Electric Trolleybus Operation on Controlled-Access Highways

JACK W. BOORSE

More than 50 years ago transit operations planners recognized the opportunity to make use of freeways to expedite selected movements of their conventional (gasoline and diesel) buses. Other planners found the medians and margins of freeways to be useful rights of way for rail lines. Meanwhile, electric trolleybus operation has been confined almost entirely to local urban and suburban streets with slow-moving traffic and closely spaced intersections. Now, driven by concerns about air quality and replenishable fuel, there is a renewed interest in the trolleybus mode. Progressive planners are considering the feasibility of expanding the operating environment of the trolleybus beyond its traditional boundaries. One possibility is to operate trolleybuses on freeways in a manner similar to diesel buses. If operation on freeways and other controlled-access highways is to be seriously considered, a number of factors not present with local street operation must be explored. These factors are identified and discussed.

Most early North American electric trolleybus (ETB) lines replaced local streetcar lines, and as a result they were born into an operating environment that consisted of local urban and suburban streets with low traffic speeds and closely spaced intersections. The quality of service that they could provide in that environment made competition with the automobile difficult. Automobile traffic (and congestion) increased and the diesel bus became the predominant surface transit mode.

As the network of freeways and other controlled-access highways grew, many transit passengers began to drive their own cars to enjoy the benefits of these new time saving facilities. Obviously, the general effect of the new highways on transit was negative, although not totally so. In certain corridors diesel buses were able to use the new freeways to reduce travel time for their passengers and simultaneously lower operating costs. Meanwhile, the increasing automobile ownership produced higher traffic volume and greater congestion on the local streets where the majority of transit vehicles continued to operate.

A few of the surviving streetcar or trolley operations were able to avoid some of this congestion by using underground alignments or aboveground private rights of way. In those cities where trolley service has been restored, decades after it was abandoned, the new lines have made extensive use of private rights of way, including the medians and margins of freeways. Now generally known as light rail transit (LRT), the number of trolley systems more than doubled in the past 15 years and very likely will double again in the next 15 years.

In contrast ETB operation has continued to decline. In 1990 11 were operations left: 2 in Mexico, 5 in the United States, and 4 in Canada. Of those, only three—Seattle, San Francisco, and Vancouver—were robust. Now there is a renewed interest in the trolleybus mode, and thought is being given to ways that it too can benefit from more traffic-free environments. If LRT can operate in highway medians and diesel buses can run on freeways, why cannot ETB do the same?

Parsons Brinckerhoff Quade & Douglas, 415 East Willow Grove Avenue, Philadelphia, Pa. 19118.

Operation in highway medians operation appears to be feasible for all three modes: LRT, ETB, and diesel bus. It is even possible that they could all use the same reserved right of way, but that is not the subject of this paper. What is explored here, and only in a preliminary manner, is the notion of operating trolleybuses in mixed traffic on freeways and similar facilities in the same manner that diesel buses now operate.

Before proceeding further, a word must be said about terminology. There is an inconsistency in the names for the various controlled-access highways resulting from colloquial usage. As an example, the portion of Interstate 676 situated in Pennsylvania is called an expressway whereas the contiguous portion of the same highway in New Jersey is called a freeway. A major freeway in downtown Pittsburgh is called a parkway.

The *Manual on Uniform Traffic Control Devices* (MUTCD) defines expressways as "divided arterial highways for through traffic with partial control of access and generally with grade separation at major intersections" (*1*). The MUTCD does not include a formal definition of freeways, but it does discuss them separately from expressways, very clearly indicating that the two facilities are not the same.

The *Highway Capacity Manual* (HCM) defines a freeway as "a multilane, divided highway having a minimum of two lanes for the exclusive use of traffic in each direction and full control of access and egress" (*2*). The HCM does not define expressway separately. It classifies all highways (including expressways) that have two or more lanes for each direction but lack full control of access simply as multilane highways.

