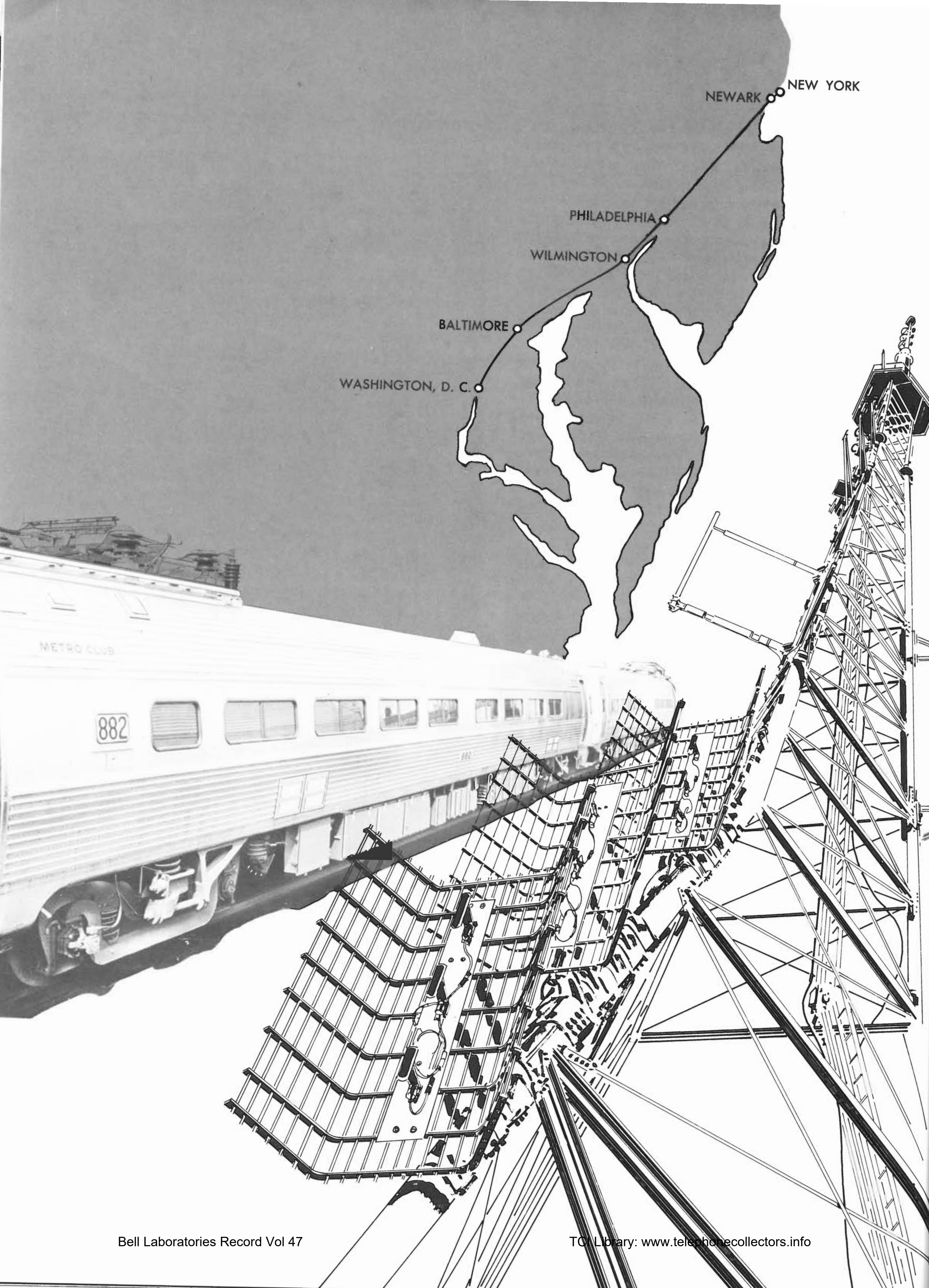

NEW YORK
NEWARK
PHILADELPHIA
WILMINGTON
BALTIMORE
WASHINGTON, D. C.
METRO CLUB
882

Passengers aboard the new high-speed Metroliner trains running between New York City and Washington, D.C., are almost as close to a telephone as they would be at home. A new Bell Laboratories designed system makes it easy to call to or from the trains.

