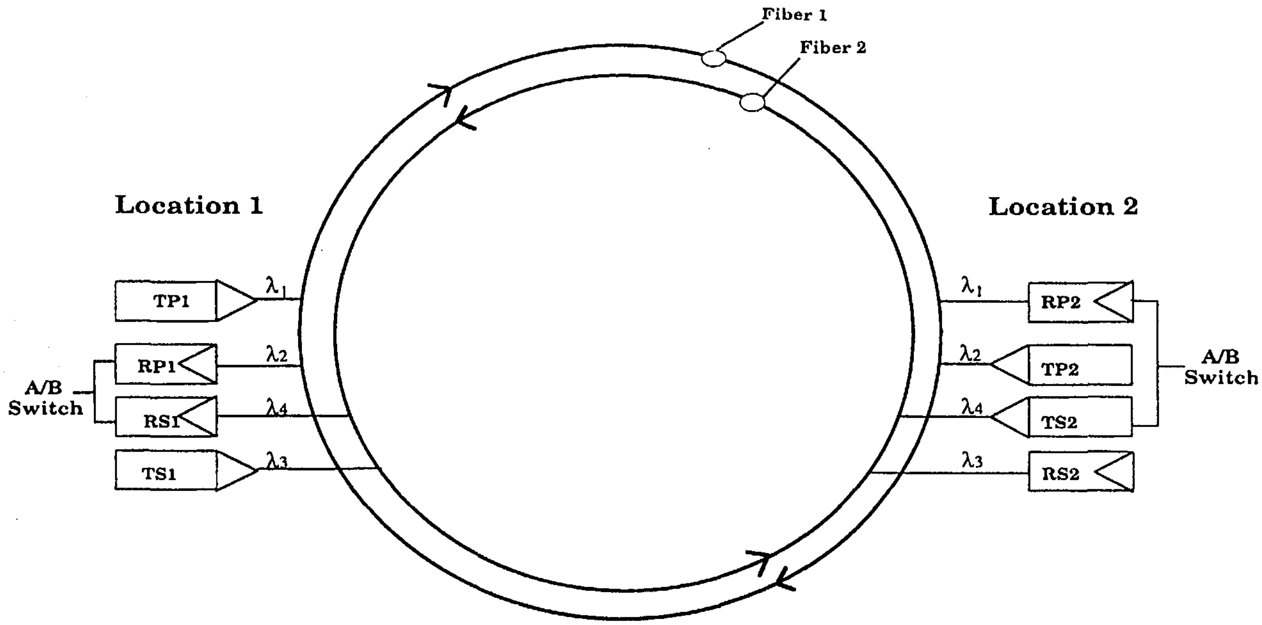

Figure 7. Counter rotating ring with full fiber and electronics protection

wavelength selective optical WDM device will be required. For high speed digital telephony systems, there may be a significant cost advantage in being able to do a drop and add function in optics versus electronically, due to the high cost of the digital add/drop multiplexor. Optical switching can perform virtually the same functions as TDM switching. The only optical limitation in multiplexor functionality s that there is not an easy way to make a drop *and pass* device.

The benefits of dense WDM are not as obvious in a smaller backbone system that employs 1550 nm high power linear transmission of CATV video channels. Although it has been demonstrated that digital and linear optical signals can be simultaneously passed through the same optical amplifier[1], the optical link budgets of high speed digital transmission systems are so dissimilar as to make this probably impractical in common implementation. For example, a 2.4 Gb/s operating at 1550 nm has a link budget of 29- 31 dB, translating to over 100 km in length, which is within the range of distance between 90% of all hubs. A typical high power linear system has a link budget of 12 - 14 dB. Therefore, the linear system will require amplifiers after a distance of 12- 14 dB which is less than half of the link budget for the digital system. Operating the digital system through these amplifiers will provide no advantage to the digital system, and therefore if digital and high power linear signals are mixed on the same fiber, extra cost must be incurred to provide splitters to the digital signals in order to bypass these optical amplifiers.

Dense WDM in HFC Distribution Systems

While there are clear capital and operational savings to be had today from building a new digital fiber backbone system employing dense WDM technology through saving of fibers and electro/optic repeaters, there are potentially larger future savings in the forward and reverse path of the HFC distribution system.

