World-Class Hardware and Transmission Design

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To serve the global marketplace effectively, AT&T's private branch exchange (PBX) hardware must be adaptable to a wide range of technical and regulatory environments quickly and at minimal cost. To control the potential expense of resolving hardware problems in remote areas, a high level of system reliability must be ensured. This paper presents the reasons for providing hardware adaptability and outlines seven dimensions of the global design problem. It also explores issues confronted in creating the proper degree of hardware flexibility, the design technologies used to address these issues, and AT&T's current, overall approach to global hardware engineering.

Introduction

With the development of the Definity® Generic 3 (G3) communications system, international and U.S. domestic PBX product lines have merged to form a single, unified product, or platform. To serve the global marketplace effectively, this platform (i.e., a product that can be readily modified to meet the needs of each relevant market) must be usable in many technical environments and must be economically attractive wherever it is sold.

A variety of strategies have been used in the Definity G3 communications system to develop hardware that achieves the objectives of technical flexibility and competitive system economics, called *world-class design*. (See Panel 1 for definitions of abbreviations, acronyms, and terms.) In this paper, we describe the problems facing designers of hardware intended for global operation, and we illustrate the application of world-class design strategies with specific examples of Definity G3 communications system hardware development. We also present some limitations of alternative approaches.

Nature of the Problem. Success in the global marketplace requires a high degree of adaptability to widely varying technical, regulatory, and social/cultural environments. This contrasts with the U.S. telecommunications environment, where regulations and technical conditions are generally well-known and stable. The main forces that drive U.S. product change are evolving customer needs, technological progress, and a regulatory decision process in which AT&T participates actively.

In many telecommunications markets outside the U.S., regulations are defined poorly, are changing rapidly, or are nonexistent. Their technical environments may be far different and more variable than what is typical in the U.S. In the United Kingdom, for example, the operating mode of the public network has recently migrated from so-called *loop start, disconnect clearing* to *loop start, guarded clearing* for loop-start trunks serving PBXs. In Spain, new connectivity requirements of the public network are being implemented as central office switches migrate from analog to digital technology.

Often this technical evolution results in conflicting standards, making it difficult to determine which requirements the hardware must meet. In some countries, multiple sets of sometimes conflicting *type approval* requirements are being used to varying degrees. During the type approval process, the government in each country determines whether a given product should be certified and licensed for sale and connection to the public telephone network. Even when requirements are somewhat stable, they frequently are not available in English, and are therefore subject to misinterpretation. A local

Panel 1. Abbreviations, Acronyms, and Terms

B-frames — bidirectionally predicted, interpolative-coded frames

CCITT — International Telegraph and Telephone Consultative Committee

dB — decibel

EEC — European Economic Community

DID — direct inward dialing, also known as direct dial, incoming (DDI), allows calls routed through a PBX to reach an extension directly without the intervention of a PBX attendant.

disconnect clearing — In disconnect clearing, the dc trunk loop at the PBX is either open or closed.

DTMF — dual-tone, multi-frequency, or Touch-Tone

FAC — feature access code

guarded clearing — This type of clearing uses a special signaling state to prevent trunks from being reused for calls before the central office has cleared the previous call.

ISDN — Integrated Services Digital Network

loop start trunks — These trunks use a signaling protocol based on connecting and disconnecting the two leads ("tip" and "ring") at the PBX

MF — multi-frequency

PBX — private branch exchange

PCM — pulse code modulation

PPM — periodic pulse metering

pps — pulses per second

PSTN — public switched telephone network

sink current — dc current absorbed at the central office

source current — source of dc current provided by the PBX

type approval process — a process in which the government of each country determines whether a given product should be certified and licensed for sale and connection to the public telephone network

Vac — volts alternating current

Vdc — volts direct current

world-class design — a design applicable to three or more countries

partner who has experience with local regulations and has dealt with the approval authorities is critical for clarifying requirements. Even with such expert help, at times we have found it necessary to resolve differing opinions of several local contacts.

Although movement toward harmonizing standards, particularly among European Economic Community (EEC) member countries, offers some hope of easing the global design problem, the reality is likely to fall short of optimistic expectations. Even with attempts to standardize public network requirements, individual countries will not be likely to change basic characteristics of their network that people have come to expect. These include network tones, ringing cadences, the way people operate certain features, voice and tone levels, etc. These attempts at standardization may result only in standardizing the documentation of feature differences, allowing type approval testing in other than the country of installation, and possibly standardizing new services such as Integrated Services Digital Network (ISDN).

Functionality that is usually implemented in a particular way in the U.S. is often implemented in different, even opposite, ways in other countries. On direct inward dialing (DID) trunks in the U.S., the trunk battery is connected at the PBX rather than at the central office. (On central office trunks, the reverse is true; the battery is provided at the central office.) In some countries, the battery is *always* provided at the central office, even on DID trunks. These circumstances pose special problems for the design of hardware intended to be used in a product — particularly in a PBX — that will be marketed in many countries.

Dimensions of the Global Design Problem. If the problem of global design is analyzed, several dimensions appear. Planners and developers try to identify the best *system* solution within this multidimensional framework. Dimensions of the problem include:

- Design time
- Design complexity
- Administrative software complexity
- Cost
- Product consolidation
- Size of customer base
- Market window.