Telephones Aboard the "Metroliner"

C. E. Paul

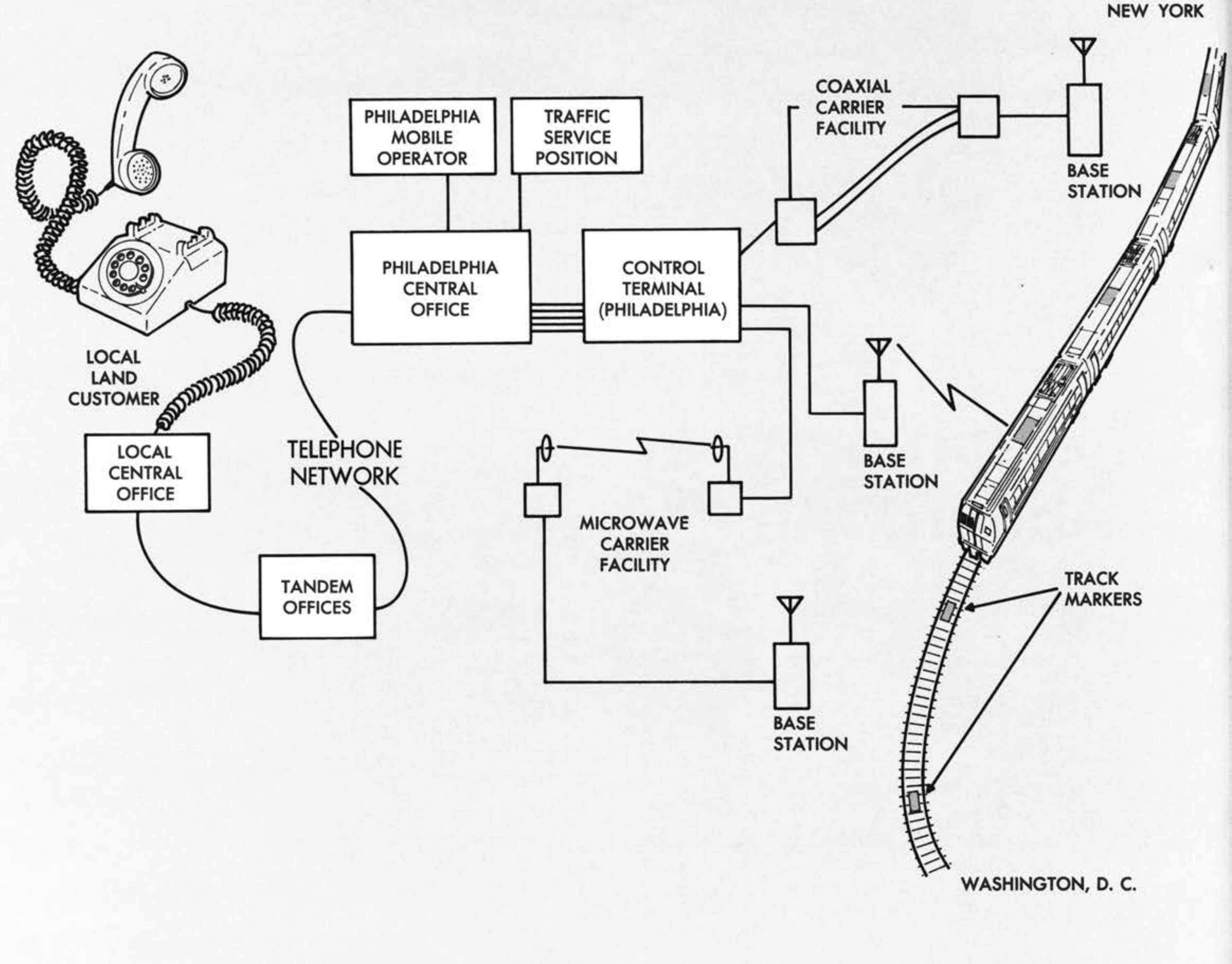
When the new Metroliner trains went into service this January, delighted passengers found they could conveniently make telephone calls while racing along at better than 100 miles an hour. This was possible because the Metroliner features a unique radiotelephone service that lets passengers place calls to or from booths aboard most of the cars. Designed at Bell Laboratories, the service presents an attractive face to the public with booths to match the cars' decor, TOUCH-TONE® dialing, single-slot coin telephones, and dial tone before depositing coins.