In this paper all references to those two types of facilities are consistent with the definitions cited. These references are made without regard to the actual local names (such as parkway, shortway, tollway, throughway, turnpike, etc.) that highways of these two types might have.

FREEWAYS

When contemplating ETB operation on freeways, one must address operating speed. Virtually all freeways are designed for speeds of at least 81 km/hr (50 mph) with most designed for more than 110 km/hr. At present in urban areas, where ETBs would most likely operate, maximum speed limits are set at 89 km/hr (55 mph) in the United States. However, it is by no means certain that those limits will not be increased. So, if trolleybuses are to operate on these facilities they should be designed to run at speeds of at least 90 and possibly 105 km/hr (65 mph).

Fundamentally the ETB is a bus, and buses are already designed to travel at 110 km/hr. The only differences between the two vehicles are the source of mechanical power (electric motor versus internal combustion engine) and the need for the ETB to collect electrical current from overhead wires.

Looking first at mechanical power, electric motors already move passenger trains at more than 200 km/hr in the Northeast Corridor and much, much faster in Europe and Japan. The ability of an electric motor to move a trolleybus at 105 km/hr would appear to be without question.

Electrical current collection is a different matter. Virtually every ETB operation in the world uses a pair of roof-mounted poles topped by sliding, grooved collector shoes to connect the vehicles' motors electrically with the bottom side of a pair of contact wires suspended about 5.5 m above the surface of the road. Thus, it would appear that, by either design or circumstance, the ETB operating authorities around the world have adopted a de facto standard technology for collecting current. It is not likely that the basics of this time-tested technology will change soon unless a very cogent reason emerges. This does not preclude further refinement and improvement of its design.

This then leads to the question of the ability of this current collection system to function reliably at, or close to, 105 km/hr. In an attempt to answer this, it appears logical to look at another mode that has successfully collected power from an overhead trolley wire by means of a pole and sliding shoe at high speed, the once common interurban electric railway. ETB poles and collector shoes are very similar, but not identical, to those that were used by most interurban railway cars in the first half of this century and many of those cars operated at substantial speeds. As an example, those that ran between Chicago and Milwaukee routinely reached speeds in excess of 140 km/hr. Therefore, at first view, it would appear that current collection by trolley pole and shoe for 105-km/hr trolleybuses should be feasible, but that may not be so.

By the nature of its design a rail car follows a precise and absolutely predictable path (Figure 1, *left*). No skill on the part of the operator is required to achieve this. The horizontal angle between the pole and the contact wire at any given point along the line is always exactly the same, 0 degrees where the alignment is tangent and within a very few degrees of that on a curve. The collector shoe is designed to rotate in a vertical plane to accommodate varying wire height, but because its horizontal orientation to the wire is always essentially parallel, there is no need for it to rotate in a horizontal plane. Therefore, it is fixed in the same vertical plane as the pole to which it is attached.

On the other hand, an ETB does not follow a precise path (Figure 1, *right*). It is designed to operate up to about 4 m (nominally one traffic lane) to either side of the center of the overhead wires feeding it. To accommodate this, the collector shoes are not rigidly attached in either plane. They swivel not just in a vertical plane to accommodate varying wire height, but also in a horizontal plane so that the groove in the shoe can remain parallel with the wire even when the pole is not (Figure 2).

With both modes a special device must be incorporated into the overhead wiring at the junction of routes. This device, called a frog, serves two purposes. One is to connect mechanically the three wires, and the other is to guide each collector shoe from the wire on the route it is leaving to that of the route it is joining.

For rail cars the frog is a simple passive device. It is attached to the underside of the wires being joined and has grooves that act as a guideway for the top edge of the two sides of the collector shoe as it rides off of one wire and onto another. Because the shoe is locked in the same vertical plane as the pole, its edges are inherently aimed toward whichever set of grooves leads in the direction that the car is proceeding.