Global design can have positive and negative effects on all these dimensions.

Design time. The broader the design goal, the more time planners and developers must spend analyzing requirements of various countries. They must conduct more market analysis before a design can be implemented, and develop more complex hardware and/or firmware designs, which significantly increases the development time.

Design complexity. As design generality increases, often so does design complexity, which, in turn, decreases manufacturability and reliability. If additional hardware components are needed, the accompanying rise in circuit pack costs must be borne by customers who usually will not need all the generalized functionality. For example, if a "universal" DID circuit pack were designed both for countries in which the central office provides the battery and also for those in which the PBX provides the battery, some customers would pay for PBX battery circuitry not needed in their country. On circuit packs used in great numbers on a PBX, such as central office trunk or analog station line circuit packs, the overhead cost of unused generality can greatly increase the total system cost. If this increase were applied to a system with 2000 analog trunk ports, an overhead increment of US $5.00 per port might make the price of a switch uncompetitive. On the other hand, for less commonly used circuit packs, the overhead of unused generality will have less effect on overall system cost.

We emphasize an initial collaboration among systems and development engineers, local consultants, and market management

Administrative software complexity. As the generality of circuit packs increases, so does the complexity of administrative software needed to select desired modes of operation. This software complexity increases development cost and may decrease reliability. From a system administrator's perspective, the greater the number of inapplicable options offered by the hardware, the more difficult the system administration. From AT&T's perspective, documentation becomes more complex, and the chance of field problems caused by administrative errors grows.

Cost. Increasing circuit pack generality may lead to economies of scale that reduce circuit pack costs, particularly if a design can be used in both U.S. and non-U.S. markets. The cost of a circuit pack may drop significantly if it can be sold in great quantity to U.S. customers, thus subsidizing special capabilities needed to support global needs. Of course, the cost to U.S. customers must not be increased, because this can reduce overall sales.

Product consolidation. As generality increases, circuit pack product lines can be consolidated, reducing the cost of inventory, servicing, field maintenance, upgrading, etc. Limiting the number of circuit pack choices can also simplify system configuration.

Size of customer base. The impact of any proposed generalization must be measured against how many additional customers the enhanced product might generate, compared to the existing product. If this number is small, the cost of generalization may outweigh its potential benefits.

Market window. Introducing generality to designs may delay initial system development. In the long run, the generality may shorten future development cycles. The cost of design generality must be considered in relation to both short- and long-term market opportunities.

Design Philosophy and Technologies. AT&T engineers have developed a variety of approaches to designing hardware for systems that are marketed globally. Each approach has appropriate applications, as well as drawbacks. The most obvious philosophy is to design for universal applicability. However, this approach usually increases the hardware design cost, development time, and complexity, adding to end-customer costs. Designers must select judiciously from available strategies, such as those described in the next section.

Identifying important differences. Although requirements often differ among countries, specific details, careful analysis, and consultation with local experts (or with a country's telecommunications authority) may reveal that differences are not important or can be disregarded. As some countries migrate from analog to digital public networks, tone-frequency detection standards that originally were used to compensate for low-performance analog central office switches are ignored; new digital central offices have better-controlled performance.

Market realities also reduce differences among countries: Often, it is not necessary to support signaling protocols that are either outdated or not used by most potential customers. We emphasize an initial collaboration among systems and development engineers, local consultants, and market management to refine the list of differences to which our hardware must adapt before it is implemented.

Hardware versus firmware flexibility. The availability of firmware control on port circuit packs blurs the meaning of universal *hardware*. Many functions that formerly would have required the implementation of complex switching capabilities in physical components are now available as firmware options. The cost of implementing procedures that can be generalized in firmware is not reflected in the cost of components. It does, however, require more complex algorithms, which increase the development and testing time and add to the final cost.

In trunk and line circuit packs of the Definity G3 communications systems, firmware-based generality is often built into timers and signaling protocols. A standardized set of firmware world-class timers handles most protocol timing functions performed by port circuit packs. System software downloads appropriate values to these timers, based on local requirements.

Portions of signaling protocols are implemented as a set of firmware algorithms. In many countries, the central office provides line supervision using the polarity of battery voltage applied to tip and ring leads. Unfortunately, the times at which these polarities are reversed, and why they are reversed, are not standardized. In some Definity G3 communications systems, analog trunk circuit packs allow system administrators to select from among four polarity-reversal signaling protocols. The firmware then interprets the reversals and presents a more standardized interface to system software.

Programmable chip technology. Components with programmable characteristics are now available for many port circuit pack applications. This technology greatly expands circuit pack universality without increasing component cost. Line and trunk circuit packs can now use programmable chip technology to provide programmable impedance and loss/gain characteristics. Local requirements are met by downloading coefficient sets that determine the chip's characteristics.

Replaceable components. Circuit pack layout can be designed to make replacement of key components easy. For example, filters can be adjusted by changing discrete resistors or capacitors. Replaceable, discrete components can be used on standard circuit board blanks to produce a variety of circuit packs.

It is also possible to generalize equipment by providing switches and straps for key characteristics, such as A- or μ-law companding mode. Although this can produce multipurpose hardware, it can also increase field maintenance problems and unreliability; correcting problems caused by an incorrect switch setting can be costly. Generally, Definity G3 communications systems do not use this approach.

