OFF PREMISES TECHNOLOGY COMPARISONS

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INTRODUCTION

The last decade has witnessed a significant change in the direction of the CATV industry. The advent of satellite delivery of premium programming has broadened the appeal of CATV as a method to supply home entertainment. This, in turn, has resulted in a huge increase in the CATV subscriber base. However, in addition to this new base, it has also resulted in the need for viable denial technologies to control the dissemination of this premium programming.

A large segment of the CATV industry accomplishes the task of programming control by means of electronics that are physically located inside the subscriber's home. These electronics may consist of a set-top converter (addressable or non-addressable). The converter or other electronics inside the subscriber's home result in many problems for the system operator, such as theft, access, and subscriber education. In addition, these electronics typically aggravate the subscriber interface problem.

A number of methods have been devised to remove the electronics from the subscriber's home. In the following paper we examine several of the various methods that have been proposed to accomplish this task.

I. NEGATIVE TRAPS

The use of negative traps is one of the first methods employed for the purpose of controlling subscriber access to premium programming. A negative trap consists of a high-Q band-reject (notch) filter with a stopband frequency centered on the picture carrier of the channel(s) to be controlled. The filters are typically located at the tap port for a particular subscriber and "notch-out" the un-authorized channels for that subscriber.

One important figure of merit for negative traps is their ability to remove energy at and around the frequency of the picture carrier of the channel(s) to be controlled. Empirically it has been shown that it is necessary to attenuate the picture carrier of a CATV television channel by at least 60 dB in order to render it unusable. A second figure of merit for a negative trap is its effect on adjacent non-secured channels. It is desirable to minimize any attenuation of the lower and upper adjacent channels.

These concerns result in a requirement for excellent shape factor of the band-reject filter response. However, conventional negative traps are built using L-C filter technology. The achievable shape factors are limited by the Q available from the L's and C's used in the filter. Temperature considerations are critical, as any drift in notch frequency may result in reduced carrier attenuation. Thus conventional negative traps generally are built at frequencies below 216 MHz. Additionally, attenuation of the adjacent channels of up to several dB may occur, especially in the upper part of the usable range of channels.

An additional concern for negative trap performance is passband return loss. High return loss is desirable in order to allow the cascade of multiple traps to secure multiple premium services. The use of conventional L-C technology has limited this cascadability to three or four traps before significant passband deterioration occurs in many cases.

It is important to note that, despite these technical challenges, negative traps have, and are, being used successfully in the industry today.

II. POSITIVE TRAPS

Positive traps are electrically very similar to negative traps. However their application is significantly different. In a positive trap system, an interfering signal is inserted in the channels to be controlled at the CATV headend. This interfering signal renders the channel unusable by the unauthorized subscriber. In the case of an authorized subscriber, a positive trap is installed at the CATV tap. The positive trap is a band-reject (notch) filter designed to remove the interfering carrier while removing a minimum of the television signal information.

The technical requirements for a positive trap are very similar to the technical requirements for a negative trap. The positive trap must attenuate the interfering signal by at least 60 dB in order to render its effects invisible in the recovered picture. Typically the interfering signal is inserted at a frequency that is midway between the picture carrier and the sound carrier of the channel to be controlled. This placement gives maximum distortion of both audio and video signals (as a result of the way inter-carrier detection is used in virtually all television receivers) and occupies an area of the channel where the energy density is very low. The low energy density is important to ensure that any television signal that is removed from the channel by the positive trap will have a minimal effect on the recovered picture quality.

However, despite this placement the shape factor limitations of L-C based positive traps result in undesirable energy removal from the television channel. With the conventional placement of the interfering carrier this energy comprises the high frequency components of the luminance signal (picture detail). This is one reason why positive traps are often called "soft traps" in the industry, as they tend to soften the picture of the channels they secure. Pre-compensation for the amplitude and delay (non-linear phase shift) distortion at the head end can minimize the perceptibility of this phenomenon. Positive trap approaches are likewise limited to frequencies below 216 MHz.

As with negative traps these limitations have not prevented positive traps from being used successfully in the industry today. The economic benefits of requiring hardware at only those subscriber locations where a premium service is being received are seen to far outweigh the technical limitations.

