Inside The TELEPHONE

In this look inside the telephone, we'll learn how one of man's most important inventions does its job so reliably.

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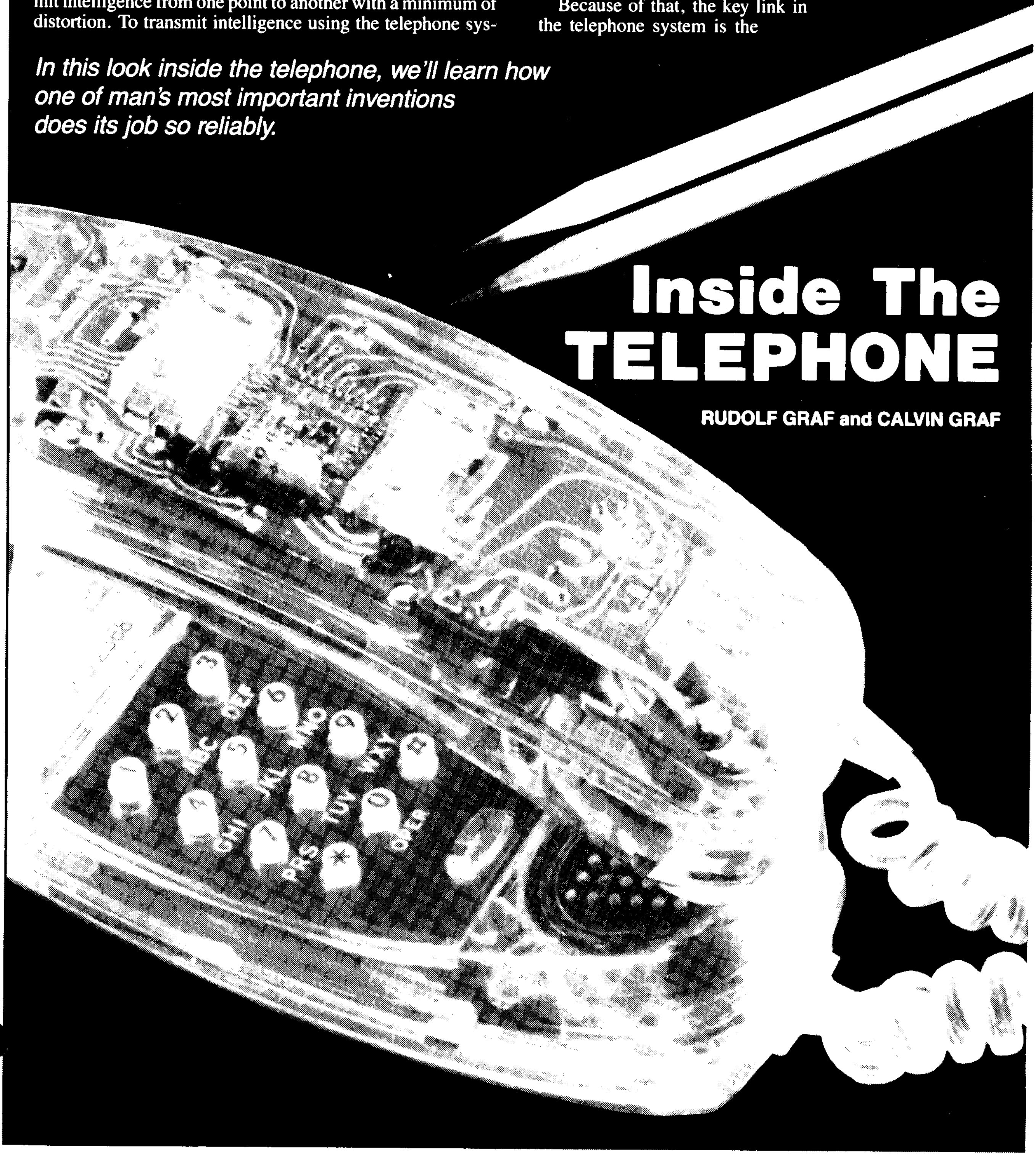
DEFINED BY WEBSTER AS AN INSTRUMENT FOR CONVERTING sound into electrical impulses for transmission by wire, the telephone has become much more than that in the over 100 years since its invention. The modern telephone is among the more sophisticated appliances in your home or office. Despite that, it is often taken for granted, even by those that are technically inclined. Let's correct that by taking a look inside that electronic marvel.

