Errata

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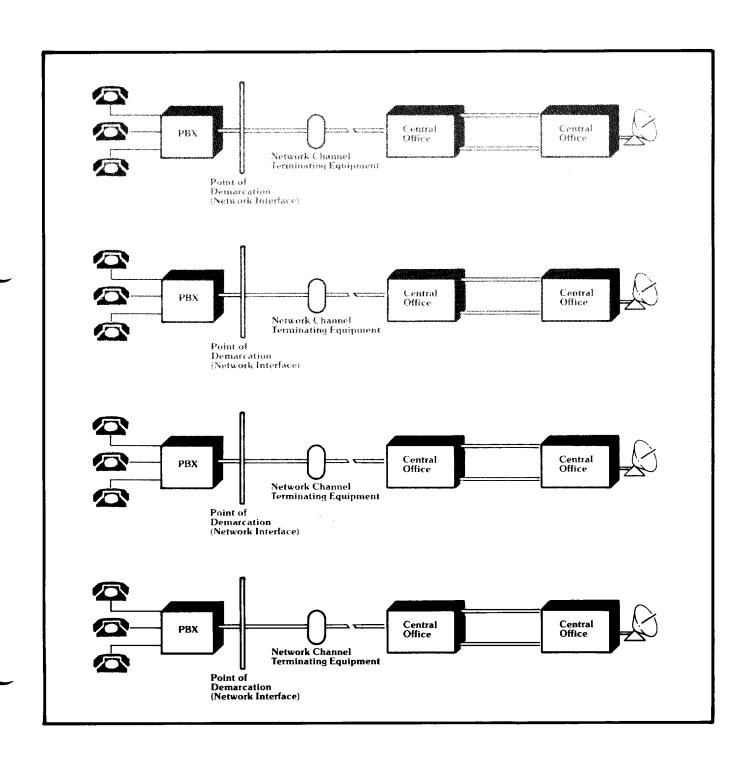
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Agilent Technologies

An Introduction to Signaling

Application Note 336

What is Signaling?

"Signaling is the process of transferring information over a distance to control the setup, holding, charging, and releasing of connections in a communications network."

In other words, signaling is what the telephone company uses to control the telephone system. It is what you use to tell the system where you want to call. Signaling can be considered to be the "protocol" that the network uses to establish a voice path from one place to another. To understand how signaling is used and what it does for us, it will help to first look at "the typical telephone call."

The Typical Telephone Call

Mrs. Smith is a typical telephone customer. She lives on the south side of Colorado Springs and has a home telephone number of 634-9000. Today she has decided to call her friend Mrs. Jones, who lives on the north side of town. Mrs. Smith has a single telephone, and a pair of wires run from her home to a central office. This is central office number 634 (the first three digits of Mrs. Smith's telephone number). We will refer to it as central office A. The wires that go from the central office to Mrs. Smith's home are used only by that one telephone, and are not shared with any other customers. This dedicated pair of wires is called a line circuit or loop. The central office places a 48 volt potential across the loop to monitor activity and power the telephone.

Mrs. Smith initiates a call by lifting the handset off the telephone. This closes a switch in the telephone and permits current to flow through the loop. This signals the central office that Mrs. Smith would like to place a call.

Upon detecting loop current, the central office searches for an unused dial pulse register to store the dialed digits as they are received. The register is connected and dial tone is sent down the line. This last part is the handshake, and is an important part of signaling. By taking the handset "off-hook," Mrs. Smith has made a request for access to the network. The central office acknowledges this request by sending back a dial tone. The handshake is an integral part of all signaling systems.

Upon hearing the dial tone, Mrs. Smith begins to dial the telephone number of Mrs. Jones. The telephone set rapidly opens and closes the loop at the rate of about 10 pulses per second. The number of pulses sent corresponds to the digit dialed (figure 1).
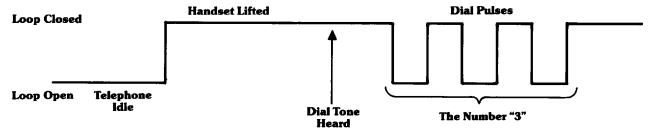

Figure 1. Telephone — off-hook and dial pulsing.

This continues until all of the digits of Mrs. Jones' telephone number have been dialed. The dial pulse register at the central office is now full and contains the number 599-1234. The central office recognizes this number as belonging to central office number 599 (central office B). Since this number cannot be directly served by central office A, it looks for a trunk that will connect it with central office B (figure 2).