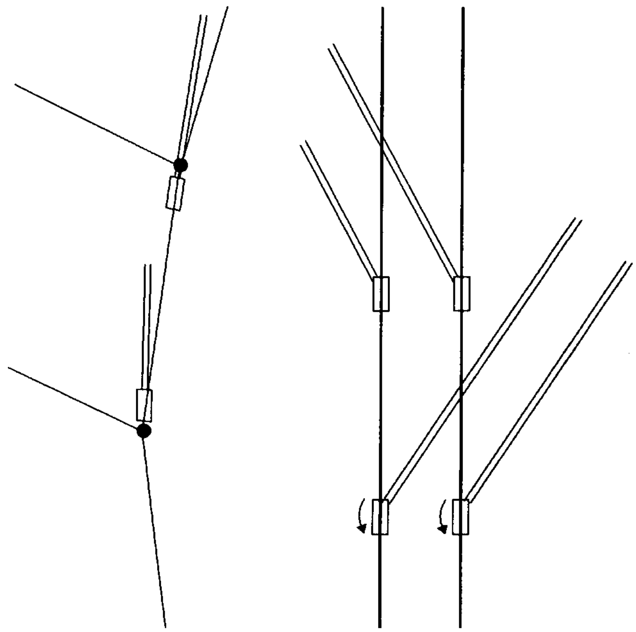

FIGURE 1 Angle between trolley pole and wire: *left*, rail car; *right*, trolleybus.

As a result of its ability to rotate horizontally, the collector shoe on an ETB is not automatically turned into a diverging path and will generally remain aimed straight ahead even when the pole to which it is attached begins to turn. Thus, the passive rail car–type frog is not usable. A trolleybus frog is an active device in which a guide bar is rotated by a solenoid or motor to direct the shoe onto the correct wire. To minimize the size and weight of the frog the length of this bar is kept short. This necessitates a significant angular difference between the two positions and that requires very slow operation of the shoe through the frog when it is set in the diverging position. A redesign of the frog perhaps using much longer guide bars to permit a higher linear shoe speed is a possibility. Reportedly, prototype hardware has been developed in Europe to accommodate collector shoe speeds of up to 80 km/hr. However, in its present North American form an ETB diverging from a freeway lane would have to slow to as low as 30 km/hr to avoid dewirement. In a traffic stream moving at just under 90 km/hr this would be hazardous.

Even on plain wire the dynamics of current collection of the two modes is different. An ETB collector shoe would have a

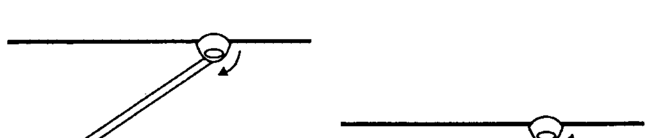

FIGURE 2 Vertical angle between trolley pole and wire.

greater tendency to dewire than that of a rail car at any given speed. Whenever the body of a moving trolleybus is not directly under the center of the wires, the angular forward force from the pole and the rearward parallel force from the friction of shoe-against-wire creates a lateral force component. This force increases with speed, and as it increases so does the tendency for the shoe to dewire. The lack of rigid fixation may also allow the shoe to exhibit some angular vibration in the horizontal plane.

The tendency to dewire would be further increased whenever an ETB driver might find it necessary to swerve suddenly to avoid a collision. The resulting lateral forces could both be increased with freeway operation as compared with local street operation because of the higher speeds. Finally, the probability of dewirement of an ETB compared with a rail car is worsened by the fact that the former has twice as many poles per unit as the latter, doubling the statistical probability of a disabling dewirement. Even if one pole remains on the wire, the flow of current from the overhead wires will still stop.

Thus, on the matter of ETB operation at freeway speeds, the successful experience with high-speed trolley pole current collection by rail vehicles should be studied for ETB application. Perhaps the use of catenary rather than direct suspension trolley wires should be considered. However, at this time the rail car experience should not be taken as conclusive proof that trolleybuses can operate at comparable speeds. Higher ETB operating speeds are potentially feasible, but considerable research and development will be needed to achieve it.