Inside the telephone

In any communications system, the basic goal is to transmit intelligence from one point to another with a minimum of distortion. To transmit intelligence using the telephone system we must convert sound into an electrical signal, send the electrical signals over the wires to a distant point, and then convert the electrical signals back into sound energy.

It is important that all of that occur with a minimum of distortion. In face-to-face communications much information is exchanged by facial expression, gestures, etc. With a telephone, all of that information must be exchanged by sound only. Feelings, emphasis, and the like are therefore conveyed by voice tones and, as a result, the recreated voice at the receiving side of the link must be as accurate as possible.

Because of that, the key link in the telephone system is the



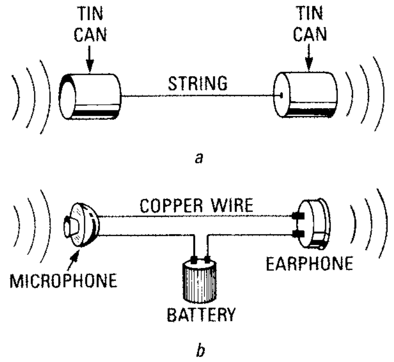


FIG. 1—TWO COMMUNICATIONS SYSTEMS. A mechanical system that is often experimented with by children is shown in *a*. The electrical system shown in *b* is the basis of our modern telephone system.

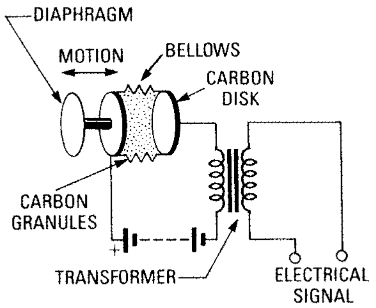


FIG. 2—IN A CARBON MICROPHONE, the vibration of a disc causes the compression of carbon granules inside a bellows to vary. That in turn varies the load across a battery.

transducer, a device for converting one type of signal into another type. The telephone "system" shown in Fig. 1-*a* uses a transducer that converts sound into mechanical energy. When you speak into one of the cans, sound waves cause the end of the can to vibrate. The vibrations from the can are carried to the receiver can a tightly stretched string. The end of the receiving can follows the in-and-out motions of the transmitting can and causes the air around it to vibrate to reproduce, albeit poorly, the transmitted sound.

A far superior system is shown in Fig. 1-*b*. There we see a circuit consisting of a microphone, earphone, battery, and wires. The microphone is a transducer that converts sound energy to electrical energy. The earphone is its compliment: it converts electrical energy into sound energy. Power for the system is supplied by the battery. If two such circuits were combined, a simple telephone system would be formed.

Let's take a closer look at the transducers. In Fig. 2 we see a diagram of a simple carbon microphone. Such microphones have been used in telephones almost since the beginning.

The microphone contains a flat, round, metal diaphragm. When sound strikes that diaphragm it vibrates. The diaphragm is connected by a rod to a bellows that is filled with carbon granules. The vibration of the diaphragm causes the bellows to expand and contract, varying the compression of the carbon granules. That varying compression presents a varying load to the battery, causing a time-varying current to be created. That current is passed through a coupling transformer and sent down the telephone line to the earphone.

The earphone converts the varying current back into sound. A diagram of an earphone is shown in Fig. 3. The current passes through the coupling transformer and then through a coil that is wound on a permanent magnet. That generates a time-varying magnetic field. That field causes a rigid metal diaphragm to vibrate, reproducing the original sound.

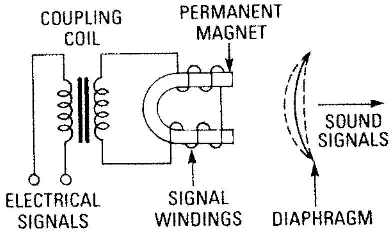


FIG. 3—IN A TELEPHONE EARPHONE, current passing through coils wound on a permanent magnet causes variations in the field of that magnet. That causes a metal diaphragm to vibrate, which generates sound.