The radiotelephone system provides continuous coverage from the west portal of the Hudson River Tunnel right into downtown Washington. Nine base stations are located along the 225-mile route, and signals are transmitted between these stations and the trains over six two-way channels in the 400-MHz region. Carrier facilities connect the base stations to a main control terminal in Philadelphia, Pennsylvania, so that all calls to or from the train go through this city.

Customers placing calls find the procedure is no different from what they are already accustomed to. The booths, telephones, and instruction displays are essentially similar to those found in conventional public telephone installations with the exception of two small lamp displays to the upper left of the handset. One goes on when all channels are busy, and the other warns customers when they have only one minute of talking time left.

Customers rarely have to wait more than a few minutes for a free channel, since three or four are available at almost every point along the way. Once a channel is available, the customer hears dial tone before he deposits a coin. He can now make any kind of call he could make from an ordinary public telephone, including credit card, person-to-person, collect, and local coin calls. All can be dialed directly from the train. Before the called telephone rings, a traffic service position operator requests information for billing or coin deposit. If the called party is not available, a message giving the car's telephone number can be left. When the called party

HIGH-SPEED TRAIN RADIOTELEPHONE SYSTEM



HIGH-SPEED TRAIN

ZONES — RADIO CHANNELS — VOICE CHANNELS

returns, he simply calls the local operator and asks for the mobile-service operator in Philadelphia. The mobile-service operator will then ring the car's telephone and set up the connection.

Of course, people "ashore" can call someone aboard the train this way without having been called first. All the caller has to know is the train's number—which he can get from the railroad or from a schedule. The Philadelphia opertor will have the telephone number of one of the parlor cars for that train and will ring it. A train attendant will answer and use the train's paging system to ask the called party to dial operator from the nearest telephone. The Philadelphia operator does not have to know where the train is, since a selective ringing code is transmitted from every idle transmitter along the route.

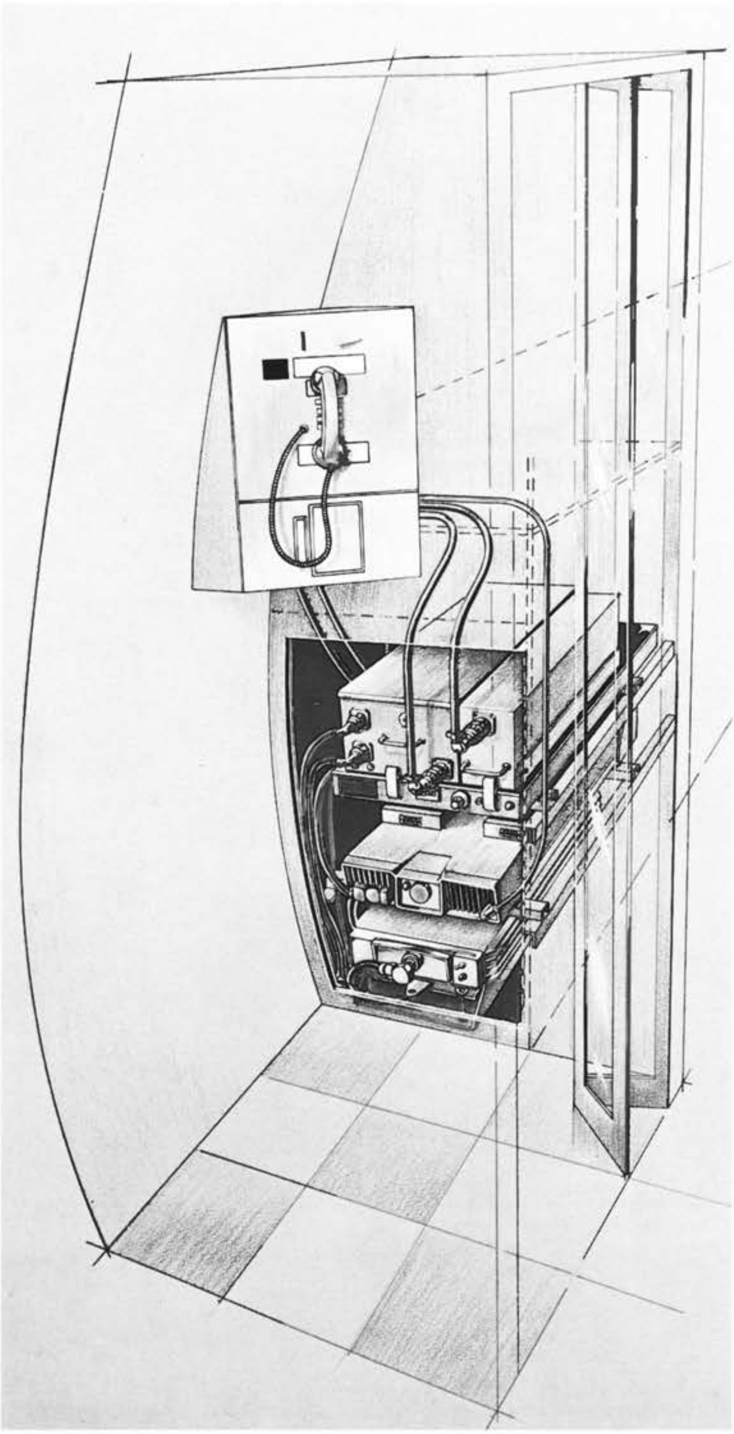
To obtain optimum use of the system's six radio channels, a frequency pattern is utilized that permits the same frequencies to be used in more than one zone along the run. (See the lower chart at left.) The frequency pattern makes it possible to transmit up to eleven simultaneous conversations between a number of trains and base stations. The pattern is based on a radio zone system that divides the 225-mile route into nine zones of approximately equal length. Each zone has its own base station, which supplies three or four of the six available channels. As the train passes from one zone to another, a call in progress is automatically switched to the next base station. The switch is always to the same channel in the next zone and happens without the customer being aware of it. In the rare event that a call is still under way when the train reaches the end of the last zone covered by the channel in use, it will be automatically terminated. In such a case, the passenger is alerted 60 seconds beforehand by a flashing light and an audible tone.