The next matter to be considered is the effect of dewirements. Measures such as limiting vehicle speed and designing an overhead contact system to tolerate higher current collector speeds address the avoidance of dewirements. But it would be as fallacious to assume that a trolleybus would never dewire as it would be to assume that an internal combustion engine would never run out of fuel or otherwise fail. The problem of dewirements on a freeway must be fully considered.

A design feature that would help address this problem is the addition of an auxiliary power unit (APU) to ETBs assigned to freeway service. An APU can be a battery or a small internal combustion engine coupled to a generator. Traditionally, ETBs have not been provided with APUs, but for freeway operation the capability to move after a dewirement could avoid some serious safety problems.

To rewire an ETB at any location, each collector shoe must be moved under its respective wire and then raised. Rewiring can be accomplished from within the vehicle, but to do so it must be positioned directly below the wires at a point where basket-like devices have been installed to catch the top of each pole and guide its shoe accurately into proper contact (Figure 3). If the rewiring is done manually, catch baskets are not needed and the body of the vehicle need not be directly under the wires, but the person manipulating the pole and shoe must be (Figure 4). Obviously, in the case of an unanticipated dewirement on a freeway, manual rewiring would be necessary.

A likely procedure would be to have the driver coast or engage the APU to drive the vehicle onto the shoulder of the freeway and await assistance. Then, under the protection of a police car or other vehicle with appropriate warning devices, the driver would drive the ETB back out into the closest freeway lane with wires, stop, raise the poles manually, disengage the APU, and resume service.

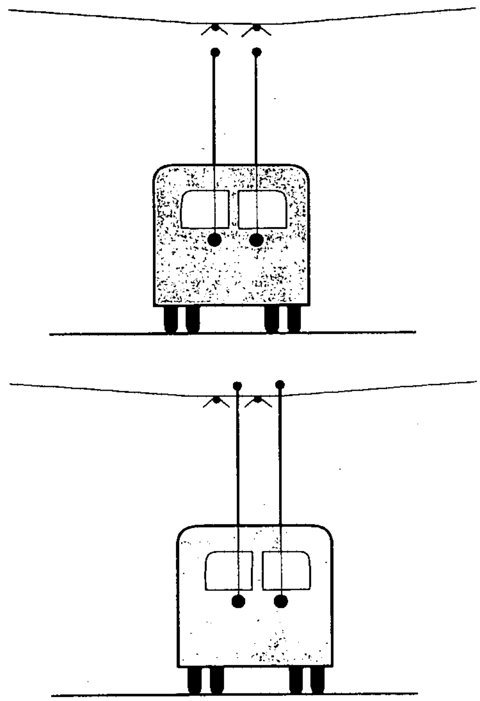

FIGURE 3 Positioning of bus for catch-baskets.

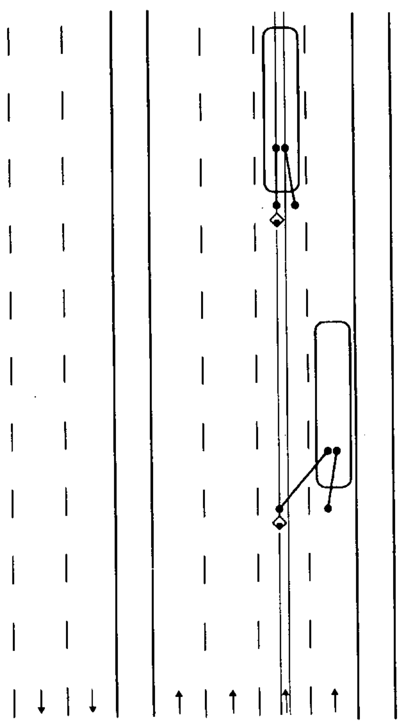

FIGURE 4 Driver standing positions for manual rewiring.