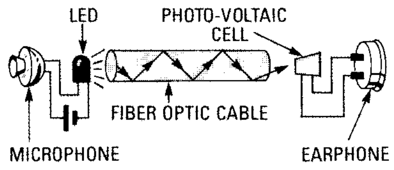


FIG. 4—COMMUNICATING WITH LIGHT. A basic fiber-optic communications system is shown here.

The principles behind the communications loop we have described have remained essentially unchanged since the invention of the telephone. However, technology does evolve. Currently, the telephone system is in the midst of one of its most significant changes. It is changing from a system based on wires and electric current to one that is based on optical fibers and light.

Figure 4 shows how a light-based communications loop works. At the transmitter end, a microphone is used to modulate the output of an LED. The light from the LED is conducted to the receiver by an optical fiber. At the receiver, the varying light levels are translated to a varying current by a photocell and fed to an earphone. The earphone turns the current into sound as previously described.

A modern telephone

As we've seen, the telephone started out as a relatively simple instrument. But it evolved quickly into a complex piece of electronic equipment as shown in Fig. 5. In addition to performing its basic task of communications, a telephone is required to perform a number of functions that help the telephone switching system make the proper connections. It also performs some basic signal-processing functions. For instance, it automatically compensates for variations in speech amplitude.

The simple telephone system that we've described thus far is of limited usefulness. That's because it can only be used to communicate between two established points. If an individual wanted to communicate with a number of people, he would need a separate telephone "system" for each of those. To overcome that limitation, we need a way to connect one telephone to a number of other telephones. That capability is provided by a system of local, exchange-area, and long-distance switching networks.

On the local level, switching functions are handled by a *central office*. That facility contains the switching and signaling equipment for a local area or *exchange*, as well as the batteries for the local system.

Each *subscriber telephone*, or individual telephone number (extension telephones are merely extensions of the subscriber telephone) is connected to the central office via a *local loop*. The loop consists of a color-coded wire pair. The positive wire is always green, while the negative wire is always red. Those wires are also designated as *ring* (negative) and *tip* (positive). That corresponds to the tip and ring connections of the plugs used in manual switchboards.

The central office and all of the local loops that it serves make up the *local exchange* or *local network*. A block diagram of a typical local exchange is shown in Fig. 6. The geographical area served by a local exchange can vary greatly. In urban areas, it might cover less than 12 square miles, while in rural areas a local exchange might serve a region as large as 130 square miles.

Central offices in a region are linked together into what is known as an *exchange-area* network. An exchange-area network might cover several cities and towns over a wide geographical area or just a single city or part of a city. Its coverage area is of course determined by the number of subscribers it must serve. Figure 7 shows a simplified diagram of an exchange-area network.