Using special- and general-purpose hardware. Designs targeted to the needs of three to five countries, rather than a larger market set, generally are more focused and produce higher quality results because everyone can get an in-depth understanding of the target countries' needs. In addition, testing can be performed on a restricted set of configurations. Although as few as three countries may be targeted, usually other markets are found with requirements close enough to make the same circuit packs usable in more countries than originally pinpointed.

Generally, these "limited-world-class" designs incorporate both specific features needed for target countries and a set of universal features intended to maximize the chance that the circuit pack will be usable elsewhere. For example, most trunk circuit packs now provide selectable A- or μ-law companding, as well as a standard set of world-class firmware timers, even if all countries in the target set use only a single companding law.

When we encounter countries with very specialized needs, such as unique battery feed levels or impedance characteristics, we sometimes produce special circuit pack releases. Because most circuit packs are now designed with this possibility in mind, they often can be adapted by changing only a few discrete components.

Using external converters and adjuncts. Using available local adapters and adjuncts may be the best way to satisfy a particular country's needs. If a country has an unusual interface requirement, local manufacturers often develop converters that accommodate standard equipment. While this may add to the expense of the system solution, it may manage overall development costs more effectively and meet customer needs on a more timely basis.

Standardized interfaces to software. Many world-class circuit packs used in Definity G3 communications systems are designed to present a consistent interface to switch software, even when a country's requirements are unique. In most countries, not all timers need to be programmable. Nevertheless, to provide a consistent system interface, most world-class circuit packs accept all timer-setting messages without reporting errors, even when corresponding programmable timers are not present. This simplifies system software, because it is not necessary to identify specific circuit packs to determine which timer messages to send from the switch software to the circuit pack firmware.

Examples of World-Class Hardware Design

In this section, we describe how we can apply world-class hardware design strategy to the development of analog trunk and line interface, tone plant, and transmission characteristics.

Analog Line Interfaces. Even in a modern digital PBX, the basic analog line interface is probably the most commonly used port. In addition to "plain old telephone sets," this interface connects to the PBX numerous external devices, including facsimile machines, answering machines, and external alerting devices.

Unfortunately, even basic analog equipment has characteristics that vary widely throughout the world. The PBX must function correctly with both old and new analog devices. Unlike the U.S., where dual-tone, multifrequency (DTMF, or Touch-Tone) sets have gained universal acceptance in the workplace, much of the world continues to use rotary (dial-pulse) telephones. Many of these telephones exhibit unusual signaling and voice transmission characteristics, requiring analog line circuits with considerable flexibility. Timers may need to be adapted to accommodate "contact bounce" that occurs when a handset is lifted from the switchhook, because this might be mistaken for digits being dialed or for a request to place a call on hold.

Design Flexibility. The *recall signal*, used to access PBX features from analog telephones, provides an example of the need for flexibility in analog line circuit design. Analog telephones generate two types of recall signal:

- A *timed break* recall, in which a timed open (break) of the telephone loop (i.e., a momentary on-hook) is made
- A *ground recall*, in which one or both loop leads are momentarily grounded.

Standards for the durations of breaks and groundings vary among telephone types. In the U.S., the timed break recall is frequently supported, but ground recall is not. However, to adapt to global needs, analog line circuit packs on Definity G3 communications systems can detect both timed break and ground recall signals. This is cost-effective not only because it is moderately priced, but also because both recall types are sometimes needed on the same system. Also, type approval standards in many countries mandate specific recall signal recognition windows to prevent users from mishandling (e.g., unintentionally dropping) calls when they access PBX features. For these and other reasons, the Definity G3 communications system has administrable recall signal durations.

Adapting to global ringing cadence requirements is another challenge for designers of analog line hardware. The 1-second-on/4-seconds-off ringing pattern common to PBX telephone users in the U.S. is by no means a world standard. Elsewhere, ringing cadences may be 1-second-on/2-seconds-off, 1-second-on/3-seconds-off, or other patterns unusual to U.S. telephone users. Local governments often regulate ringing patterns of PBXs to match the ringing signals provided by their public switched telephone network (PSTN). Also, in some markets cultural preferences influence the choice of ringing patterns. In Japanese offices, the U.S. 1-second-on/4-seconds-off cadence is perceived as too "drawn out." Japanese custom dictates that ringing phones be answered quickly. Consequently, they prefer a 1-second-on/2-seconds-off ringing cadence. To meet type approval requirements and satisfy customer expectations, the Definity G3 communications system offers a variety of selectable ringing cadences, implemented in firmware timers on world-class analog line circuit packs.

The question of ringing cadence has design implications beyond the need to provide programmable timers. Rapid ringing cadences, such as those used in Japan, require a higher average power to be delivered to ringing telephones. Therefore, either ringing circuit capacity must be increased or some other way of handling this larger load must be provided.

Providing increased power capacity on analog line circuit packs could significantly increase system cost for customers who do not need rapid ringing cadence. Instead, in cases where called analog phones cannot be rung immediately because the power limits the maximum number of phones that can ring simultaneously, software routes the overflow to PBX attendants or invokes other procedures. In addition to software procedures, hardware designs also address this problem. Circuit pack hardware and firmware assign ports in groups of four, each with its own ringing generator. One port in each group can receive active ringing (at which time the other ports in the group must be in the silent portion of the ringing cycle). Port grouping statistically reduces the chance of calls not being able to ring at a station, because such blocking can occur only when four ports (or three, in some special cases) in the same group are ringing.

