SILICON INTEGRATION FOR NEXT GENERATION VOICE OVER CABLE CUSTOMER PREMISE EQUIPMENT

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Abstract

The voice over cable (VoCable) market is defined by both constant bit rate (CBR) and voice over internet protocol (VoIP) technologies. Operators that have previous CBR VoCable experience have provided significant input on the features required for next-generation VoIP. VoIP has gone through an initial deployment ramp in 2004 with many of the world's service providers either rolling out a commercial service or conducting extensive, large scale field trials. Feedback from this process along with industry input on the future direction of the market has provided a valuable set of features and optimizations to be included in next generation products. This paper will explore the features necessary in a next generation EMTA and the integrated, cost effective silicon necessary to support these features. The paper will explore the integration options that can reduce the component count and cost of the design. The paper will focus on factors and tradeoffs associated with silicon integration that can optimize power supply, battery charger and telephony interface costs. The paper will also explore the integration level necessary to support add on of peripheral components such as wireless LAN technology and convergence with mobile voice technology

INTRODUCTION

For the past ten years Voice over cable (VoCable) has been offered by several multiple service providers (MSOs). VoCable deployments, starting as early as 1995, utilize traditional constant bit rate (CBR) and are the dominant method of providing cable telephony service today. More recently, deployments have started to utilize voice over internet protocol (VoIP) technology. VoCable deployments have reached nearly twelve million subscribers and less than 10% of the total subscribers are served by VoIP systems. In both CBR and VoIP systems, a key element to successful VoCable deployment is the client device installed at the service subscriber's site. This client device, referred to as customer premise equipment (CPE) has evolved over a decade of deployments. The CPE evolution has been driven by customer feedback and market trends. Valuable experience has been gained during field trials, initial service introductions and full scale deployments of VoCable CPE. This experience and feedback has provided CPE vendors valuable information to aid in the analysis and development of cost effective silicon technologies.

CPE Evolution

When first introduced, VoCable CPE devices used in CBR systems were expensive and bulky because they were developed with a Carrier Grade telco mindset, and typically deployed outdoors. As VoCable deployments grew and field experience increased, CPE vendors developed newer generations of CPE based on MSO feedback. Key factors that needed to be addressed included cost, system availability, power consumption, and terminal equipment (ie. black phone set) compatibility.

VoIP technology offers an opportunity for the MSOs to continue to lower the cost of VoCable deployments as well as provide an open platform to add new future services. The earliest VoIP CPE were essentially DOCSIS Cablemodems with discrete voice interfaces, provided for early lab evaluations and field trials. These specialized Cablemodems are now often referred to as an embedded multimedia terminal adapter (EMTA). Many MSOs have completed lab evaluations and field trials and have begun VoIP cable telephony service introductions and plan large scale deployments of EMTAs.

VoCable CPE designed for CBR and VoIP systems consist of similar functional blocks. Both types of CPE utilize a cable MAC and PHY, a communications processor, memory, RF tuner, telephony line interface and power supply. EMTAs for VoIP systems include a voice digital signal processor (DSP) that is not required in CBR system CPE.

CPE for CBR systems typically use proprietary MAC and PHY silicon while EMTAs utilize DOCSIS cable modem MAC and PHY silicon. The communications processor, memory, RF tuner, and telephony line interface provide similar functionality for both types of CPE. The power supply circuitry is dependent on the requirements of the remaining functions.

Silicon integration has been applied to the various functional blocks of VoCable CPE for cost reduction. EMTA's have also benefited from the lower costs associated with large volume deployments of data-only Cablemodem as well. In particular, silicon vendors already offer products with the communications processor and DOCSIS MAC and PHY functions integrated into a single ASIC. CBR systems have also enjoyed cost reduction due to silicon integration, however the pace of additional cost reduction has slowed due to the R&D investment shift to VoIP. Further opportunity still exists for additional silicon integration and lower costs for VoIP CPE.

<u>CPE Features</u>

Experience gained from VoCable deployments in both CBR and VoIP, along with industry input on the future direction of VoCable has helped to identify a set of key features to be considered for next generation CPE. This paper will focus on a few critical features and the cost effective silicon integrations necessary to support these features. The features to be explored are:

- low product cost
- telephony line count
- ILEC replacement
- installation environment
- mobile voice

LOW PRODUCT COST

As with most Consumer Electronics products, cost is one of the most important factors in designing a VoCable CPE. Cost is also one of the most difficult challenges facing the CPE design engineering team. Economics ultimately drives every design decision so cost tradeoffs must be considered when developing the next generation of VoCable CPE. This is especially important when considering cost reduction through silicon integration of CPE functions.