A trunk is the long snout on the head of an elephant. Unfortunately, this kind of trunk will not help us much. The type of trunk we want is the one that provides a signal path between two central offices. Unlike the loop, a trunk is shared by many different subscribers, although only one uses it at any given time. There may be 100 trunks between these two central offices, and as one telephone call ends, a trunk is released and made available for another call.
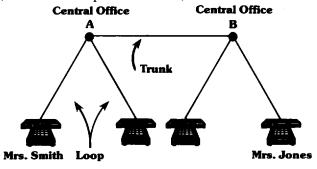

Figure 2. Central office trunking.

1

Central office A seizes the first available trunk it finds. This trunk is a dedicated path to central office B, so only the last four digits of Mrs. Jones' telephone number need to be sent. These digits are received by central office B which proceeds to make a connection with the appropriate loop.

Although a path has been established, Mrs. Jones still needs to be alerted to the fact that there is an incoming call. Central office B therefore sends an 86 volt, 20 hertz signal down the loop to drive a bell inside the telephone. This signal is repeated with a 2 second on, 4 second off duty cycle to create the telephone ringing sound we are all familiar with. When Mrs. Jones lifts the handset, current flows in the loop, telling the central office to disconnect the ringing and establish the audio connection.

This is the basic anatomy of a typical telephone call. Although there are many more details that could be discussed, many of the basic elements of signaling have been illustrated.

The Basics of Signaling

There are four functional classes of signaling: Supervisory, Address, Informational, and Network Control. The first three encompass the vast majority of signaling used today, so we will not delve into the details of Network Control.

Supervisory signaling deals with the circuits that monitor the status of a line or trunk. The number of states is binary; a signal path is either idle or active. We can illustrate this with our telephone call example. The type of signaling described is loop (or loop start) signaling (figure 3).

48 V

**Current
Detect**

**Central Office
(Terminate)**
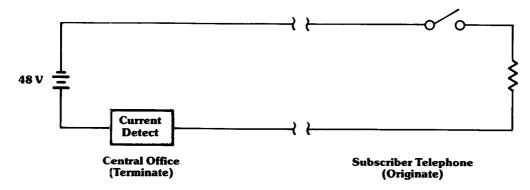
**Subscriber Telephone
(Originate)**

Figure 3. Loop signaling.

We start with the line in the idle state. When the telephone user lifts the handset from the cradle he closes the switch and permits current to flow. This is called the "off-hook" state (for obvious reasons). The central office detects the current flow and responds with a dial tone. We can consider this to be the central office's off-hook indication. With both ends off-hook, the line is now active. When the subscriber hangs up the telephone, it opens the switch and goes to the "on-hook" state. The terms on-hook and off-hook are used universally to describe the state of signaling equipment regardless of the actual type of signaling used.

Notice that the signaling circuitry is not symmetrical in this case; one end has a 48 volt battery while the other end is totally passive. To identify the circuit in question we use the terms originate equipment and terminate equipment. For loop signaling the terminate end supplies the battery and current detect circuitry while the originate end simply provides a DC current path via a switch. Note that the terms originate and terminate refer only to the hardware configuration and have nothing to do with who started the call. The originate end can either initiate a call (as in the case of Mrs. Smith) or receive a call (as with Mrs. Jones).* Unfortunately the phrase "originating a call" is often used in Bell System documents and the reader must determine whether the reference is to originate end equipment or the action of initiating a call.

Address signaling is what the caller uses to control and direct the switching system. Most telephones in North America have a unique telephone number or address. They consist of a three digit area code, a three digit central office code, and a four digit extension code (e.g., 303-599-1234). Before your telephone call can be switched to its final destination, the network must know the address of that destination. Address signaling is how the network obtains and transfers that information.

The most commonly used method of address signaling is dial pulsing. In a loop signaling circuit the digits are sent from the originate end by opening and closing the current path. The number of consecutive opens and closures is proportional to the dialed digit (figure 1).

*This is similar to the originate and answer modes of modems. The terms only refer to the hardware configuration and do not relate to which end connected first or which is sending data.

Another form of address signaling is TOUCH-TONE™ dialing. Each digit is formed by selecting two out of seven possible frequencies (figure 4). The frequenceies were carefully chosen to minimize the possibility of accidental voice tripping.

For example, the digit "5" would be indicated by sending a 770 Hz tone and 1336 Hz tone simultaneously. Since the phrase TOUCH-TONE™ is a registered trademark of AT&T, this address signaling technique is often referred to as Dual Tone Multi-Frequency (DTMF) signaling.