Trunk Interfaces

PBXs connect to the PSTN through network trunk interfaces. DID trunks allow PSTN callers direct dial access to PBX extensions. A central office trunk carries outgoing PSTN calls and accepts incoming PSTN calls to PBX attendants. Tie trunks provide private connections between two PBXs. Because trunk interfaces connect the PBX to a variety of PSTN equipment, from modern digital to very old step-by-step central offices, PBX trunk interface hardware must be flexible. Designing trunk interfaces to satisfy a particular country's official specifications does not guarantee compatibility with all of its central offices, especially those with step-by-step switches, for which accurate specifications may not even exist. The next section describes two examples of the need for flexibility in network trunk interface hardware and design approaches that provide it.

Central Office Trunks. Ground start central office trunks are used widely in the U.S. to connect central offices to PBXs. In ground start trunks, central offices initially signal incoming calls to the PBX by grounding one of the trunk leads and then applying ringing. In loop start trunks, ringing is the only signal that indicates an incoming call.

Circuit pack hardware for a world-class central office trunk must detect and generate all required signals to and from a wide variety of central offices

Ground start trunks were designed to solve problems that arise when simpler loop start trunks are connected to PBXs. Two particular problems are *glare* and *lack of disconnect supervision*. Glare occurs when both the central office and PBX end of a trunk are seized simultaneously (i.e., a PBX party attempts to use a trunk to send an outgoing call at the same moment that the central office is sending an incoming call to the PBX). Lack of reliable disconnect supervision (the ability to determine when each party disconnects from a call) makes it difficult to ascertain whether certain types of calls have been completely disconnected. This often creates problems with conference calls or calls to automated answering devices such as Audix® telecommunications products.

Despite problems associated with loop start central office trunks in PBX applications, most countries continue to use them because, by comparison, ground start trunks are more costly and complex. In some countries, central offices use battery polarity signaling to overcome problems of glare and disconnect supervision with loop start trunks. Unfortunately, these specialized central office protocols have not been standardized. Worldwide, there are at least five different implementations of polarity reversal signaling. For example, when an outgoing call is placed in Hong Kong, central offices reverse battery polarity as soon as the called party answers. But in The Netherlands, the central office reverses battery polarity to signal that it has received the outgoing address digits.

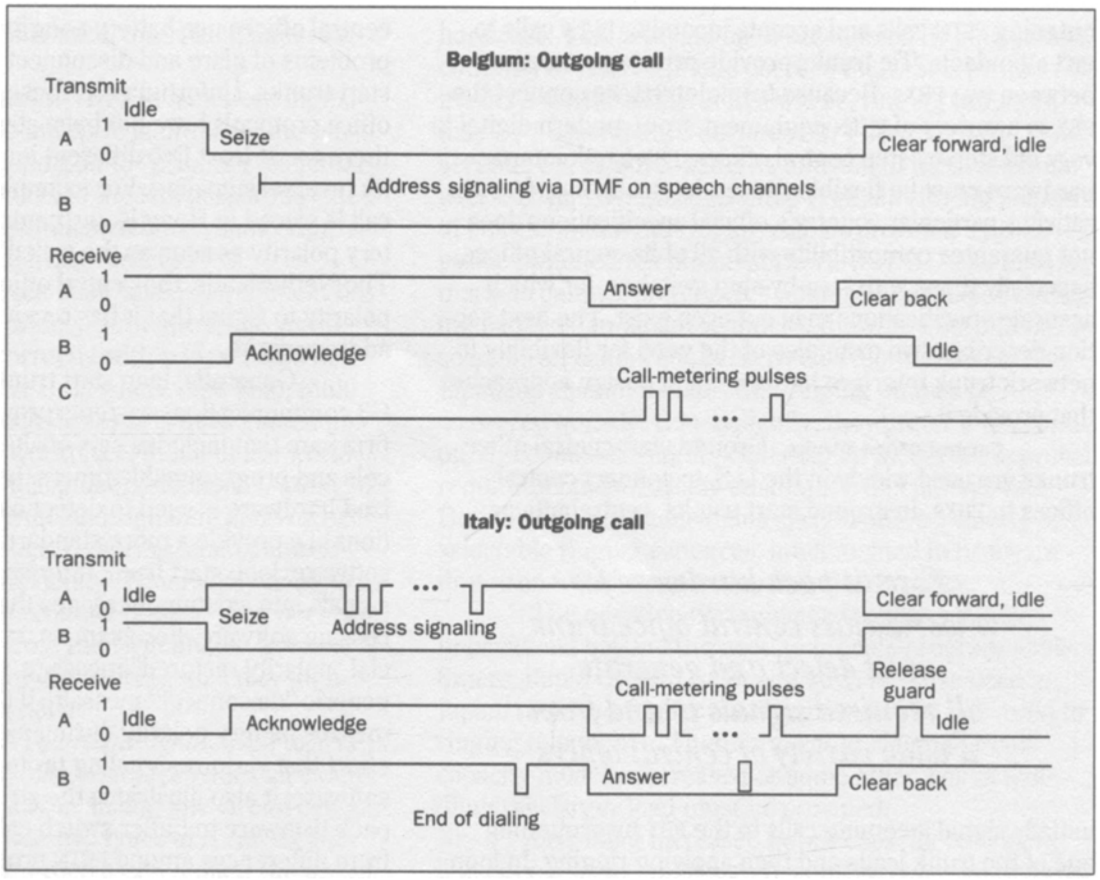
Generally, loop start trunk interfaces on Definity G3 communications systems provide circuit pack firmware that includes sets of alternative signaling protocols and programmable timers. In addition, some specialized hardware is used to detect battery polarity transitions. To provide a more standardized interface to switch software, loop start trunk interfaces map polarity reversal signals into existing messages that are sent to call processing software. For example, rather than using a special "polarity restored" message, the circuit pack sends a generic "disconnect" message if the central office normalizes battery polarity during a call. This minimizes the effect that various signaling protocols have on switch software; it also illustrates the strategy of using circuit pack firmware to buffer switch call-processing software from differences among PSTN protocols.