Logic circuitry aboard the train keeps track of the train's direction and zone and automatically selects an idle channel that will be available in a zone ahead. Unless the train is nearing the end of a run, coverage over at least the length of one full zone is always guaranteed. Since it takes the train approximately 12 minutes to pass through one zone, this is the minimum talking time guaranteed to a caller.

The area covered by any particular channel varies: some channels cover an area four zones long. Others, such as channel "a" in the Newark area, cover only one zone. This is because these are terminus zones and must handle the heavy traffic normal to "end-of-run" areas—people call-

Overall view of the high-speed train radiotelephone system. The Philadelphia terminal acts as a common control center for the system, and all calls to or from trains pass through this terminal.

A frequency pattern based on a unique zone system is used to obtain optimum usage of the six assigned FM channels. The 225-mile route is divided into nine zones. Radio coverage is provided by unattended base stations that are located near the center of each zone. Some of the six FM frequencies are re-used along the route. To prevent interference, buffer zones (three zones long) separate areas in which channels are being re-used.



Telephone booths were designed to blend into the modernistic decor of the new cars. Instruction displays on the single-slot, TOUCH-TONE *telephones are essentially similar to those found on stationary sets. The mobile radiotelephone installation is housed in a concealed equipment locker in the side of the booth.*

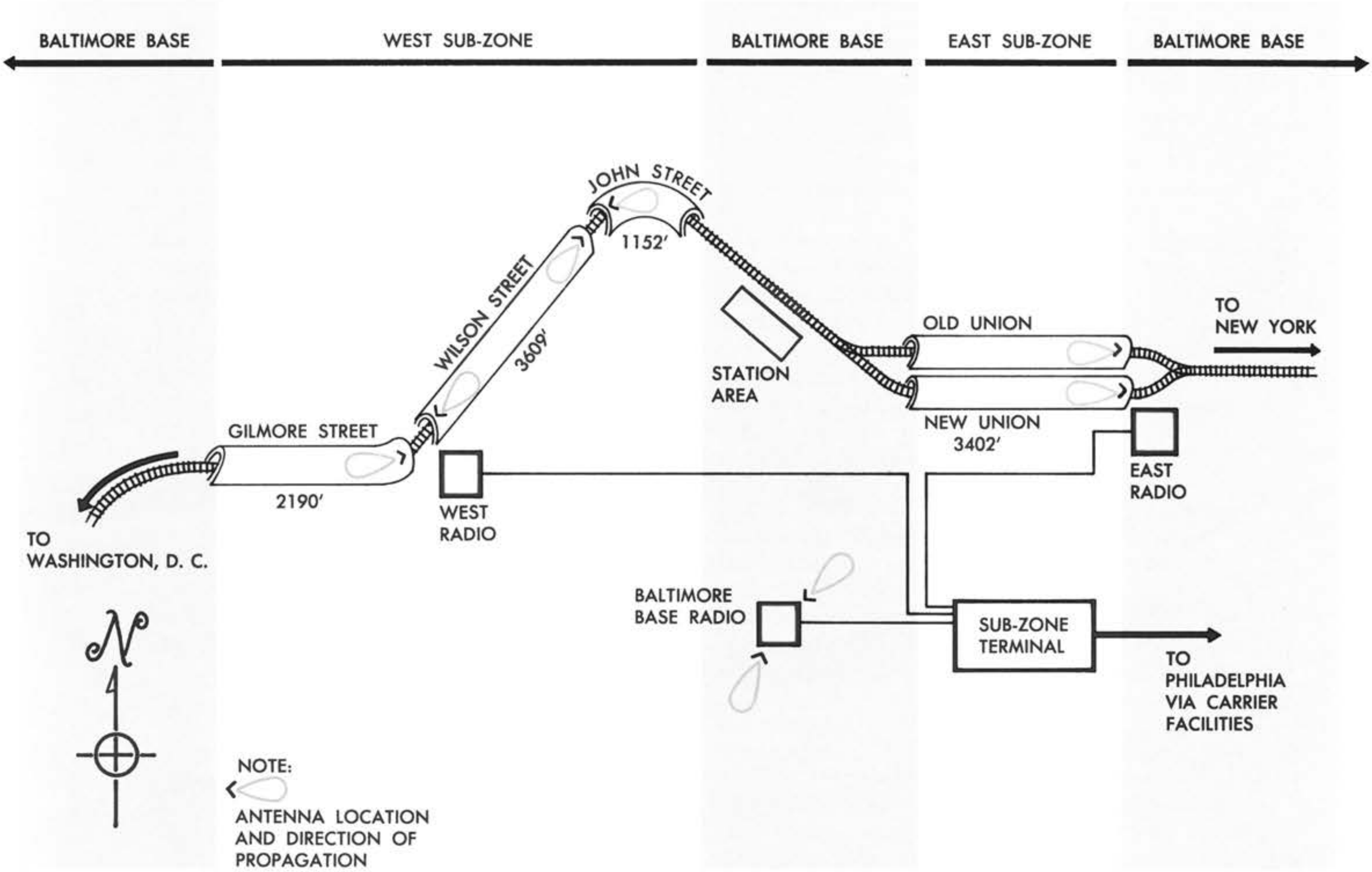
ing for appointments, confirming dates, and that sort of thing. There are also buffer areas separating zones in which frequencies are re-used. Three zones long, these buffers prevent interference between calls on the re-used frequencies.

Boundaries between zones are very sharp. They are established by electronic track markers which are part of an elaborate system for determining the train's position and automatically selecting available radio channels. A sensor on the train detects each marker as the train passes over it. The sensor and its fiberglass enclosure are installed under the car in a mounting that maintains about a one-foot spacing between the bottom of the sensor and the track markers. The sensor consists of two mutually coupled coils which are connected to the input and output, respectively, of an amplifier in the channel control unit. When the sensor passes over a track marker, coupling between the input and the output coils increases enough to cause the amplifier to oscillate at the marker's resonant frequency. How long it oscillates depends on how fast the train is going. At 100 mph, for example, oscillation will last for 10 milliseconds. At higher speeds, the period will be shorter.

Track markers are mounted between the rails in protective wooden enclosures. There are two markers in an enclosure, each resonant at a different frequency. From the combination of frequencies used by the two markers, logic circuitry on the train determines the zone boundary being passed. The sequence in which the frequencies are detected also tells the logic circuitry which direction the train is moving.

