



# Low Speed Maglev Technology Development Program

U.S. Department  
of Transportation

**Federal Transit  
Administration**

**March 2002  
Final Report**



**OFFICE OF RESEARCH, DEMONSTRATION, AND INNOVATION**

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# **Low Speed Maglev Technology Development Program**

*Final Report*

**March 2002**

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**Report Number:**

**DOT-CA-26-7025-02.1  
GA-A23928**

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**REPORT DOCUMENTATION PAGE**Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

March 2002

3. REPORT TYPE AND DATES COVERED

Final Report June 2000 – Nov 2001

4. TITLE AND SUBTITLE

Low Speed Maglev Technology Development Program

5. FUNDING NUMBERS

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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REPORT NUMBER

GA-A23928

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Department of Transportation, Federal Transit Administration,  
Office of Technology, 400 Seventh Street, SW, Washington, DC 2059010. SPONSORING/MONITORING  
AGENCY REPORT NUMBER

FTA-CA-26-7025-02.1

11. SUPPLEMENTARY NOTES

This is a Web Document, available on FTA website (<http://www.fta.dot.gov>)

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Available From: National Technical Information Service/NTIS, Springfield, Virginia,  
22161. Phone 703.605.6000, Fax 703.605.6900, Email [orders@ntis.fedworld.gov]

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The overall objective of the Low Speed Maglev Technology Development Program was to develop magnetic levitation technology that is a cost-effective, reliable and environmentally sound transit option for urban mass transportation in the United States.

Magnetically levitated vehicles offer a number of benefits over traditional urban transit options, such as buses, light rail lines, subway systems, etc. Maglev vehicles are a quiet, safe, and efficient alternative, which enables city planners to place a transit system where it is most needed. Maglev technology offers a revolutionary solution to relieve congestion in highly populated urban and surrounding metropolitan areas.

This report summarizes an assessment of maglev development status, provides the results of a number of trade studies performed by the General Atomics team. It also provides a summary of urban maglev design requirements, and a description of a system meeting these requirements. In addition, an engineering and construction schedule for the selected system is provided, as well as a budgetary cost estimate. An outline of a commercialization plan is presented.

14. SUBJECT TERMS

Maglev, Magnetic Levitation, Low-Speed, Urban

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY  
CLASSIFICATION  
OF REPORT

Unclassified

18. SECURITY  
CLASSIFICATION  
OF THIS PAGE

Unclassified

19. SECURITY  
CLASSIFICATION  
OF ABSTRACT

Unclassified

20. LIMITATION OF ABSTRACT

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# Acknowledgment

This report presents the results of a research effort undertaken by General Atomics under Cooperative Agreement No CA-26-7025 to the Office of Research, Demonstration, and Innovation, Federal Transit Administration (FTA). This work was funded by the U. S. Department of Transportation, Federal Transit Administration's Office of Technology. The interest, insight, and advice of Mr. Venkat Pindiprolu and Mr. Quan Kwan of the Federal Transit Administration are gratefully acknowledged.

The valuable comments provided by the representatives of transit agencies, research institutes, and other independent organizations are gratefully acknowledged. Special thanks are due to George Anagnostopoulos of the DOT-Volpe Center, Jim Guarre of BERGER/ABAM Engineers Inc., John Harding of DOT-FRA, David Keever and Roger Hoopengardner of SAIC, Frank Raposa of Raposa Enterprises, and Marc Thompson of Thompson Consulting, for their valuable comments during the period of this effort.

General Atomics also acknowledges the support of a number of subcontractor corporations and other entities, who are team members in this activity. They include Booz-Allen Hamilton, Inc., Carnegie Mellon University, Hall Industries, Inc, Lawrence Livermore National Laboratory, Mackin Engineering, Inc, P.J. Dick, Inc., Sargent Electric, Inc., Union Switch and Signal, Inc., U.S. Maglev Development Corporation, and the Pennsylvania Department of Transportation.

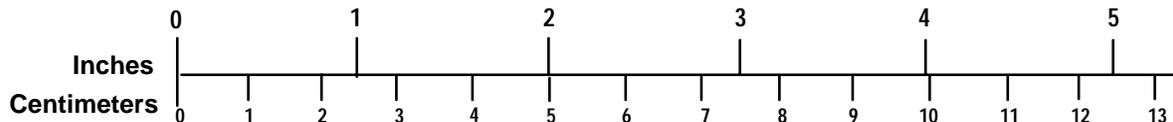
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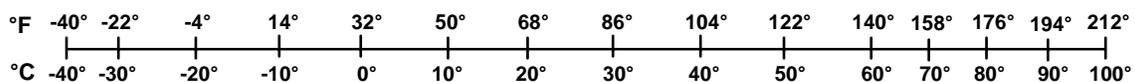
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Updated 6/17/98