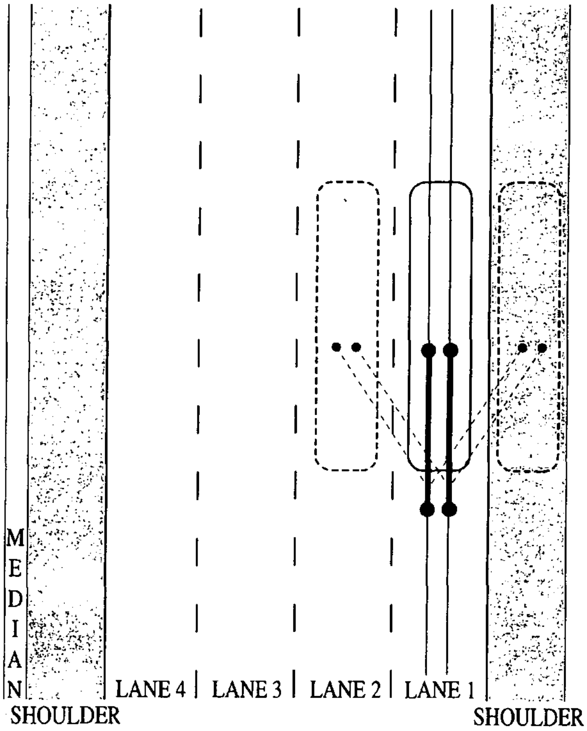

FIGURE 5 Travel lane options: wires over right lane.

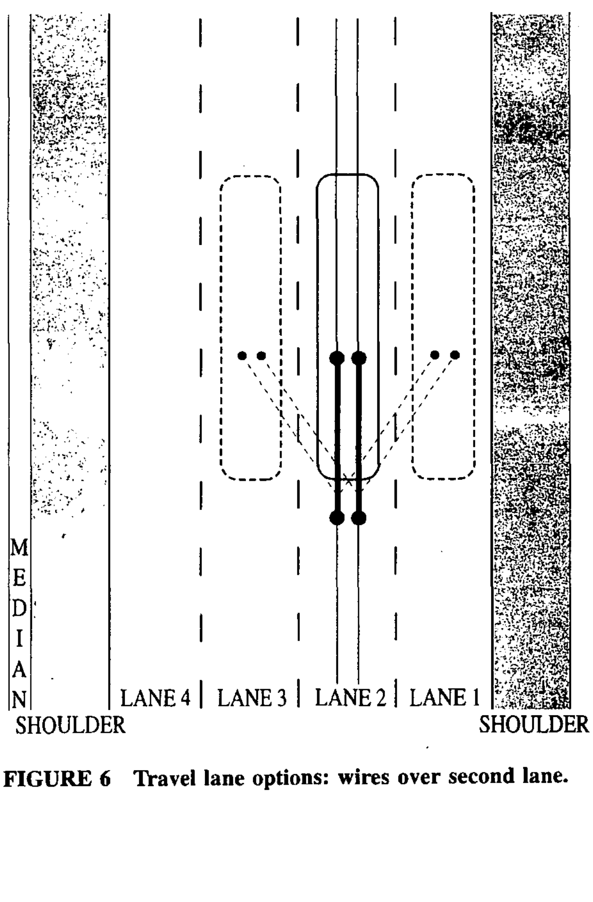

FIGURE 6 Travel lane options: wires over second lane.

Another matter that must be addressed is the positioning of the wires over freeway lanes (Figures 5 and 6). The ETB is designed to operate in the lane over which the wires are placed and in the immediately adjacent lane to the right or to the left of that lane. Traffic lane widths on urban streets are usually in the range of 3 to 3.5 m. On freeways they are 3.65 to 4 m. The additional lateral deviation required by the wider lanes can be mitigated, at least to some extent, by using longer current collection poles. However, there is no apparent possibility of providing for a two-lane deviation from the lane over which the wires are positioned.