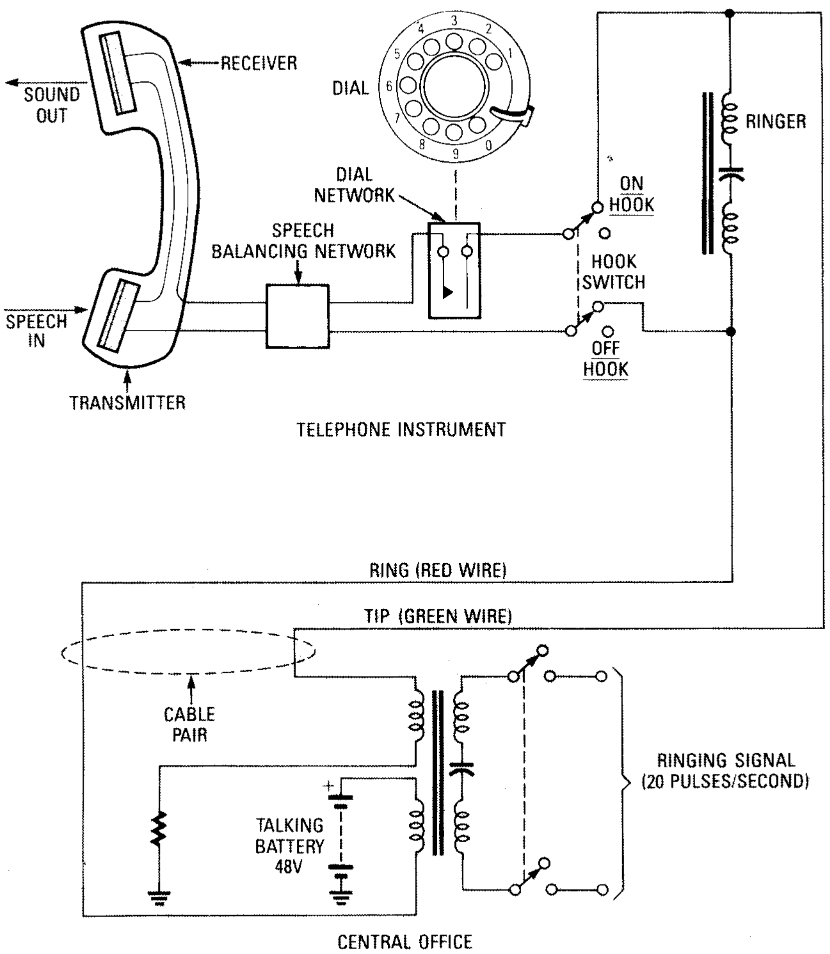


FIG. 5—A TELEPHONE is connected via the local loop to a central office. The central office supplies power for the phone and handles switching functions.

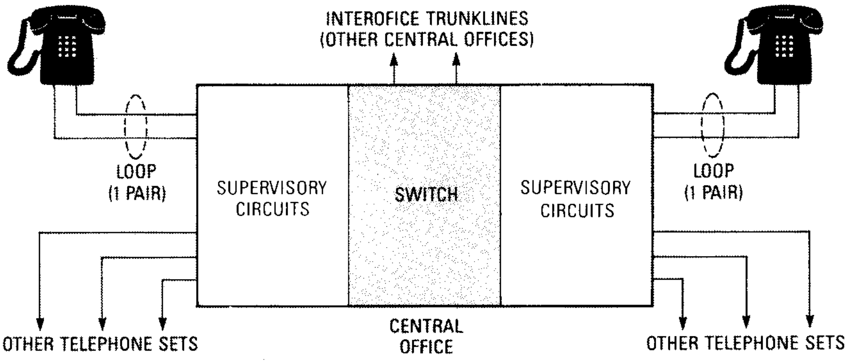


FIG. 6—CENTRAL OFFICE block diagram. Such an office is responsible for thousands of telephone subscribers.

Calls to points outside of your exchange area require use of the long-distance or *long-haul* network. In that network, exchange-area networks are interconnected. Figure 8 shows a portion of the long-haul network. That portion covers the busy West Coast of the United States.

Because of the high amount of volume it must carry, the links in that network have become highly sophisticated. Overhead cable has largely been abandoned in favor of microwave, satellite, and fiber-optic technologies.

Making connections

As we previously stated, a telephone would be of limited use if it could not be used to communicate with a number of different parties. In the early days, all switching was done manually. That is, a user would signal the operator, perhaps by turning a crank, that he wished to place a call. The operator would come on the line and request the identity of the party that the caller wished to reach. The operator would then complete the call by physically connecting the local loops of calling and desired with a patch cord.

While manual switching adds a pleasant touch to the process of making a telephone call, it is not terribly efficient. That led to the development of the rotary-dial telephone and its associated automatic switching system by Almon B. Strowger in 1892. That type of equipment is still in widespread use, so let's spend a few moments and examine its characteristics.

The signaling mechanism in a rotary-dial phone is spring loaded and designed to produce pulses at a rate of 10-per-second. Therefore, it takes 1 second to output a 0 (10 pulses) and ⅒ second to output a 1. A governor in the dial mechanism prevents any changes in that rate, no matter how the dial is manipulated. The reason that the constant rate must be maintained is that the line switches at the central office are designed to act only at that rate. Any disparity will result in inaccurate switching.

Since the dialing pulses are all of the same duration, and the spacing between pulses is identical for all digits, some small time interval is required between digits. That interval is called the *interdigit time*.

The *switching time* or pulse duty cycle is also constant. It is specified as 39%; that is, the pulse waveform is high 39% of the time for each digit. That low duty cycle is used to conserve battery power.