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# 1. Introduction

The overall objective of the General Atomics Low Speed Maglev Technology Development Program (Urban Maglev) was to develop magnetic levitation technology that will be a cost-effective, reliable, energy-efficient and environmentally sound option for urban mass transportation. The system baseline represent a refinement that evolved from existing maglev technologies and the efforts during this program by both the General Atomics and FTA teams. The resulting system offers great simplicity in its design, operation, and capabilities. The vehicle glides silently on an elevated guideway, with an entirely passive levitation system, and efficient propulsion system (Figure 1-1). Because the vehicle has no moving parts in its levitation and propulsion system, the reliability is very high and the operational maintenance costs are low. The ability of the vehicle to negotiate a 18.3-m (60-ft) radius turn and climb grades greater than 10%, coupled with its quiet operation, provide planners great flexibility in selecting the alignment that can most efficiently and cost-effectively serve their needs. The modular construction also allows easy system expansion, including the operation of additional vehicles as passenger throughput requirements increase with time.

In this final report, we provide an overview of the progress made during the 18 months of the General Atomics Low Speed Maglev Technology Development Program.



**Figure 1-1**  
**Urban Maglev System**

## 1.1 BACKGROUND

Maglev is the generic label for a family of technologies, including magnetic suspension, guidance and propulsion with linear motor drives for guided transportation applications. The idea of magnetically levitating, propelling and guiding vehicles was invented to overcome the problems associated with conventional trains using wheel-on-rail technology. Conventional trains have been in commercial service for over 150 years. In spite of this long history, these systems have not changed much. All of the major components, including the primary suspension and guidance (steel wheel on steel rail), and the propulsion (using adhesion between the wheel and rail) have basically remained unchanged. These wheel-on-rail systems have been used as the reference point for maglev systems from the very first day. Some of the major characteristics of the two suspension approaches are compared in Table 1-1.

**Table 1-1  
Comparison Between Conventional and Maglev Suspensions**

<b>Wheel-on-Rail Suspension</b>	<b>Magnetic Suspension</b>
Point contact	Non-contact, large area footprint
Suspension, propulsion depend on wheel to rail adhesion	Non-contact suspension and propulsion
Velocity limited adhesion	Minimal velocity dependence

The major hurdles of the wheel-on-rail system are: (1) speed and acceleration are limited by the adhesion between wheel and rail, (2) high noise and vibration are generated by the contact between wheel and rail, and (3) excessive maintenance is required for both wheels and rail. Maglev overcomes these major hurdles by using a non-contacting system for levitation and propulsion. This non-contacting system allows higher speeds, and virtually eliminates noise, vibration and maintenance.

A number of maglev systems have been developed and demonstrated worldwide. These systems can be categorized primarily by the type of levitation and propulsion systems employed.

For the levitation system, either attractive or repulsive forces between the magnet and guideway can be used. An attractive suspension is inherently unstable and requires precise levitation control to maintain the gap between the magnets and guide rail. Repulsive suspensions, on the other hand, are inherently stable and do not need active levitation control. However, it typically requires higher magnetic fields and vehicle motion to generate strong repulsive forces. The attractive suspension is generally achieved with conventional electromagnets and is referred to as electromagnetic suspension (EMS). Repulsive suspensions are referred to as electrodynamic suspension (EDS) due to the motion of the vehicle required for the levitation. Advantages of EMS systems include controlled levitation at standstill and low induced magnetic drag while moving. Potential disadvantages of EMS systems are the small air gap allowed and the reliability associated with the levitation system. The advantages of the EDS systems are the inherent

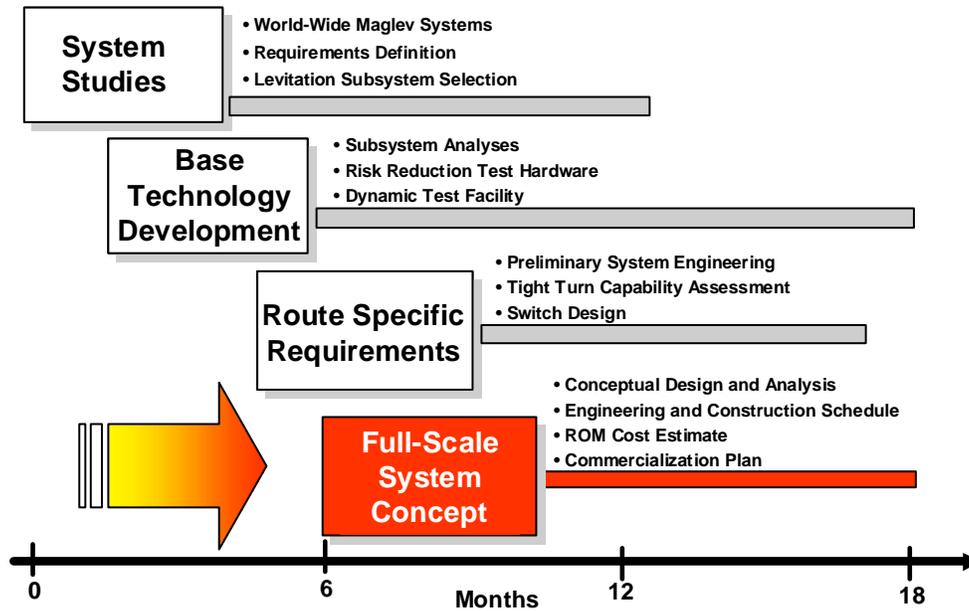
magnetic stability of the suspension and the ability to provide large gap levitation. Potential disadvantages of the EDS systems include the potential for high magnetic drag forces due to the currents induced in the guideway by the levitation, the associated leakage of magnetic fields into the passenger compartment, and possible poor ride quality due to the under-damped nature of the primary magnetic suspension. Our design minimizes these effects, while emphasizing the “enabling” features of an EDS maglev system, including large air gap, very tight turn radius, high grade-climbing capability and all-weather/quiet operation.