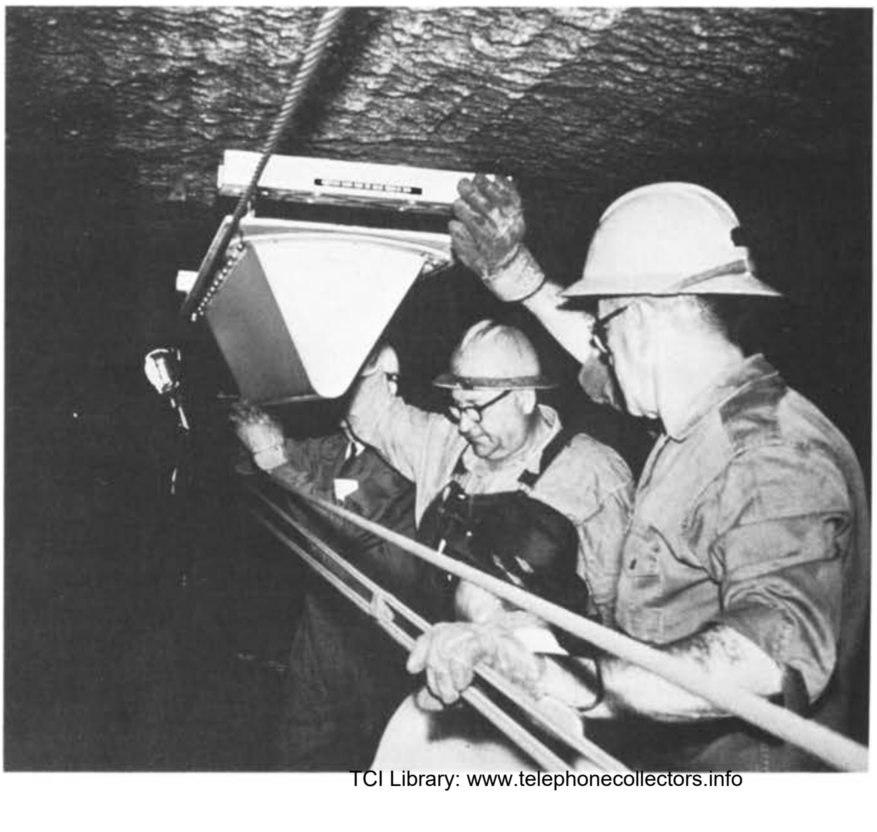
The logic circuitry is preceded by a high-gain amplifier with coupled input and output. This amplifier's output circuit includes a bank of seven filters tuned to the seven resonant frequencies of the track markers. The outputs of these filters are fed into the logic circuitry, which operates on a sequential two-out-of-seven basis to identify radio zones. The logic circuitry then switches the radio unit to the best available channel. A call cannot be originated on a channel if that channel is not available in the zone ahead and, on the average, customers will have about 30 minutes to talk.

All transmissions to and from the train are frequency modulated. The FM channel carriers are separated by 50 kHz. The mobile transmitters produce 12 watts of radio-frequency power —typical for mobile operation at these frequencies. In addition to delivering the audio signal to the telephone set, the radio unit provides control signals to the coin-control unit. These sig-