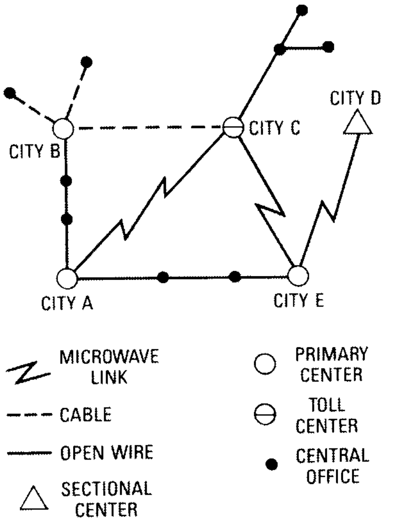


FIG. 7—A SIMPLIFIED EXCHANGE AREA network. Links between the various central offices and centers are handled by buried cable, overhead wire, and occasionally by microwave.

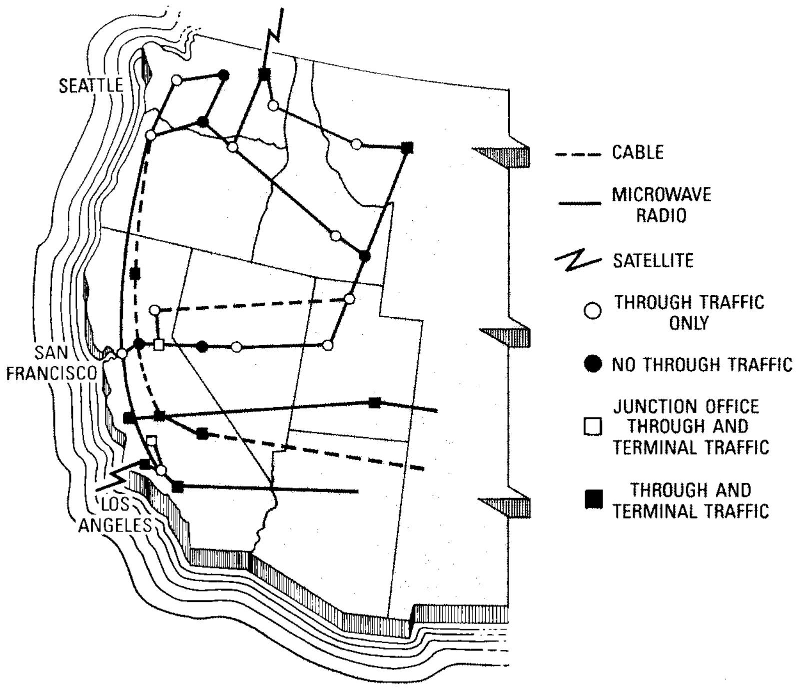


FIG. 8—THE LONG-HAUL NETWORK handles telephone calls to points beyond an exchange area. Here, a simplified diagram of the west-coast portion of that network is shown.

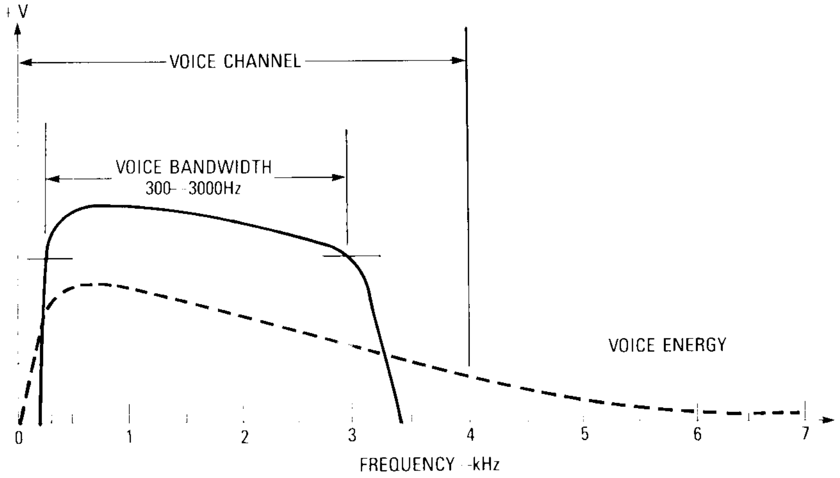


FIG. 9—ELECTRONIC TELEPHONE block diagram. Such a phone uses tone dialing. All circuitry is contained on just a few IC's.