To accommodate countries where loop start trunks do not provide any disconnect supervision, other strategies are needed. Definity communications system software incorporates strict software algorithms that specify the types of connections that the PBX can maintain. These algorithms only allow connections that guarantee complete disconnect supervision.

Circuit pack hardware for a world-class central office trunk must be designed to detect and generate all required signals to and from a wide variety of central offices. In addition, circuit pack firmware must support many different protocols that use these signals. Switch administrators must select protocols, signal options, and timer values, often based on the specific central office to which the PBX is connected within that country.

In many countries, to provide billing information the central office sends call charge metering pulses, also called periodic pulse metering (PPM), to the PBX. These metering pulses, consisting of brief tone bursts over the tip/ring pair, are detected and counted to determine call

Figure 1. Digital protocol sequences for basic outgoing central office calls in Belgium and Italy. The Italian protocol uses fewer bits from the control channel than does the Belgian protocol, but it has a more complex state architecture. In Belgium, DTMF signals on the speech channels are used for address signaling; in Italy, toggling the A bit simulates rotary dialing (make/break signals).



charges. Among countries, three basic pulse types are used: 50-hertz (Hz) longitudinal, 12-kilohertz (kHz), and 16-kHz transverse pulses. In addition, frequency tolerances, levels, timing, and termination requirements differ among countries. To handle these various requirements, the frequency, level, timing, and termination impedance of world-class PPM detectors must be programmable. This capability is implemented primarily in hardware rather than in firmware. Most of the world-class central office circuit packs used in Definity G3 communications systems do not support all three basic pulse types. Generally, it is better to support only two of the three types on a single circuit pack, because the group of countries in which a particular circuit pack will be used often has similar PPM requirements.

To prevent outgoing calls from being made on faulty lines, some countries (e.g., Australia) require the PBX to test central office trunks before making each outgoing call, either by detecting PSTN dial tone or testing the dc condition on one or both trunk leads. Because Definity G3 communications systems support dial-tone detection administrable for a wide range of countries, extra hardware usually is not needed to meet this requirement. A solution has been developed based on software rather than hardware to minimize hardware complexity and take full advantage of existing world-class tone-detection capabilities.

DID trunks. By accepting and processing extension address signals from the central office, DID trunks provide direct dial access to PBX stations from the PSTN. There are two major categories of DID trunks: those for which the PBX provides dc current (source current) and those for which a PBX absorbs dc current (sink current). There are many signaling protocols even within the same category. Supporting economical DID service across many countries requires at least two types of hardware — current sink and current source — with administrable firmware designed for the specific signaling protocols and timings of the countries in which they are marketed. The difference in the design of sink- and source-type circuit packs makes a single design, adaptable to both applications, costly. Each customer would be paying for two types of DID circuit pack hardware, one suitable for their country's DID (source or sink) mode and another suitable for an unneeded mode.

Digital trunks. DS1 (U.S.) and E1 (European) digital trunks use bit-oriented signaling (BOS) to provide central office, DID, and tie trunk services. As in analog trunk protocols, digital BOS protocols used by DS1 and E1 trunks vary widely among countries. DS1 trunks have 24 channels that transmit 1.544 megabits per second (Mb/s) compared to E1 trunks, which have 32 channels that transmit 2.048 Mb/s. In addition, most countries have their own system for line signaling and call processing.

Figure 1 illustrates digital protocol sequences for basic outgoing central office calls in Belgium and Italy. Even though the Italian protocol uses fewer bits from the control channel than does the Belgian protocol, it has a more complex state architecture. In Belgium, DTMF signals on the speech channels are used for address signaling, while in Italy, toggling the A bit simulates rotary dialing (make/break signals). The two protocols are different, even for a simple outgoing call.

To be applicable to as many world-class digital trunk processes as possible, signaling protocols are handled by circuit pack firmware. The firmware can be programmed through system administration to process many signaling protocols. Programmable parameters include the correct number of speech channels, proper timing, and companding mode.

World-class tie trunk design. A PBX tie trunk is a direct circuit interconnecting two PBXs without intermediate switching. One, two, or three pairs of wires may connect the two PBXs.