Consider that the average hub serves between 20 and 80 optical nodes. It is typical to provide 4-6 home run fibers between the hub and each node, since at least two fibers are normally required for bidirectional transmission, and extra fibers are installed to support future migration of nodes closer to the subscriber, or additional services close to the node. Multiplying the nodes times the fibers per node calculation means that as many as 480 fibers are required at the hub. Given that WDM would allow multiple linear signals to be transmitted on the same fiber, the number of fibers at the hub could be reduced by 67% while maintaining the ability for future expansion of nodes closer to the subscriber. Even greater savings are possible if fiber branching is allowed. For example, if 16 nodes could be served using 16 wavelengths originating on one fiber from the hub, then it is possible to serve 80 nodes two-way using only 10 fibers total. Figure 8 illustrates this concept. Note also, that in building a metropolitan system that there may easily be ten or more hubs, so that the savings realized is factored by the number of hubs (i.e. distribution networks) in the overall system. To accomplish this savings technically requires future development of both the lasers which can support 110 channel linear transmission at various wavelengths around 1550nm, as well as WDM optical devices which demonstrate excellent long term stability and performance while installed in an outdoor, unprotected environment.

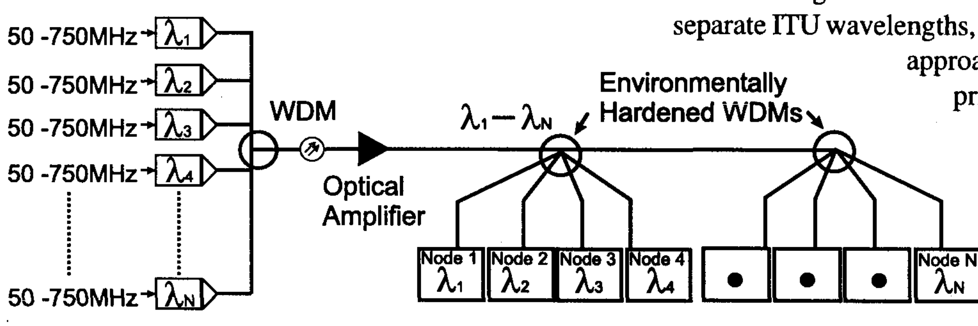

Figure 8. Potential Future Dense WDM in HFC Forward Path

Another alternative that has been postulated is to transmit in the forward path from the hub to nodes the common broadcast channels (typically from 50 - 550 MHz) at one common wavelength, and then to send the narrowcast signals to each node on a different wavelength where they are combined in the optical receiver. Although this is possible from an optical perspective, the combining of signals at the node receiver may be a more difficult approach in actual implementation. This is because it is difficult to combine the signals at each node with the correct RF level. Without going into a detailed technical explanation in the space of this paper, suffice to say that the RF output level of a signal out of an optical receiver is proportional to the input optical power of the received signal and the square of the depth of modulation. Trying to match two different optical transmitters' outputs coming into the node receiver with two power levels and two depths of modulation would probably be difficult.

Dense WDM may also hold future promise for return path expansion. Today, block upconversion is the most often proposed means of taking up to four 5-40 MHz return paths and transporting them across a single fiber back to the hub. In the future it may be possible to optically multiplex the return paths instead of frequency multiplexing these signals. Of course this will require both the multiple optical wavelength transmitters which are cost effective, and the WDMs which meet the environmental rigors required to be installed in a strand mounted unprotected optical node.

All Optical Network Challenges

The current barriers to All Optical Networks center around devices and availability. The ITU has suggested standardized channel spacing based on specified optical wavelengths in the 1550nm bandpass region of optical amplifiers. In the digital realm, high speed 1550 nm wavelength lasers are becoming available for 40 separate ITU wavelengths, at prices which are rapidly approaching standard 1550nm pricing. Work is being done by some vendors on creating multi-wavelength laser arrays to further drive down pricing. However, using 40 different channels brings up the real world problem of transmitter sparing. Currently, this limits the flexibility. The ideal solution is a tunable wavelength laser, if not for all transmitters, then at least as a universal spare. This is a comparable problem to that which the CATV industry had in the 1980's, when VSB/AM modulators were fixed channel. The advent of tunable lasers will significantly accelerate the implementation of WDM systems. Correspondingly, similar breakthroughs are required in broadband linear optical devices.

Another key requirement is the availability of low cost/ highly efficient WDM devices, both fixed wavelength and tunable, suitable for indoor and outdoor installation. In this area, technology is moving forward very quickly, and the emergence of these devices appears on the horizon.

Conclusions

Dense WDM technology and the ability to create All Optical Networks will allow further improvements in the cost, flexibility and reliability of CATV networks.