If you want to convince yourself that this is how TOUCH-TONE™ really works, try this experiment sometime. Lift the handset and listen for a dial tone. Now get rid of the dial tone by pressing a digit ("3" for example). Now while listening to the handset, press the digits "4" and "5" simultaneously. You will hear a pure 770 Hz tone. By pressing "2" and "5" simultaneously you will hear a pure 1336 Hz tone. Now notice that the digit "5" sounds just like a combination of these tones. By pressing any two keys in a row or column you can hear the corresponding tone for that row or column.*

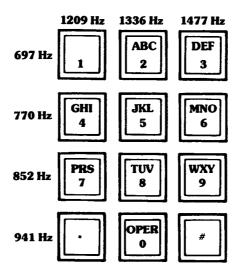|	1209 Hz	1336 Hz	1477 Hz
697 Hz	1	ABC 2	DEF 3
770 Hz	GHI 4	JKL 5	MNO 6
852 Hz	PRS 7	TUV 8	WXY 9
941 Hz	*	OPER 0	#

Figure 4. Touch-tone dialing frequency groups.

Another type of address signaling is Multi-Frequency (MF) signaling. Unlike dial-pulsing and TOUCH-TONE™, MF signaling is used only on trunk lines. It is similar to TOUCH-TONE™ in that pairs of tones are used to represent digits. Six different tones are used, providing for ten digits and five control functions. The standard MF transmitters and receivers have been optimized for speed, making this the most commonly used interoffice address signaling arrangement.

The third functional class of signaling is Informational Signaling. This is simply the collection of tones and recorded messages used by the network to inform the user of the progress of the call. The informational signal we are most familiar with is the busy signal. Dial tone and the audible ringing signal are two more examples. At one time or another, we have all experienced the obnoxious "Your call cannot be completed as dialed . . ." All of the messages and call progress tones are grouped together as Informational Signaling.

We have now examined three of the basic functional classes of signaling: supervisory, address and informational. In test equipment informational signaling is of little concern. Address signaling, although by no means trivial, only has three forms with which to deal. Supervisory signaling is the one that causes the most difficulty. This is because as the telephone system grew, dozens of different types of supervisory signaling appeared to handle the problems of digital carriers, microwave links and PBX's. In this application note we are interested in the types of supervision that might be found in the vicinity of a PBX. But first let's look at how the PBX fits into the public telephone system.

*This experiment is known to work on nearly all AT&T telephones, but does not work on many of the new telephones now becoming available since divestiture.

The Telephone System Hierarchy

In our typical phone call example, we assumed there existed a group of trunks connecting the two central offices that serve Mrs. Jones and Mrs. Smith (figure 2). This is not always the case. There are thousands of central offices throughout the U.S.; it would not be reasonable to completely interconnect all of them.

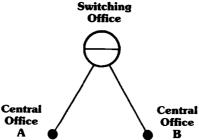Instead, central offices are grouped together and served by an area switching office (figure 5). This forms a two level hierarchy.

Switching Office

Central Office A

Central Office B

Figure 5. Two level switching system.

A switching office only has trunks entering and leaving; it does not handle any subscriber lines directly. Now we can see the possibility of alternate call routing. If all the direct trunks from central office A to central office B were in use, a call could be routed through the switching office instead.

This scheme still leaves too many switching offices to be interconnected, so switching offices are grouped together into a higher level switching office (figure 6).
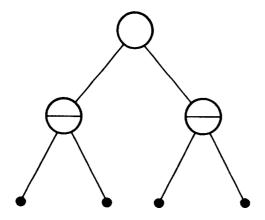
Figure 6. Three level switching system.

This process is repeated in the telephone system until we have the five level switching system hierarchy (figure 7).
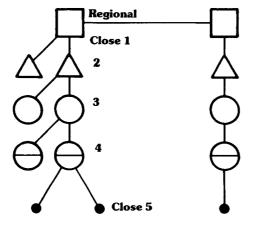
Regional

Close 1

2

3

4

Close 5

Figure 7. Five level switching system.

4

Each level is numbered with central offices being considered class 5 offices up to the regional class 1 offices. Presently there are only twelve class 1 offices for the U.S. and Canada, and these are all fully interconnected.

One may notice the similarity between the telephone switching system and the software hierarchy chart used in structured software. This structure allows for a highly reliable, deterministic system. To avoid burdening the system excessively, it becomes desirable to add additional trunks that are not part of the tree structure where there is a high usage path (figure 8).

Figure 8. A switching network.

This might be considered analogous to the data paths required when structured software is applied to real-time systems.