III. ACTIVE (DYNAMIC) NEGATIVE TRAPS

A modified negative trap has been developed that uses active circuitry to solve some of the limitations of the conventional negative trap. This technique uses a notch that is too narrow to ensure frequency stable picture carrier attenuation in the conventional negative trap sense. However, this notch is slightly frequency variable by electronic means. This is accomplished by embedding a varactor diode in the notch filter topology. During operation the notch center frequency is modulated at an audio frequency rate. If such a notch is placed at the frequency of the picture carrier of a television channel to be secured, the resulting amplitude and phase modulation of the picture carrier will render that channel unusable.

The advantages of this technique lie in the requirements for the notch. As stated earlier the conventional or static negative trap requires excellent shape factor and at least 60 dB of stop-band attenuation. However it is the parasitic modulation of the picture carrier and not the attenuation of that carrier that results in the "scrambling" of the picture. A dynamic notch can obscure a channel with only 30 dB to 40 dB of ultimate rejection. Additionally this attenuation may be very narrow in frequency. The requirement of the notch frequency stability versus temperature is also relaxed with respect to static negative traps, as the notch is intentionally moved in frequency.

Conceptually the idea solves several problems that have plagued static negative traps. However, the physical embodiments of this technique have thus far proven to have serious deficiencies. The reduced shape factor requirement allows for significantly lower attenuation of the adjacent channels. Unfortunately there still remains a small amount of attenuation and this attenuation is modulated along with the notch frequency. The parasitic modulation imparted on the adjacent channels will result in visible artifacts even if the amount of modulation is only a small fraction of a dB. In addition, the introduction of any active device into the CATV system brings with it the requirement for powering with all of its associated problems.

This technique has met with extremely limited acceptance in the CATV industry.

IV. OFF-PREMISES CONVERTERS

A great deal of study has gone into the development of an off-premises (or "pole-mounted") converter. The technical challenges of this task are substantial. Attempts at developing and using an outdoor converter have met with only limited technical success.

There is, however, a more fundamental reason for why systems using off-premises converters have been unsuccessful. The main problem with this approach is that it does not solve any of the problems that lead to the examination of off premises technologies in the first place. For example:

1. It does not solve the consumer interface problem. It delivers a narrowband signal to the home.
2. It does not remove hardware from the home. Some sort of channel selection console is required in the home.

Even if a technically sound approach to this technique could be found, it is unlikely that it would offer anything of interest to the system operator.

V. ADDRESSABLE BASES

Addressable bases have been proposed to be used in conjunction with the filter techniques that were mentioned previously. The simplest form of an addressable base is an addressable service disconnect. The addressable service disconnect is useful but does not solve the problem of control of individual premium services.

More sophisticated addressable bases do permit the addressable control of individual services. However they do not solve the other technical problems associated with these techniques. Many operators see addressable bases for filter techniques as stepping stones to more sophisticated programming denial techniques.

VI. INTERDICTION SYSTEMS

Interdiction is defined in Webster's Ninth New Collegiate Dictionary as "to destroy, cut or damage". In CATV, interdiction means injecting an interfering carrier in one or multiple TV channels to deny the viewer these TV channels. The TV channels may be in any format of i.e. NTSC, PAL I, HDTV, etc.

The interdiction system is basically a negative technology. This means that some electronic device must be installed at the users locations to deny the TV channels which have not been subscribed. There are several methods to implement such electronics. The first method is to design one fixed oscillator per TV channel denied in any given system. Thus, if a system is designed to deny 16 pay channels, the number of oscillators required is 16.

The second method is to design one or more electronically tunable oscillators which will hop among all denied TV channels. So if a system is designed to deny 16 pay channels, the number of oscillators required will be less than 16. One can do a trade off between the number of pay TV channels and the number of oscillators to hop.

There are practical limitations to both methods. It is difficult to combine a large number of oscillators with a broadband signal path containing television channels in the first method. In the second method, it is difficult to control jamming oscillator side bands generated by hopping.

The most important consideration in the interdiction system is how well the system obscures the TV channel which is denied. The parameters associated with the interfering carrier are very important (i.e. dwell time, hopping rate, interfering carrier strength with respect to video carrier, placement of the interfering carrier with respect to video carrier, AM/FM side bands etc.)