Availability of the optical components necessary to create these networks will occur within 2-3 years, giving network providers additional means of providing better service and additional capacity to their customers.

References

[1] Chinlon Lin, Keang-Po Ho, Hongxing Dai, Janyi Pani, Hermann Gysel, Mani Ramachandran, "Hybrid WDM Systems for High Capacity Video Trunking Applications", National Fiber Optics Engineers Conference Proceedings, September 1996, p. 261.

Wireless Telephone Industry Opens Doors for Cable

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Abstract

The wireless industry is a leader in the development of new technology for low-power communications equipment. The integration of microwave frequency circuitry and new SMD filters for wireless has created new opportunities for other industries. These new components offer tremendous opportunities to improve and simplify cable products. A 860 MHz Dual-Conversion tuner is described which uses wireless technology to meet the requirements of all cable transmission formats, including NTSC, PAL, and 64 QAM, while eliminating all adjustments.

Cable Tuner Technology

Dual-Conversion tuners are used in cable systems in order to achieve the required composite distortion performance. These tuners have traditionally been designed using discrete oscillators, balanced diode mixers using ferrite baluns, and aperture HI-IF filters. General Instrument's 550 MHz tuner, using traditional technology, required tuning of the HI-IF aperture filter, Up-Converter mixer and oscillator, Down-Converter oscillator, and IF filter section. A total of seven separate adjustments were required for each tuner.

Predicting the performance of mixers is difficult when mixing multiple signals (1), (2) regardless of the technology used. Eliminating the variable of discrete diode based mixers and replacing them with a MESFET based Gilbert-Cell mixer makes the performance more predictable. Using GaAs technology (3), we were able to integrate an oscillator with the Up-Converter mixer and a differential RF amplifier in a single RF ASIC, eliminating the need for a separate pre-amplifier. Figure 1 shows a differentail amplifier driving a Gilbert-Cell MESFET mixer. This device takes advantage of a FET's superior third-order distortion performance while the Gilbert Cell's structure improves second order distortion. This change was implemented in 1992 and reduced the number of components in the Up-Converter section from 124 to 64 while eliminating two adjustments. Over 20 Million tuners have been manufactured using the integrated GaAs Up-Converter IC, making General Instrument a leading user of GaAs ICs.

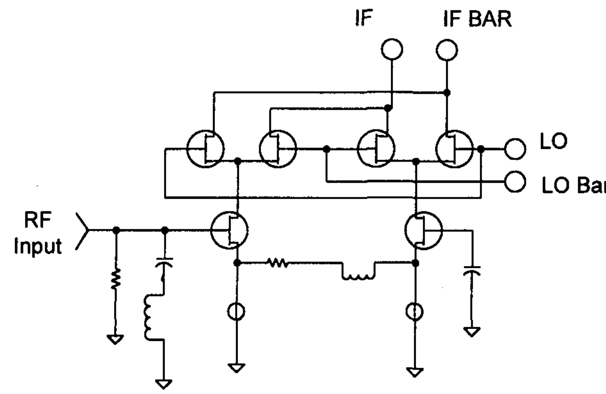

Fig. 1 Gilbert-Cell Mixer with Diff-Amp Input

The trend towards integration continued in our 1 GHz tuner which used an integrated Up-Converter, Down-Converter, and two single-chip synthesizers. As 1 GHz cable systems proved to be more marketing than reality this product was modified to a 860 MHz tuner. While we had increased the bandwidth and achieved a significant amount of integration we still retained a single-sided PCB and aperture HI-IF filter design.

General Instrument had two basic tuners (550 MHz and 860 MHz), with different versions for NTSC, PAL B, or PAL I output. Each version had different tuning procedures and Bill of Materials (BOM). These products used single-sided PCBs and a wave-soldering process which required a significant amount of inspection and touch-up. The total cost of supporting these products was becoming non-competitive due to labor costs.

A goal was set to design a single tuner for all converters, regardless of format, including digital terminals such as the DCT-1000 (64 QAM). The tuner needed to significantly reduce the direct labor requirement and eliminate all adjustments. In order to achieve this goal all cost items were considered, including manufacturing costs, test requirements, alignment cost, and indirect labor costs. Switching from a single-sided PCB to a double-sided PCB, which was traditionally rejected automatically due to the increased cost, was left open to consideration if the total cost was reduced. The basic block diagram can be seen in Fig. 2, showing the key sections of the tuner.