Silicon integration is not always the most effective way to optimize the CPE cost. Care must be taken to avoid adding silicon for features that may not be utilized in volume applications.

Integrated circuit (IC) packaging must also be considered. IC power density and thermal considerations limit what can affordably be integrated in a single die and a single package.

As the number of integrated features grow so does the complexity. Size and complexity determine design, test, and manufacturing of ICs, all of which impact cost.

Increased silicon density magnifies integrated circuit susceptibility to process parameter variations and noise disturbances. As the geometry of the IC decreases the designs may require more fault-tolerance which could add cost.

In the near future, complexity will increase due to a larger range of applications and higher level of design abstractions in silicon integrations. Robust solutions will be required for the integration of mixed technologies. Implications of increased integration will result in increasingly difficult cost decisions.

TELEPHONY LINE COUNT

An important feature of any VoCable CPE is the number of telephony ports that are supported. The number of telephony ports required is primarily driven by the type of service offering. Three types of services are considered:

- residential service
- multiple dwelling service
- enterprise service

Residential Line Count

Residential telephony service is by far the largest portion of the total deployment of VoCable CPE today. MSOs have been fairly consistent in their requirement for the number of telephony lines for residential service. Early CBR system deployments typically required two telephony ports on CPE, although there are cases when up to four telephony ports are required. Four telephony lines provide a significant potential service differentiator for the MSO over the Incumbent Local Exchange Carrier (ILEC). The various MSOs deploying VoCable with CBR systems found that the actual number of telephony ports being deployed per resident ranged between 1 and 4 with the average being around 1.2 lines.

As expected, CPE requirements for VoIP systems have mirrored those of CBR systems. Two telephony lines per EMTA continue to be the volume preference. Silicon vendors have recognized this and are already taking steps to optimize their products for two telephony lines through integration. However, interest for CPE with a single telephony port is also being discussed as an option to provide a lower cost alternative to subscribers. Currently, single line CPE cost will be burdened by the silicon utilized to implement the prevalent two line CPE.

Multiple Dwelling Unit Line Count

Multiple dwelling unit (MDU) telephony service requires a higher line count than residential services. MSOs prefer to use a multi-line CPE device for economic reasons including ease of installation, footprint and equipment recovery. Modularity is also an important feature to the MSOs so that additional lines can be added easily as subscriber penetration increases.

Larger line sizes and modularity create a particular challenge for silicon integration. Cost per line is a critical factor in multi-line

CPE so silicon integration should be a consideration, but volumes may not justify the development cost. Also, it is important not to burden the cost of the residential CPE.

CPE silicon optimized to provide two telephony lines should contain "hooks" to provide the capability to easily expand the number of telephony lines supported. Telephony line expansion is possible by including the capability to support cascaded DSP ASICs. CPE silicon integration could also provide the ability to increase processor clock speeds to support multi-line applications. Continued telephony line interface integration is also under investigation.

Enterprise Line Count

Enterprise telephony service is targeted at small to medium size businesses with line counts between residential and MDU services. Telephony service can be provided to many small business subscribers with four line CPE. Modular multi-line CPE is ideal for businesses requiring more than four lines and also provides a means for expansion. A key distinction of enterprise service is a tendency toward higher telephony traffic which puts an added burden on the selection of features for silicon integration. Additional DSP resources are typically required to support frequent use of feature such as 3Way calling, voice compression, and T.38 Fax Relay.

ILEC REPLACEMENT

Most MSOs that have deployed VoCable CPE have offered facilities-based telephony services in order to compete directly with the ILEC. A key part of this strategy is to deploy VoCable CPE that provides a "primary line" telephony service. Primary line CPE requirements include:

- interfacing with a wide range of standard terminal equipment
- interfacing with existing in-house wiring
- broad range of technical specifications
- reliable battery backup with real-time status

Terminal Equipment Compatibility

Since the MSOs strategy for cable telephony includes ILEC replacement it is important that existing terminal equipment operate the same when switched to VoCable CPE. This is a critical contributor to the subscriber's experience. Much has been learned regarding terminal equipment compatibility from the extensive deployments of CPE in CBR systems. Early CBR deployments were affected by a few terminal equipment incompatibilities, such as:

- handset volume and side-tone
- fax machine issues
- caller ID issues
- analog modem issues

Early CPE telephony line interfaces for CBR systems were designed to meet the Bellcore TR-909 specification. TR-909 specifies different values for some of the voice and signaling parameters than those typically seen on traditional ILEC lines. TR-909 is a specification targeting short subscriber loops like those expected in cable telephony applications. Unfortunately, some terminal equipment is impacted by these parametric differences and the equipment either worked unsatisfactorily or not at all. In CBR systems these issues have, for the most part, been resolved.

It is not surprising that some of these same issues are appearing in early deployments of VoIP cable telephony, and in most cases for completely different reasons. This is primarily due to the fact that the CPE for VoIP systems is required to perform many of the audio functions that were handled by the public switched telephone network (PSTN) in CBR systems. These audio functions include:

- call progress signaling
- tone generation
- tone detection
- voice activity detection
- echo cancellation
- voice compression
- fax relay

Since VoIP is base on packet switched technology, a DSP is required in EMTA designs to perform these audio functions. The DSP used in the MTA must be carefully selected to insure that the required audio features can be supported on all EMTA telephony lines simultaneously. This is particularly true for two and four line residential EMTAs. In multi-line applications it may be possible to allow for a traffic model that requires simultaneous support for a percentage of the total number of available lines. This is more likely the case for multiple dwelling EMTAs but less true for EMTAs expected to support enterprise services.

Optimizing a DSP for integration with other EMTA functional blocks becomes a challenge when the audio functions are considered. VoIP CPE deployment forecasts indicate that an optimal DSP would support the full audio feature set for two telephony lines.

Particular audio functions must be considered when determining DSP requirements for silicon integration. The number of simultaneous active telephony lines and call features supported dictate the voice codec and compression bandwidth requirements. If three-way calling is a required call feature then the voice codec processing requirements are doubled. Low bit rate (LBR) compression also adds to this processing requirement. The number of simultaneous telephony lines requiring LBR compression must also be considered.

The expected EMTA volumes support the economic integration of the DSP with the cable modem ASIC, which consists of a communications processor and a DOCSIS MAC and PFY. The size of DSP and supporting memory depends on the audio function optimization for the number of lines and call features requirements. DSP requirements are also impacted by the amount of margin in performance desired. Field upgrades for new or modified call features are possible if the DSP is sized appropriately.

The telephone line interface is also instrumental in providing terminal equipment compatibility. The line interface circuits provide the BORSCHT functions:

- **B**attery feed
- **O**ver-voltage
- **R**inging
- **S**upervision
- **C**odec
- **H**ybrid
- **T**est

The BORSCHT functions are implemented primarily with a voice signal processor and a subscriber line interface circuit (SLIC). The line interface must be software configurable to adequately address terminal equipment compatibility. The voice signaling processor provides channel filtering, input impedance synthesis, transhybrid balancing, gain adjustment, and voice path diagnostics. The SLIC provides the high voltage interface for battery feed and ringing, as well as the two-to-four wire conversion and loop test.

Various options exist for telephony line interface silicon integration. The voice signal processor is often implemented with a DSP so that a suitable integration with the DSP is possible, thereby providing the audio features described earlier. The difficulty is determining if this is a cost effective integration. Expanding the capabilities of a DSP to provide both the audio features and the voice signaling may not provide a cost advantage over discrete components. Integration of DSP functions can be a cost advantage if the DSP is properly optimized and volumes are high enough. Concerns with integrating the DSP functions are possible feature reduction due to memory size constraints and the number of telephony lines supported.

Alternately, the voice signaling processor could be integrated with the SLIC. This option has the disadvantage of mixing low and high voltage silicon technologies but is ideal for multi-line telephony applications.

Service Availability

An important requirement of primary line service is to provide telephony service during utility power outages. In CBR systems this was implemented with three distinct CPE powering schemes:

- network power
- local external uninterruptible power supplies (UPS)
- internal battery backup

For today's CPE, the power system design and the use of low power, high performance subsystems has the greatest effect on achieving the powering goals of primary line service. Since the CPE power consumption directly affects battery backup time, a highly efficient, low power design is a must. The subsystems, including the cable modem IC, battery charger, telephony interface and RF tuner, must continue to provide high performance while consuming as little power as possible.