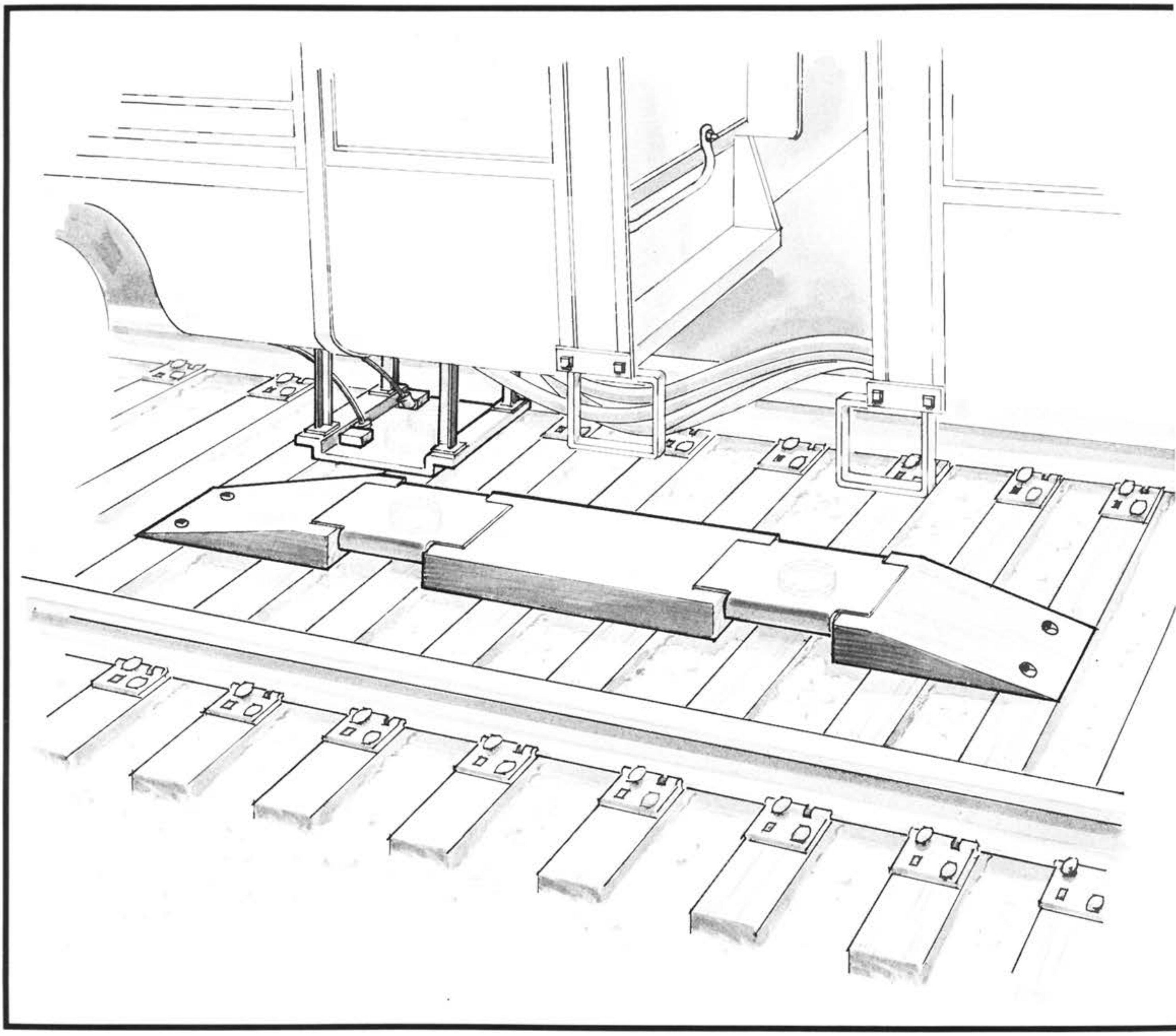


BALTIMORE TUNNEL
SYSTEM

Special arrangements were necessary to provide radio coverage inside a complex of five long tunnels in Baltimore. Two radio coverage "sub-zones," east and west, were established by locating base station transmitting and receiving equipment near the tunnels. These "sub-zones," together with the Baltimore base station, are controlled by a local terminal, which is connected to the main control terminal in Philadelphia.



Workmen install an overhead antenna in one of a series of five tunnels in Baltimore. Part of a subsystem needed to provide radio coverage inside the Baltimore tunnel complex, the antennas are located about 50 feet from tunnel portals. They are mounted in protective fiberglass radomes similar to the ones that are used on the trains.



Track markers mounted between the rails sharply define boundaries between the system's nine radio zones. Sensors on the trains detect the markers, each of which consists of a capacitor plus a coil embedded in a fiberglass plate. Two markers, which are tuned to different frequencies, are installed at every boundary. The sequence and combination of marker frequencies indicate the train's direction as well as the zone being entered.

nals are initiated by the Philadelphia operator for the usual public telephone functions such as collecting and returning coins.

Aboard the trains, the radiotelephone installation in each car is completely independent of the installation in any other car. This autonomous approach is in keeping with the basic design of the cars themselves, each of which has its own power, braking, propulsion, and air-conditioning facilities. The installations consist of seven basic units—power supply, track-marker sensor, channel control unit, radio unit, coin-control unit, antenna, and telephone set. The installation is connected to the car's internal battery system, which varies from 56 to 88 volts. This storage battery system provides power if the car's external power system fails. A fiberglass radome on top of the car protects the antenna against icing and the stiff brushes that are used to clean the cars. Its location was chosen to minimize the noise generated by arcing as the car's pantograph rides on the 11,000-volt overhead power cable.