For safety reasons a failing trolleybus should have the same access to the shoulder of the freeway as any other vehicle. For a traditional ETB this means that because of the lateral limitations described earlier, the wires must be placed over the extreme right-hand operating lane. As a result, ETB operations on a freeway would have to be limited to the two traffic lanes closest to the shoulder, regardless of how many might actually exist for each direction of traffic flow. From a transit operations viewpoint this restraint is not desirable, but it probably is not serious and certainly not a fatal flaw. However, if all ETBs assigned to freeway routes carry an APU, the immediate proximity of the wires to the shoulder is no longer essential.

The presence of the wires would have several potential adverse effects on other freeway operations, particularly those of high vehicles (Figure 7). The highest vehicle that would likely be permitted on a freeway without a special permit is a double-deck bus with a height of about 4.42 m (14.5 ft). The highest truck should not exceed 4.12 m (13.5 ft). Vehicles of both types could easily pass beneath trolleybus contact wires that are 5.5 m above the road surface. Any span wires or mast arms supporting them would be even higher and so, in theory, the wiring would not create a vertical clearance problem. In practice there could be some problems.

A potential problem would exist if a trolleybus, while operating in the second lane from the right, was overtaken by or overtook a high truck or double-deck bus in the extreme right lane. Since the wires, of necessity, would be over the right-hand lane, the poles on the trolleybus would be "reaching" to the right to follow them. Depending on where (laterally) in their respective lanes the ETB and the high vehicle were, the poles of the former could come into physical contact with the latter. In that situation a dewirement would be virtually unavoidable.

Another factor to be considered is that, in practice, freeways also accommodate overheight loads. Although such movements require advance notice and special permission, possibly including an escort, none of these procedures can circumvent the laws of physics. Overheight loads in excess of about 5.4 m (17 ft 9 in.) would not be able to cross under the ETB wires. Therefore, when entering or leaving the freeway, such loads would be unable to use any ramp that would require passage under the wires (Figures 8 and 9). In extraordinary circumstances (and provided that catenary was not used) those wires could be temporarily raised or severed and reconnected by maintenance forces to allow passage of the overheight load. Needless to say, in those circumstances ETB operation would have to be suspended until the wires were returned to their normal position. Such a service suspension would constitute a major inconvenience to the transit passengers.

Obviously, the occasional movement of an overheight vehicle should not dictate the design of a public transit facility. On the other hand the need to move overheight vehicles on a freeway system from time to time cannot be disregarded. The potential

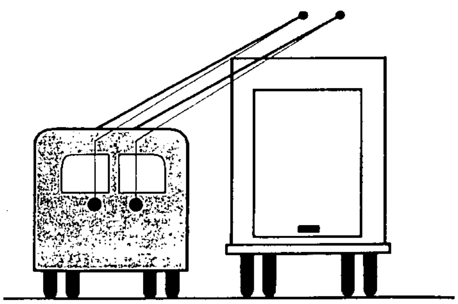

FIGURE 7 Potential physical conflict: high truck in travel lane under wires.

interface of overheight vehicle and ETB operation must be taken into consideration.

These may not be insurmountable problems. Lowering the poles and exiting (but not entering) under APU power might be feasible. If so, the wires at some of the problematic locations could be deleted. Obviously, full and careful consideration will be required when designing the wires at these sensitive locations.

EXPRESSWAYS

Expressways have many characteristics in common with freeways. Obviously, all of the foregoing observations and comments that relate to those common characteristics also apply to ETB operation on expressways and need not be repeated. The following comments address those elements that are not relevant to ETB operation on freeways.

Probably the biggest difference between freeways and expressways is that the latter have some at-grade intersections. These intersections are not universally signalized, although commonly they are. When designing a new expressway ETB operation, if a routing onto or off of an expressway can be at an intersection under signal control rather than at a ramp interchange some of the potential problems associated with ramps discussed earlier would be avoided. However, if that would require an overall routing significantly inferior to one that would involve entering and leaving the expressway via ramps, it might be preferable to accept the effects of the ramp option.