TABLE 1—CALL PROGRESS TONES

Tone Type	Frequency (Hz)	On Time	Off Time
Dial	350 and 440	continuous	
Ringback, normal	440 and 480	2 sec	4 sec
Ringback, PBX	440 and 480	1	3
Busy	480 and 620	0.5	0.5
Congestion (toll)	480 and 620	0.2	0.3
Reorder (local)	480 and 620	0.3	0.2
Receiver off-hook	1400, 2060, 2450, 2600	0.1	0.1
No such number	200 to 400	continuous (Frequency modulated at 1 pulse per second rate.)	

The first tone-dialed telephones appeared in 1964. Those units were extremely sophisticated for their time but still relied on electromechanical bells, a carbon microphone, and a pushbutton pad that consisted of 120 separate components. In modern versions of that device, the circuitry is contained in IC's, the bells have given way to piezoelectric ringers, and the carbon mike has been replaced by a dynamic unit. A block diagram of a tone-dial phone is shown in Fig. 9.

While tone dialing is a relatively recent development, tones have been used for various system-signaling functions for a very long time. Among the tones that should be familiar to you are the dial tone, ringback tones (normal and busy), receiver off-hook tone, and circuits-busy or congestion tone. Most of the signals are actually made up of tone pairs, though some use a single tone while others use multiple tones. A summary of the most common tones, their frequencies, and their duty cycles (on time vs. off time) is provided in Table 1.

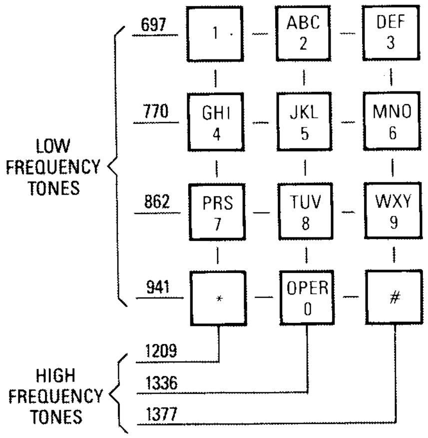


FIG. 10—IN TONE DIALING, each digit is represented by a frequency pair as shown here.

In tone or *D*ual *T*one *M*ulti*F*requency (DTMF) dialing, each press of a key generates a duplex tone. (That type of dialing is also called *Touch-Tone*, which is a trade mark of AT&T.) Figure 10 shows the frequencies for each digit. Note that the frequencies can be classified as low or high. There are four frequencies in the low range (697-, 770-, 862-, and 941-Hz) and three frequencies in the high range (1209-, 1336-, and 1377-Hz). Also note that none of the frequencies are harmonically related. That ensures that a signal harmonic will not confuse the telephone company's switching equipment.

The presence of a keypad does not in itself indicate whether a telephone uses tone or pulse dialing. Many keypad-equipped telephones have pulse-dial capability that allows them to be used with any telephone system. Remember that not

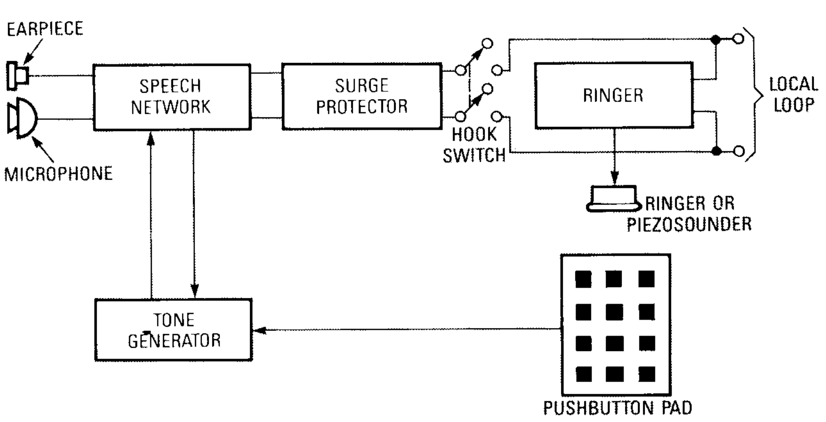


FIG. 11—ALTHOUGH THE HUMAN voice spans a wide frequency range, in the telephone system voice bandwidth is limited to just 300 Hz to 3 kHz.