The interdiction system delivers a broadband signal which is compatible with all home electronics equipment. Interconnection of the in home electronics becomes less confusing. The TV channel that is received by the authorized subscriber has not been subject to any scrambling techniques. Thus the signal contains no descrambling artifacts. The electronics associated with the interdiction system will always be off premises. So the system operator will always have direct access to and control over his investment. It will also be less intruding to the end user.

Certain technical requirements exist for the interdiction approach. Interdiction systems prevent reception of a TV channel by placing an interfering carrier (jammer) near the video carrier frequency of the channel. The jammer is injected at each subscriber's tap location, and may be turned on or off addressably to control access to the channel. Jammer level and frequency must fall within certain bounds. Level must be high enough to mask the picture, but not so high as to cause distortion in the television set or interference to adjacent channels. Jammer frequency must be located accurately within a tight window with respect to the video carrier to assure masking of the video and to prevent adjacent channel interference. There are two further benefits of locating the jammer close to the video carrier. First, severe interference to audio occurs because the jammer disrupts the intercarrier detection process within the television set. Second, it is impossible to pirate the signal by trapping-out a jammer located close to the video carrier.

As stated earlier, there are several ways to implement an interdiction system. For example, a very simple method would use several fixed-frequency oscillators to generate jammers, the oscillator frequency being controlled by crystals or perhaps SAW resonators. This approach has the disadvantage that the choice of controlled channels is fixed and limited to the number of oscillators. The cost of such a system is high if more than a very few channels must be controlled, since one oscillator is required for each channel.

Using several tunable oscillators would add flexibility in channels controlled, but one oscillator per jammed channel would still be required.

These disadvantages can be overcome by using a voltage-controlled oscillator (VCO) which hops in frequency among the channels in its tuning range. Several techniques have been proposed to do this. Conventional oscillator techniques result in significant energy at harmonics of the oscillator fundamental frequency. If not dealt with properly, these harmonics can result in objectionable artifacts in unsecured channels. One approach to an interdiction system uses a single variable oscillator to jam all channels to be secured. The frequency range of this oscillator is the upper octave of the CATV band. Placement of the frequency in this range results in harmonic energy falling outside of the CATV band where it does minimal damage. However, this approach makes the transition to interdiction technology from conventional denial technology very difficult as programming to be secured is traditionally located in the lower part of the CATV spectrum due to the reasons mentioned earlier. It can also be shown that as a single oscillator is used to secure more and more channels, the amount of scrambling of these channels is reduced.

A wide range of channels can be controlled by using several hopping oscillators. For example, four oscillators, each having a tuning range of 1.3:1 can cover all channels from 120 MHz to 325 MHz. The relative frequency range is determined by the ability of practical filters to attenuate harmonics of the oscillators to an acceptable level. The outputs of four VCOs are combined and then added to the broadband signal. An isolation amplifier prevents jammers from leaking onto the feeder. VCO frequency is controlled by a staircase tuning waveform which is generated from digital words stored in memory for each jammed frequency. Frequency accuracy is assured by calibrating these stored values using a frequency-locked loop. Finally, there must be a means of preventing the jammer from interfering with authorized channels while hopping in frequency. This function is performed by RF switches located at the output of each VCO.

A basic question regarding the hopping-jammer system is: how many channels can be securely controlled by each oscillator? (Here, secure control means that the jammer will cause any television set to lose horizontal synchronization.) As the jamming carrier hops to an increasing number of channels, it dwells a shorter period on each channel. Not surprisingly, this reduces its jamming effectiveness. Eventually, a point is reached where loss of horizontal synchronization cannot be guaranteed.

However, dwell time is not the only determinant of jamming effectiveness. Jammer amplitude and hopping rate are also important. Higher jammer level can to some extent compensate for short dwell times, but jammer level is limited by distortion and adjacent channel considerations. And there is a range of hopping rates which produces maximum jamming. Combining the factors of dwell time, hopping rate, and jammer amplitude, it has been determined that four channels can be securely controlled by each oscillator using the definition of "secure control" given above (this result has been verified on a large number of television receivers of various makes and models). Eight or more channels can be controlled per oscillator if loss of horizontal synchronization is not a requirement. Eight channels jammed per oscillator produces severe degradation of the picture and sound.

An important aspect of the interdiction system is control of jammer level relative to video carrier level. Low jammer level results in reduced security, while high jammer level can cause distortion and adjacent channel interference. AGC is thus a necessity. Two methods of AGC are possible: AGC of the video carriers and AGC of the jammer with respect to the video carrier being jammed.