Certain expressway interchanges are partially grade separated, with some of the through lanes overpassing or underpassing the intersecting street and others crossing at grade. Generally these are accompanied by slip ramps in advance and beyond to allow traffic to move between the grade separated "express" lanes and the "local" lanes that cross intersecting streets at grade.

An expressway ETB line having no need to enter or exit at such an interchange could be routed along either set of lanes. Selecting the at-grade lanes would offer the opportunity to provide a passenger stop. It would also provide a potential connection to a future intersecting trolleybus line. Selecting the grade-separated lanes would bypass the traffic signals and avoid delay. However, since the wires probably would initially lead into and eventually lead from the local lanes, this would require that they be routed through the slip ramps. The incremental time saving of that routing would have to be weighed against the problems generated by weaving across the local lanes, through a slip ramp, then back through another slip ramp and back across the local lanes. The

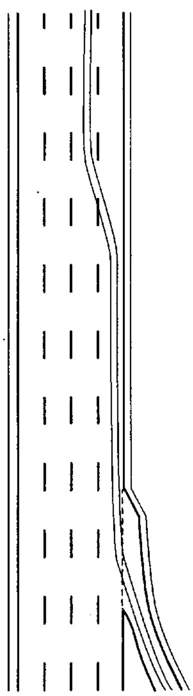

FIGURE 8 Wire configuration, on-ramp from right.

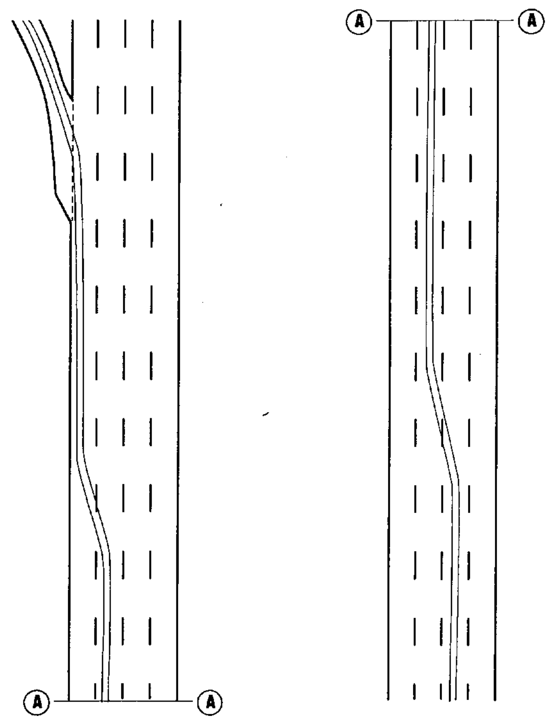

FIGURE 9 Wire configuration, off-ramp to left.

disadvantages of using the grade-separated lanes of an expressway could outweigh the advantages.

SUMMARY

When the electric trolleybus first appeared in the 1920s there was no such thing as a freeway. Today, seven decades later, these marvels of roadway engineering are an integral part of the street and highway system of virtually every North American city. Freeways will be with us for a long time.

Now, there is renewed interest in the electric trolleybus as an urban transit mode. How large a role it will play remains to be seen. Certainly its chances will be enhanced if new applications are considered. Operation on freeways (and also expressways and parkways) is one of those applications.

The foregoing, as indicated at the outset, is not an in-depth study of the ramifications of freeway trolleybus operation. Neither is it, nor was it intended to be, conclusive. It identifies some serious concerns but finds no generalized fatal flaws.

At a minimum, current collection equipment must be perfected or redesigned to accommodate higher operating speeds and practical APUs need to be developed. More detailed studies are needed and demonstration installations on a test roadway or even on actual freeways should be considered as an inescapable element of those studies. Much work lies ahead.

REFERENCES

1. *Manual on Uniform Traffic Control Devices.* FHWA, U.S. Department of Transportation, 1978.
2. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.

Publication of this paper sponsored by Committee on Bus Transit Systems.