Basic design characteristics for analog tie trunk circuits are mode and signaling protocols. The *E&M signaling mode* is the FCC-registered tie trunk interface designation that ensures full compatibility with signaling equipment in the U.S. These signaling modes are sufficient for most tie trunks in use throughout the world. The E&M leads are used for dc signaling between two tie trunk interfaces; dc signals are sent on the E lead and received on the M lead.

Because of its simplicity, type 1 signaling protocol is used with many E&M tie trunks. With type 1 signaling, grounding or ungrounding the M lead at the transmit end signals off- or on-hook conditions, respectively.

Unfortunately, type 1 signaling cannot provide universal compatibility with signaling equipment in all countries. For example, in Australia, analog tie trunks must support two non-type 1 signaling protocols. One type is "ground off idle," or type 5 signaling, and the other is "ground idle," or reversed type 5. In reversed type 5 signaling, grounding on the M lead indicates an on-hook condition, while ungrounding indicates an off-hook condition. A fully universal analog tie trunk must provide a flexible signaling scheme to support at least type 1 standard, type 1 compatible, type 5, and reversed type 5 protocols. As with circuit packs in the analog central office trunk, tie trunk circuit pack firmware is programmed through administrable software. This software allows one circuit pack to handle multiple E&M signaling protocols, including the four protocols just mentioned.

Other tie trunk circuit pack capabilities (excluding signaling protocols) must be flexible enough to meet a range of global requirements. In the U.S., the standard decadic-dialing pulse rate is 10 pulses per second (pps), whereas in other countries (e.g., Japan), the nominal rate is 20 pps. To support both 10- and 20-pps rates, circuit pack dial-pulsing circuits are controlled by firmware that can vary dial-pulsing signal durations.

When an existing fixed (U.S. standard) firmware timer is changed to a programmable world-class timer, the software/firmware design strategy must be compatible with both old (fixed U.S.) timers and new ones. To maintain backward compatibility with earlier U.S. software releases, each programmable timer defaults to its standard U.S. value. Generally, circuit packs do not support programmability of all timers. To reduce complexity by using standardized algorithms, administrative software usually sends a *complete* set of timer-setting messages to circuit packs, even if a circuit pack does not support the full set of programmable timers. Circuit packs are designed to accept all timer-setting messages without reporting maintenance errors, even for timers whose programmability they do not support. Therefore, administrative software does not have to calculate particular timer-message sets when programming world-class analog circuit packs.

Tie trunk transmission requirements vary among countries. Italian specifications require that analog tie trunks provide 0-decibel (dB) digital loss. Without flexible circuit pack capabilities, this would be incompatible with other system transmission plan components. By adding firmware-controlled elements to the analog transmission circuitry, the overall loss plan for any country can be achieved while still meeting specific digital loss specifications.

Tone Plant Design. A global PBX must be able to handle problems arising from three intercountry tone variations:

- *Register-signaling tones* — Tones that send addressing and call type information between the PBX and the PSTN hardware. The tone sets used, as well as the mappings between specific tones and their meanings, differ among countries.
- *PSTN call progress tones* — Tones (e.g., dial tone, busy tone, ring back) sent by the PSTN as call progress feedback to callers. Often, the PBX must be able to detect these tones automatically. For DID operation, the PBX also may be required to transmit these tones to the PSTN.
- *PBX call progress tones* — Tones produced by the PBX as feedback to callers within the PBX. Problems arise in global designs because type approval regulations often specify particular types of PBX tones. Also, users in different countries often have conflicting expectations as to the "correct" tones for various functions (e.g., "normal" PBX dial tone differs among countries).

Globalization requirements for register tones affect two types of Definity G3 communications system circuit packs, as well as system software. Trunk interface circuit packs are affected because these control tone timing. However, common system tone-detection circuit packs control tone generation and detection. Switch software requires globalization because the meaning of various tones, particularly multi-frequency (MF) signaling tones, differs from country to country.

The Definity G3 communications system administrator can control numerous tone-related parameters on both individual trunk interface circuit packs and common-tone-detection/generation circuit packs. For example, these parameters control the power levels of individual frequencies transmitted to the PSTN, levels of to-be-detected signals offered to common-detection service circuit packs, and DTMF tone and intertone pause durations on trunk interface circuit packs.

Register signaling. Two tone-based systems, DTMF and MF, are used for register signaling. Originally, MF was developed for signaling between central offices, but in many countries it also is used for central office–PBX applications.

Two basic MF tone sets are needed for global operation. The 2/5 system forms signals by combining two frequencies from a set of five signaling tones, while the 2/6 system uses two frequencies from a set of six. Besides being able to select particular tone frequencies and signal levels, administrators use system software to assign particular meanings to MF tones on a country-by-country basis. For example, in Spain, an outgoing call placed through the Spanish virtual private network, known as IBERCOM, begins with a particular MF code to the PSTN to indicate that this route should be used. In other countries, the same MF tone is used for a different purpose.

PSTN call progress tones. Each country has its own, sometimes evolving, requirements for call progress tones, such as dial tone, busy tone, and ring back. These tones signal the PBX hardware and users when dialing can start, when the called party is unavailable, and when the called party has not answered. To avoid confusing callers, some countries require PBX-generated call progress tones to be identical to those used by the PSTN. However, some countries are concerned that callers might not be able to differentiate whether the PBX or the public network is the source of particular call progress tones. These countries require that certain PBX-generated tones be specifically distinguishable from PSTN tones. In Australia, PBX-generated tones sent to the PSTN before a called party answers (e.g., ring back or busy tones) must sound similar to those generated by the PSTN, but PBX-generated tones sent after the called party answers (e.g., tones sent during call transfers) must differ from PSTN-generated tones, ***unless*** they have the same meaning as the corresponding PSTN tone.