Now let's examine how the Private Branch Exchange, or PBX, fits into this structure. Consider the problems involved in a medium-sized business with 2,500 employees and 1,300 telephones. The majority of calls are to other telephones within the plant. It would be a difficult task to provide for 1,300 two wire telephone pairs from the nearest central office, not to mention the cost involved. The ideal solution would be to place a small central office inside the plant; this is exactly what a PBX does (figure 9).
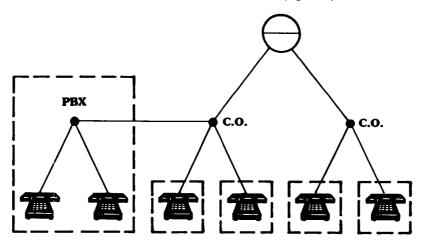

Figure 9. PBX—a small central office.

Trunk Signaling

Now that we understand how a PBX fits in, let's get back to supervisory signaling. There are three types of supervisory signaling commonly used for PBX trunks: ground start, loop reverse battery, and E/M (read "E and M").

Ground start is a modification of loop signaling that avoids the problem of both ends attempting to seize the trunk simultaneously. Take the case of someone calling you at about the same time that you were going to use the telephone. As the incoming call is connected to your line, the ring generator starts. But there can be up to 4 seconds before the first ring is heard due to the quiet interval between rings. If you should pick up the handset during this time, you would be surprised to find not a dial tone, but a person on the other end. This is not a real problem for subscriber loops since you were the person they were trying to call anyway.

This becomes a problem on trunks. Since trunks are shared lines that are switched in where they are needed, two unrelated calls could be connected together if switching equipment at both ends of a trunk seized the trunk simultaneously. This is called "glare" in the telephone system, and is the same in principle as a "collision" in a local area network.

Ground start solves this problem by providing current paths to ground so each end can sense whether or not the trunk is in use (figure 10).
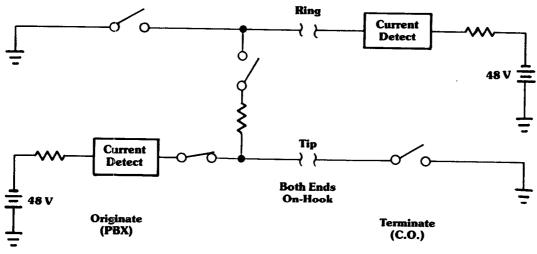

Figure 10. Ground start signaling.

It may not be immediately obvious how this array of switches, resistors and batteries implements a useful signaling technique, so we will follow the process for the case where the PBX seizes the trunk.

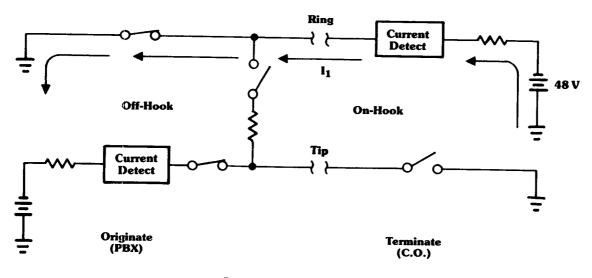The PBX begins by grounding the ring, causing current I_1 to flow (figure 11).

Figure 11. Ground start seizure.

The central office (C.O.) senses this current flow and interprets it as a request for the trunk. It acknowledges the request by grounding the tip and causing current I_2 to flow (figure 12).
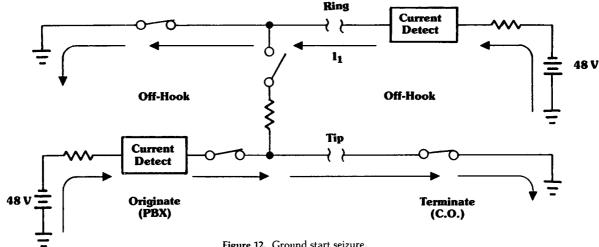

Figure 12. Ground start seizure.

Once the PBX recognizes the tip ground path, the handshake has been completed. The PBX then performs one final act: ring round is removed, the 48 V battery is removed, and a hold coil is placed between tip and ring. All three of these events happen simultaneously, effectively redirecting the path of current I_1 (figure 13).
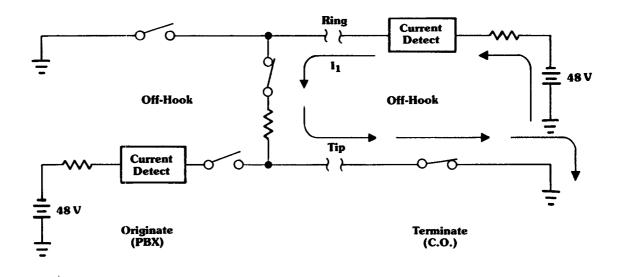

Figure 13. Ground start seizure.