TABLE 2—OPERATING PARAMETERS

Parameter	Typical U.S. values	Limits	Typical European values
Common battery voltage	–48-volts DC (on-hook)	–47 to –105 volts DC	Same
Common battery voltage	–6-volts DC (off-hook)		
Operating current	20 to 80 mA	20 to 120 mA	Same
Resistance of telephone set	300 ohms	100–400 ohms	
Subscriber loop resistance	0 to 1,300 ohms	0 to 3,600 ohms	
Loop loss	8 dB	17 dB	Same
Distortion	–50 dB total	not applicable	
Ringing signal	20 pps, 90-volts rms	16 to 60 pps 40 to 130 volts rms	15 to 50 pps 40 to 130 volts rms

every exchange can handle tone dialing, although the number with that limitation is shrinking rapidly.

Incidently, keypad pulse-dialed telephones require some type of memory device. That's because you generally can key in a number faster than the telephone can output its pulses. The pulse-duration requirements that we mentioned earlier hold whether the phone is equipped with a rotary dial or a keypad.

Odds and ends

Figure 11 shows the frequency response of the telephone system. While the human voice can generate sounds over the range of 100 Hz to 6 kHz and beyond, that entire range is not needed for communications. In the telephone system, a voice "channel" of 4 kHz is used. Within that channel, frequencies between 300 Hz and 3 kHz are passed. While the conversations such a system allows are not "Hi-Fi," they are certainly intelligible enough for satisfactory communications.

That voice channel and voice bandwidth are just two of the operating standards adopted many years ago. Others cover such things as handset dimensions, sound-pressure levels, and ringing voltage and frequency. Some of those parameters are summarized in Table 2.

One parameter not listed in that table is the *R*inger *E*quivalence *N*umber (REN). When your phone is on-hook, only the ringer bell is connected across the line. No current flows in your local loop because of a capacitor connected in series with the ringer circuit and no power is consumed from the central office battery. As we know, there are thousands of telephones to be rung from each central office, but since we are dealing with battery power, only a finite amount of power is available to ring all of those telephones. As a result, the telephone company only guarantees to supply enough power to each subscriber to sound five standard electromagnetic ringers. That amount of power is referred to as 5 REN.

The importance of that to a subscriber is that it limits the number of devices that can be connected to a line. For instance, if five standard telephones are connected to a line, each must have an REN no greater than one. Otherwise, there's no guarantee that any of the ringers will sound for an incoming call.

These days, the REN has taken on greater importance because a number of telephones and telephone accessories draw power for their features from the ringing voltage. Those include telephone-answering machines, extension bells, telephone-hold circuits, etc. On the other hand, many new telephones have electronic sounders that draw very little power. Some may be rated at as little as 0.1 REN. It's important to remember that you must notify your local phone company whenever you hook up a new device to your line and supply them with its REN.

All telephones that have been registered with the FCC by their manufacturer have an REN. It is usually stamped on the bottom of the unit along with the serial number and similar data. Sometimes, the REN may be followed by a letter (A, B, etc.). That letter refers to the ringing frequency. Table 3 lists the various ringing frequencies and their letter designations. The telephone company automatically provides a type A frequency to all single-party subscribers. As a result, most telephones are designed to respond to a type A frequency. If no letter is specified, it is safe to assume your telephone is one of those.

TABLE 3—
RINGING FREQUENCIES

Ringing Type	Ringing Frequencies (Hz)
A	20 ±3 and 30±3
B	15.3 to 68.0
C	15.3 to 17.4
D	19.3 to 20.7*
E	24.3 to 25.7
F	29.3 to 30.7*
G	32.6 to 34.0
H	39.2 to 40.9
J	41.0 to 43.0
K	49.0 to 51.0
L	52.9 to 55.1
M	53.8 to 61.2
N	65.4 to 68.0
P	15.3 to 34.0

*Frequency-selective ringing (party line use)

Next time

In the past, customers were prohibited from tampering with their telephone equipment in any way. If you wanted a telephone installed or moved, telephone company personnel did the job, for a fee. That all has changed since the break-up of AT&T. Now, you pretty much can do what you want—as long as you know what you are doing! A service call to correct an error, or for any work for that matter, can be extremely expensive. Next time, we will provide you with a crash course in telephone installation that can help you save time, money, and aggravation. **R-E**