Certain call progress tones must be detectable by Definity G3 communications system hardware to support capabilities, such as automatic route selection, that use automatic dialing. Often, type approval regulations specify that a PBX cannot send addressing signals to the PSTN until it detects PSTN dial tone. This is particularly critical in countries with limited telecommunications resources, where the PBX may not receive PSTN dial tone for several minutes after a trunk is seized for an outgoing call.

For flexibility and low cost, the tone plant architecture of Definity G3 communications system hardware places tone generation/detection on common system circuit packs separate from line and trunk interface circuit packs. Because call progress tones are only applied for short intervals, tone generation/detection can be shared to minimize overall system cost.

To meet global tone-detection requirements, the Definity G3 communications system enables the system administrator to control tone-detection precision. At the least precise level, tone detectors are activated by any above-threshold burst of acoustical energy, regardless of its frequency or cadence. To classify tones at the most precise level, detectors are tuned for specific narrow frequency, cadence, and power level ranges. In the least precise mode, one of two broadband filters and a validation timer classify tones. The timer distinguishes short tones from long ones, for example, to differentiate a busy tone from a ringing tone. Because most countries have continuous PSTN dial tones, the timer can also detect PSTN dial tone.

To generate call progress tones, the Definity G3 communications system uses multiple tone sets built from a set of standard frequencies. The Definity G3 communications system allows system administrators to change any of these tone sets. System administrators can create specialized tones with a simple tone-programming language by choosing predefined frequencies and specifying a cadence for each selected frequency. These can range from a single burst to multiple bursts of differing frequencies, as well as repeating or non-repeating custom tones.

Power and Safety. A PBX designed for the global marketplace must be able to use input power from many sources. Electrical power specifications around the world vary almost as much as network signaling standards. Reliability of local power is even less consistent. In the U.S., 120- and 208-Vac, 60-Hz power is universal and homogeneous. Unfortunately, much of the world uses different voltages and power line frequencies (e.g., 220 Vac, 50 Hz in Europe) than those used in the U.S. Regional differences exist among power types within some countries. Power connectors also vary among countries, and even within buildings. A simple solution to this dilemma is to use the local power cords, which terminate in a standard connector on the Definity G3 communications system.

Reliability of local power sources is often an issue, especially when a PBX is the lifeline between customers and emergency services. Consequently, PBX power systems must be designed for high reliability in the wide range of environmental conditions encountered on a global basis. Using advanced switching power supply technology, the Definity G3 communications system can achieve high reliability while being able to use power sources throughout most of the world, including both 120 and 240 Vac, 50 and 60 Hz, as well as a 48-Vdc battery. Potential problems with physical connections are often eliminated by using locally available power cords or adapters that terminate standard Definity communications system power sockets and plugs. These connections already meet local safety codes, which may differ significantly from those in the U.S.

Safety approval is often a tedious, expensive proposition. The stringent standards set for types of insulation used on power cords and PBX wiring, physical spacing between electrical components and conductors, and even the colors of wires required in the PBX may conflict with U.S. standards. These problems cannot be resolved by programming solutions and are sometimes major impediments to intercountry PBX sales. This fundamental issue can be addressed only through standardization. A movement is under way to set global safety standards; this should reduce the expensive testing needed to obtain separate safety approval in each country.

Transmission Characteristics. Two-wire analog interfaces, such as the tip/ring pair that connects a telephone to the PBX, carry voice signals bidirectionally over the same wire pair. However, within a digital PBX, such as the Definity G3 communications system, the transmission medium is not bidirectional. Separate, single-direction channels carry either transmitted or received voice signals. Figure 2 illustrates this combination of one- and two-way transmission.

The basic connection elements illustrated in Figure 2 are always the same, regardless of where the PBX is installed. However, four connection parameters vary among countries:

- Two-wire port input impedance — European input impedances often differ from the U.S. 600Ω standard.
- Input and output analog gains — When analog voice signals are converted to digital form, the signal levels must fall within specified ranges.
- Encoding law — Regulatory bodies specify which of the two CCITT-defined encoding laws, A- or μ-law, must be used.