Notice that the final configuration is basically the same as loop signaling. The PBX can now send dial pulses to the C.O. by opening and closing the hold coil.

Although ground start is somewhat more complicated than loop signaling, it does have one major advantage: when one end seizes the trunk, providing a ground path, the other end can detect the resultant current flow immediately. This virtually eliminates the possibility of glare. Ground start is also a two-way trunk; either end can initiate a call by providing a ground path.

Another signaling type similar to loop signaling is loop reverse battery. As one might guess, the on-hook and off-hook states at the terminate end are indicated by reversing the battery polarity. The only other change from loop signaling is the addition of a directional current detector at the originate end to sense battery reversals (figure 14).
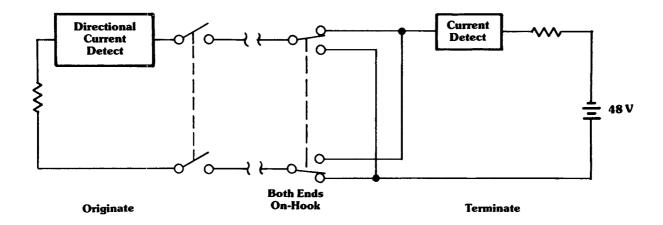
Figure 14. Loop reverse battery signaling.

There is one significant characteristic of loop reverse battery that makes it unique; it is used only for one way trunks. A call can only be initiated by the originate end. Examination of figure 14 reveals the reason: battery reversals can only be detected after the hold coil is applied. This means that the originate end must always be the first one to go off-hook. The term "one way trunk" only refers to the signaling characteristics of the trunk. Once the connection is established, two way voice communication can begin. You can think of this as a "don't call us, we'll call you" trunk.

Loop reverse battery is most often used in PBX's for direct inward dial (DID) lines. Direct inward dialing permits an outside subscriber to dial directly to an in-plant extension without operator assistance.

E/M signaling is perhaps the most straightforward signaling technique. Rather than attempting to superimpose both voice information and signaling information over the same pair of wires, E/M uses a separate pair of wires for the signaling path. This simplifies a lot of things at the expense of more wire for each trunk. There are five types of E/M signaling, each one being a slight improvement over the previous ones. The original E/M, E/M type I, is illustrated in figure 15.
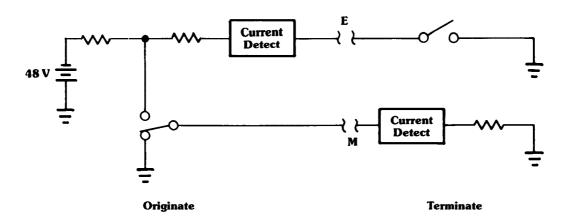

Figure 15. E/M type I signaling.

8

The letters E and M come from the words Ear and Mouth. This is from the lineman's experience with the originate end; the E lead listens to the signaling status of the other end while the M lead tells the far end what its signaling state is.

There is a problem with E/M type I. Its operation depends on the fact that the ground potential at the two ends differs by less than 3 volts. For trunk lines that go between two PBX's in different buildings, this is often not the case. So now comes E/M Type II to the rescue. By adding two more wires to Sense Ground (SG) and Sense Battery (SB), we can avoid ground loop problems (figure 16).
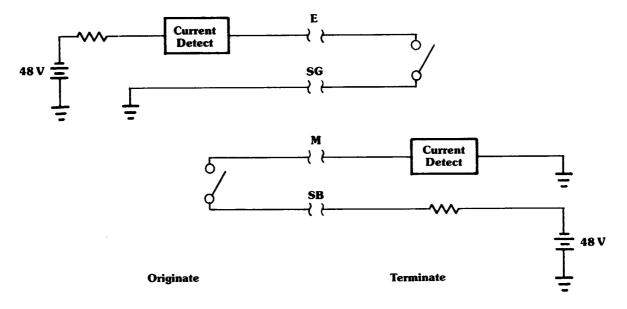

Figure 16. E/M type II signaling.

Since the E/M signaling techniques use more wire than the loop type signaling methods, E/M is usually restricted to the internal switching of the PBX or short haul trunks between two PBX's. Although it appears that E/M type II uses even more wire than type I, it is not as serious as it looks. Normally one SG/SB pair is used in common by all the trunks in a cable bundle.

In Conclusion . . .

In our search for the true nature of signaling, we took a brief glimpse at the typical telephone call. Looking back at the typical telephone call, we saw how we have been using various types of signaling every day. Next we examined the telephone system hierarchy and saw the importance of trunks. We then took a look at three more types of signaling that are used on trunks that enter and leave PBX s.

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