Many of the power system components can be readily integrated into the cable modem IC for improved cost. To make this successful, attention must be directed to low noise designs, versatile circuit blocks, and high power efficiency.

Linear regulation is perhaps the easiest function to integrate and is available in today's cable modem ASIC's. These regulators should operate with low dropout voltage requirements to maximize efficiency and provide excellent ripple and noise rejection across a wide range of frequencies. The output voltage of these regulators should be available outside of the cable modem ASIC for powering external circuits. The available current from these regulators should allow powering of typical CPE functions. Thermal limitations should also be addressed within the ASIC.

The efficiency demands of certain voltage rails will preclude the use of a linear regulator. For these requirements, the integration of a generic Pulse Width Modulator (PWM) function will allow the power systems designer to design a highly efficient (>90%) switching converter using external power components. This PWM function must be versatile to allow implementation flexibility for the system designer. Within the cable modem IC, care must be taken to minimize noise effects from the PWM and associated external power components on the cable modem functions.

The battery charger and monitoring circuits are excellent candidates for silicon integration. Today's chargers are implemented with simple 8-bit microprocessors, A/D converters, Op amps and similar circuit functions. These items are inherently simple to integrate into the silicon and are low power by design. The implementation within the silicon must maintain flexibility to allow charging of multiple battery chemistries, voltages, currents and algorithms.

Finally, silicon integration should take advantage of power management features. The integrated components can be controlled to provide the lowest power consumption during various states of operation. During idle modes, selected IC functions could be shut down providing maximum battery back up efficiency. Processor clock speed should also be controllable to allow optimal power consumption. The processor clock could then be slowed during idle modes to save power.

INSTALLATION ENVIRONMENT

VoCable CPE deployed in CBR cable telephony systems are principally installed outdoors, either on the side of a building, on a pole, or occasionally strand-mounted. MSOs preferred this outdoor method to simplify installation and maintenance. Outdoor CPE are required if network power is the preferred powering scheme.

VoCable deployments have shifted towards indoor EMTA installation to take advantage of lower product, but outdoor EMTAs are being considered for some residential and multi-line deployments. ASIC operating temperature becomes an important aspect of silicon integration if outdoor deployments are supported. Silicon cost is impacted by extended temperature requirements due to compensation circuits and expanded test times. There is also the possibility that certain integrations are not cost effective at extended temperatures.

MOBILE VOICE

Several additional features related to mobile voice services are worth examining related to EMTA silicon integration. These features include implementing cellular codecs in the audio feature DSP and adding wireless capabilities to the EMTA.

Each time a voice packet is translated from one codec format to a second codec format, voice quality is degraded. This codec format translation is referred to as transcoding. A call between a cell phone and an EMTA goes through at least two transcodings. For example, the call would be translated from GSM to G729 and then from G7.29 to GSM. As the number of transitions increases the voice quality decreases.

Instead of compressing voice traffic using the standard set of cable-centric codecs that are transcoded at network gateways, an EMTA could use a cellular based codec. This would eliminate a transcoder operation that contributes to lower voice quality.

Codecs are audio functions so they are implemented within the DSP. The addition of cellular based or any other native equipment codecs impact the DSP requirements and must be considered when planning silicon integration.

At some point market economics will support the integration of silicon for wireless local area network (WLAN) applications. Broadband-enabled phones will support high-quality audio, live video streaming, full-speed web access, automatic and instantaneous synchronization with address books and email services, and real-time internet gaming.

An EMTA's ability to support voice-over-WLAN also enables convergence of the cable and cellular networks. Subscribers will use the traditional cellular network when they are mobile, and access the VoIP network when they are in the office or at home, utilizing the same dual-mode cellular/Wi-Fi handset.

SUMMARY

Much has been learned during the past decade of VoCable deployments, and there is still more to learn with the advent of VoIP cable telephony. What has been learned can readily be applied to designs for the next generation VoCable CPE. The next generation EMTA designs must take advantage of silicon integration opportunities to meet the cost requirements of the MSOs. Many options exist for integrating EMTA functions into single ASICs cost effectively. The key to a successful cost reduction is to carefully select the features, scaling capabilities, upgrades and future expansions. Timing is also critical in cost effective silicon integration. It is important to apply the proper level of integration for optimal performance for a given market.

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