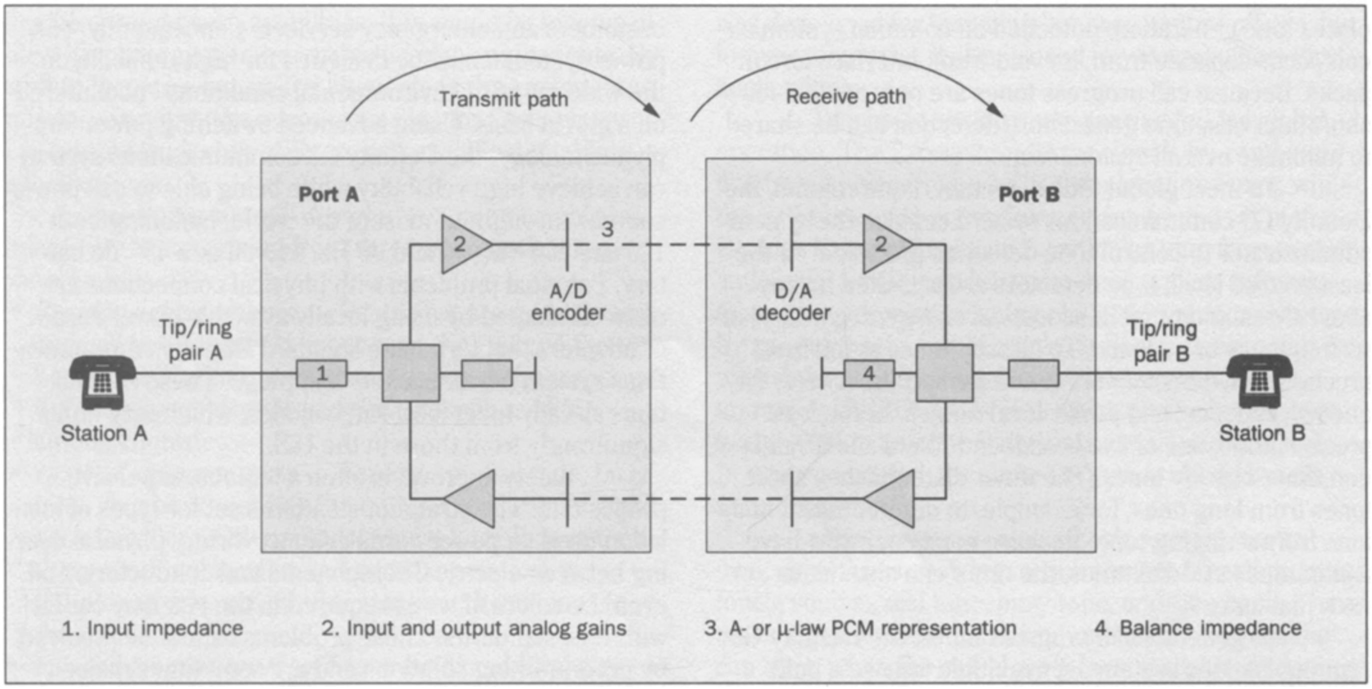


Figure 2. A voice signal travels along a path from station A to station B as follows: The analog voice signal from station A is extracted by port A and placed on a single-direction medium. This signal is then digitized according to either an A- or μ-law pulse code modulation (PCM) process. This digitized signal is "switched" (i.e., connected) to port B and then decoded from PCM back to analog while still on a single-direction medium. Finally, port B places the decoded analog signal on the bidirectional tip/ring leads to station B. In an actual connection, a voice signal path from station B to station A will also be established within the PBX.

- Balance impedance — Balance impedance removes the receive signal from the transmit signal in a single- to bidirectional conversion.

A PBX intended for global use must accommodate significant variation in all four parameters. At least two solutions are possible: (1) Use specialized port hardware for each country, or (2) use one flexible port design that can be adapted under software control.

Country-specific port hardware can be developed economically by designing a standardized, basic circuit pack that includes all the common hardware required to interface to the PBX digital switch and control complex. This design should also allow the circuit pack's transmission characteristics to be set using discrete, off-the-shelf resistors and capacitors. A new circuit pack identification code is required for each country, but otherwise only component value changes are needed. This reduces development time because new circuit packs need not be designed and tested from beginning to end.

Evolving, commercially available telecommunication integrated circuits (ICs) now enable analog port designers to create ports that have programmable transmission parameters. For some time, D-to-A, A-to-D conversion, companding, decompanding, and filtering functions that comply with either CCITT G.711 A- or μ-law standards have been available on a single IC. Subsequent IC designs have added selectable transmit and receive gains. These ICs contain registers that can be programmed to select gains within a given range and resolution. ICs also implement the transhybrid loss function using digital signal processing and provide programmability to emulate the analog balance impedance function. These second-generation ICs provide programmability of all but one transmission characteristic of analog ports. Two-wire input impedance still needs to be set with passive components. The most recent generation of ICs returns a filtered version of the transmit signal to the receive signal, thus affecting the input impedance. These filters are also implemented in digital signal processing (DSP) technology with programmable filter coefficients. This newest IC technology allows transmission characteristics of analog circuit packs to be programmed in their entirety.

Some Definity G3 communications system analog ports now use this technology, and other circuit packs under development will also use it. System administrators select country-specific transmission parameter sets. These are loaded into circuit firmware to produce operating characteristics suitable for each country.

Conclusions

The design of a product for the global market demands not only flexibility and adaptability in hardware, firmware, and software, but also flexibility in design strategy. Just as a single, universal hardware design is seldom the best system solution, neither is a single global design strategy. The goal of creating a circuit pack that can be used anywhere with just administrable changes to firmware configuration settings is not, at present, the best approach, because it would be extremely difficult to design and manufacture.

Use of the strategies we have described in this paper has produced savings by consolidating circuit pack product lines and simplifying system configuration processes. In addition, we have minimized development time and problems associated with specialized hardware for particular countries. Customers in a wide variety of countries are now getting the products that fit their telecommunications needs at a competitive cost without paying excessive overhead for unused features.

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