At the base stations, two antennas pointing in opposite directions are used for each channel. Power output from the transmitters is divided between them. Because of variations in terrain, antenna heights, and distances between base stations, the power fed into an antenna oriented one way may be considerably greater than the power going into the antenna oriented the other way. The main objective is to provide adequate signal level right up to zone boundaries—but not far beyond. Using too much power would cause interference in channels that are re-used in other, non-adjacent zones.

The transmitter-receivers at the base stations are fixed tuned and are equipped for automatic testing and control by the Philadelphia terminal. The units provide signal-to-noise-level information to this terminal to help select the optimum receiver-transmitter pair. Thus, the Philadelphia terminal serves as the common control for the base stations as well as for the mobile units. It automatically transfers calls from base station to base station as the train progresses. To determine when and where to make such transfers, the terminal monitors the signal-to-noise ratio of all receivers involved in a voice path. If any available receiver maintains a signal-to-noise ratio better than one in use for several seconds, the better one is switched in after this "smoothing interval" along with its associated transmitter. The better receiver-transmitter pair is turned on about 200 milliseconds before the poorer one is turned off so that the customer hears practically no change. Without this time gap between transmitters, he would hear a loud rush of noise. Because of variations in the transmission path, the base station selected is not always the one closest to the train. Sometimes, calls may be transferred to a station ahead and then back to the one behind. However, this kind of switching is held to a minimum by the smoothing interval.

An unusual problem was posed by the 30th Street Station in Philadelphia and by a series of five tunnels in the Baltimore area. Providing radio coverage in these areas requires special equipment since they are underground and, in some cases, out of the radiation pattern of the nearest base station. To provide radio coverage for the 30th Street Station, for example, requires the installation of another set of antennas—all directed at the station.

Obtaining adequate radio coverage for the complex of five tunnels in Baltimore was more difficult. Two sub-zones were established for this purpose—both served by stations near the tunnel entrances. (See the drawing on page 81.) These stations feed antennas located inside the tunnels and are conected to a sub-zone control terminal in Baltimore. This control terminal selects receivers and transmitters for the main Baltimore zone as well as for the two sub-zones. Like all the base stations, it is connected to the Philadelphia control terminal.

The antennas inside the tunnels are mounted on the ceilings about 50 feet in from the entrances and are covered by the same protective radomes used for the train antennas. Cables to the transmitter-receivers have grounded-stub safety protection because they are close to the high-voltage power wires.

The tunnel portion of the system functions pretty much the same as the rest of the system. For example, if a long call on channel "b" were started in the Edgewood zone while the train is traveling southward, the call would initially be served by the Edgewood station. Farther south, the call would be automatically transferred to the main base station at Baltimore, which is connected to the sub-zone control terminal. As the train entered the Union tunnel, the call would be transferred by the sub-zone control equipment to the East Tunnel radio equipment. After the train left the tunnel, the call would be transferred back to the Baltimore base station. Similar transfers would occur as the train went through the West Tunnel complex. A call of this kind could last as long as 45 minutes and could be started inside or outside any of the tunnels.

Another modification of the basic system is the use of track markers at locations other than at zone boundaries. This is done in some areas in order to extend zones and, hence, increase the system's call capacity. For example, track markers have been placed on the south side of the 30th Street Station in Philadelphia. These make it possible to begin a call on channel "f" from a southbound train while the train is still inside the station. Without the added track markers, this would be impossible as the next zone, Wilmington, does not provide coverage on channel "f". Similarly, markers are used at several other locations to extend the length of a zone for some particular channel.

Development of the high-speed train radiotelephone system has given the Bell System a practical means of supplying unattended public telephones on moving vehicles. Some of the concepts employed represent distinct advances in mobile radiotelephony. For example, the technique of automatically transferring calls by comparing reception in a number of receivers is superior to previous methods.

If some of the problems discussed seem unique, this is simply because the system itself is unique. It is the first practical integrated system to use the radio-zone concept within the Bell System in order to achieve optimum use of a limited number of radio-frequency channels.

Future mobile systems will probably put these concepts to even better use by determining the mobile unit's position from the base stations. This should provide greater flexibility and permit the allocation of channel frequencies on a demand basis. In addition, prediction techniques based on call-traffic conditions as measured at a common control center will almost certainly be introduced. The future may also see these concepts used by other kinds of mobile radiotelephone systems on land, at sea, and in the air.