AGC of the video carriers is fairly simple to implement and has the advantage of providing a stable video carrier level to the subscriber. One approach controls the average level of several carriers located near the center of the bandwidth of the VCOs. Average level variations due to temperature changes or other causes are removed. AGC of the video carriers does not remove level variation due to non-flatness of the video carriers or seasonal tilt changes. These variations are not so large, however, as to cause jammer level to fall outside the window defined by loss of secure jamming at low levels, and distortion or adjacent channel interference at high levels. Level error due to cable tilt at a fixed temperature can be avoided by the use of a cable equalizer in the interdiction unit.

AGC of the jammer with respect to the video carrier being jammed has the advantage of eliminating level error due to non-flatness and seasonal tilt changes. It is most appropriate when only one VCO is used, due to circuit complexities which result when multiple VCO levels must be controlled.

VII. POWERING

Since the use of active Off-Premises technology requires the replacement of passive tap devices with active Off-Premise devices, the system power consumption will be increased. As the larger number of active devices require an increase in the number of power supplies, "Who pays for the increase?", becomes more of an issue with cable operators.

There are basically three powering schemes to address the problem.

1. Feeder Cable Powering
2. Subscriber Drop Cable Powering
3. Hybrid Powering

As with any design, there are certain pros and cons that must be evaluated before decisions can be made. This section hopes to address some of these issues.

Conventional CATV plants are powered by 60 volt AC ferroresonant power supplies situated in the trunk and feeder lines. Additional power supplies may be required to cable power new active devices in the plant. Since most existing system ferroresonant power supplies have high current ratings (15 amps) and are loaded to near maximum, one cost effective solution is the use of smaller ferroresonant power supplies inserted in the feeder system itself. This approach minimizes system redesign requirements as well as the cost impact of the larger 15 amp ferroresonant supplies.

The Off-Premise unit itself must make every effort to reduce its power consumption and thus limit its impact. The use of DC switching power supplies (with efficiencies of 70 to 80 percent) instead of linear power supplies (with efficiencies of 40 to 50 percent) is one way of reducing power consumption. With emphasis on such parameters as power factor and component losses, much can be done in ways of optimization.

As with any aerial mounted active device, reliability (especially the ability to withstand lightning strikes and other transients) are extremely important.

The use of subscriber drop cable powering may resolve the problem of plant redesign for power. In addition it reduces power cost impacts by having the subscriber pay to power the off-premises electronics. There are several considerations associated with the use of home powering:

1. The payback of the cost of the transformer in the home

2. The possibility of local zoning requiring the house transformer be hardwired

3. Service calls for unplugged transformers

4. Access to the drop (i.e. lock boxes over ground blocks)

5. UL restrictions

6. Home circuitry needing to be hardened for transient and lightning survivability

7. Customers may try to split the signal between the home transformer and the Off-Premise unit

8. The possible uneven sharing of powering burden depending on cable drop lengths.

9. The liability from electrical shock.

Additionally, one must decide on a format for the power to be delivered over the drop cable. Two major approaches have been proposed: AC powering and DC powering.

Some of the advantages associated with AC powered drop cable are: low cost, simplicity and ruggedness to lightning. The disadvantages are: sheath currents, potential problems with power summing in Off-Premise unit, shock hazards, U.L. violations (?), and corrosion. With ferroresonant AC powering, there are additional disadvantages of the home transformer cost, size and weight.

DC powered drop cable advantages are: minimal sheath current effects, ease of power summing, maximum power transfer in long drops, low cost, fairly rugged and potentially lower shock hazard. The main disadvantage with DC powering is corrosion unless special precautions are observed.

The hybrid powering approach involves using feeder cable powering for part of the electronics while using drop cable powering for the remainder. Unfortunately, this method has the advantages and disadvantages of both powering schemes. While it is possible to argue in favor of this approach, it is not a "cure-all".

VIII. DISTRIBUTION ISSUES

As one of the main requirements of an Off-Premise is to act as a functional tap replacement, there are certain distribution system concerns that must be addressed.

One issue of immediate concern is the insertion loss of the Off-Premise unit compared with conventional taps. If the Off-Premise units were to have more through loss, additional line extender amplifiers would be needed. It is therefore desirable to make any off-premise device insertion loss comparable with conventional taps.

The power passing capability of an Off-Premise approach is a significant concern. It may become necessary to pass more current than the typical 6 amp limit of conventional taps. A 10 amp limit is suggested as a reasonable goal. It is important that hum modulation is monitored to ensure that the additional current does not create objectionable artifacts in the television pictures.

IX. MECHANICAL CONCERNS

As described elsewhere in this paper an off premises unit combines functions performed in the headend (scrambling/ interdiction), taps and set top terminals. The headend and set top terminal functions are not normally performed out-of-doors, but in this unit they are. Therefore we add many of the mechanical concerns normally associated with distribution equipment to a product that performs few distribution functions.

Although the housing required to enclose all of these functions is much larger than a tap, it should resemble a tap for ease of installation and replacement. The installation of this type of product should be no more difficult than installing a tap. To ease the design of the system a unit that has the same number of drops as a tap is also required. In addition, if the active part of the electronics are not used at a location, then provisions should be made for the unit to function exactly like a tap.

Since the unit is normally out-of-doors, a major concern is to make the housing weather resistant. Especially important is to provide a water proof enclosure for the electronics. Since temperature changes can change the air pressure inside the enclosure, the connections and the housing seal should be pressure tight to approximately 10 psi.

Being outside also subjects the unit to corrosion problems. Selecting a corrosion resistant alloy for the housing will reduce the problem in most cases. Salt air and constant immersion in water require that the unit be protected with an epoxy resin and that stainless steel hardware be used to retard the corrosion. The aluminum alloys typically used in housings may show good corrosion performance, but they do not show good electrical performance and are not used in connectors. So even when corrosion resisting alloys are used, problems associated with dissimilar metals can occur. The use of compatible materials and platings will minimize this problem.

The addressable nature of an off premises product will allow service to be electronically disconnected from the headend. Because this eliminates removing the drop as the primary way to remove service from the home, damage to the port from frequent connections is also eliminated. The permanent nature of the drop, similar to a telephone connection, will support the development of a more rugged F connector.

When fully populated, the unit will serve multiple customers. But, if the unit is designed for modular functions, it is not necessary to fully populate the unit to bring only one customer on line. A unit with field replaceable modules will reduce the time that a subscriber would be without service in case of an electronic failure. If a major failure were to occur it is also important to be able to remove and replace the entire unit very quickly to restore service with a minimum of interruption.

As the unit is larger than a standard tap, how to mount it is an important question. The design of the housing should follow the guidelines used for most strand mounted equipment. Properly designed, this equipment should not cause any problems in an aerial mount. For pedestal mounts the design should be such to allow use of a standard pedestal enclosure. As the unit incorporates functions not usually found in a tap, it may be necessary to use a pedestal enclosure slightly larger than that used for conventional taps. An eight inch enclosure, typically used in amplifier applications, should be the largest enclosure used to house this unit. This pedestal imposes a maximum length constraint on the unit of 16 1/2 inches.

Since use of interdiction technology allows the transmission of the original signal in the clear, use of a secure housing is extremely important. In an unsecured housing the clear signal is accessible to a pirate. The housing developed for an off premises product should have provisions for a mechanical lock or tamper evident seal. Electronic protection that shuts off service when the housing is opened without authorization should also be included.

The heat generated by the various power supplies used to support the electronic functions should be considered in developing the outside housing. Adequate mountings for transferring heat from the modules to the housing should be included. The exterior of the housing should be designed to insure sufficient heat transfer to the surrounding air to keep the unit with in its specified operating temperature range.

Besides the purely mechanical functions previously described, the housing has to provide several electronic functions. Attenuation of RFI/EMI signals to acceptable levels and grounding of power and signal voltages are important functions of the enclosure. In addition to the water seal, a conductive gasket should be used to assure that a conductive path exists between the halves of the housing.

CONCLUSIONS

Several methods have been described that will accomplish the task of programming denial. Each of the methods has its own technical strengths and weaknesses. It is important for the system operator to weigh these technical concerns against the economic benefits associated with each technique.

As work and development continues in our industry, there will most certainly be new additions to the methods described herein. As responsible members of the CATV industry we should all review these methods to determine which will provide the most satisfying service to the ultimate customer, the subscriber.