For maglev system propulsion, linear motors are generally employed. Two types of linear motor topologies are used: linear induction motors (LIM) and linear synchronous motors (LSM). A LIM is driven by a vehicle-mounted primary coil, which induces currents in passive guideway plates. LSM systems are driven by primary coils installed on the guideway, and energized in synchronization with the motion of the vehicle. The field generated by the coils interacts with the magnetic field of the levitation coils to produce thrust. The choice between LIM and LSM propulsion is driven by the specific application. A LIM-driven system results in a heavier and more expensive vehicle system, but typically a simpler and cheaper guideway. LSM driven systems result in a more complicated (and potentially more expensive) guideway, with considerably lighter and less expensive vehicle systems. The choice between the two approaches requires a top-level systems analysis to ascertain which approach results in the lowest system life-cycle cost (including both capital and operating costs).

Magnet technology has also progressed during the development of the EDS and EMS levitation approaches. EMS systems all use conventional electromagnets to provide the attractive forces and thus can operate efficiently only at a small gap (<1 cm). EDS systems can use superconducting magnets for very high lift forces (resulting in ~10 cm gap), as well as permanent magnets if the gap requirements are more modest (2 to 3 cm). Considerable advances have been made in the last decade in more advanced superconductors, better cryogenic systems, as well as rare-earth permanent magnets with very high remnant fields. Recent ideas of using high field permanent magnets in a configuration called a “Halbach array” to further enhance the field on the guideway and to naturally provide a very low field signature in the passenger compartment offer new approaches with the promise of further improving the state-of-the-art.

## **1.2 PURPOSE AND SCOPE**

The FTA Low Speed Maglev Technology Development Program objective is to “develop magnetic levitation technology that is a cost-effective, reliable, energy-efficient, and environmentally sound option for urban mass transportation in the United States”. The principal subsystems investigated include: levitation, propulsion, power supply, communication and controls, guideway, and vehicle. The overall purpose of this initial phase of the Urban Maglev project was focused on four key tasks, as shown in Figure 1-2.



**Figure 1-2**  
**The General Atomics Team Plan**

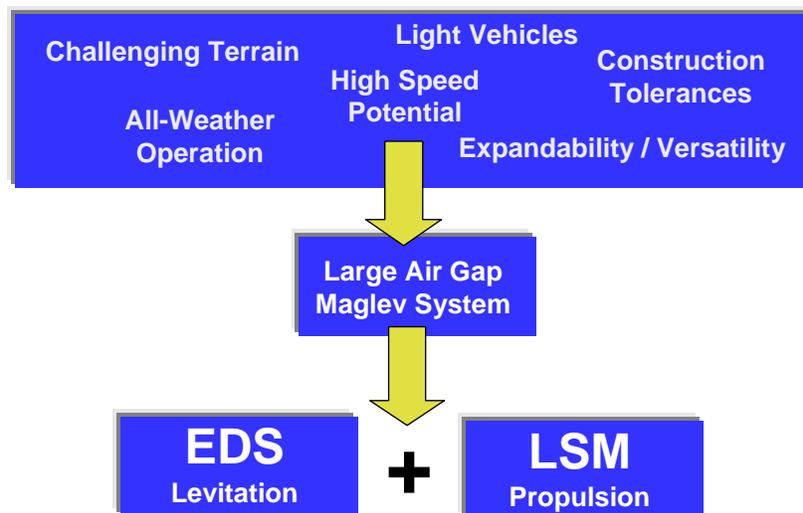
The first sub-task “System Studies” started with review of the state of maglev systems built around the world, followed by a detailed system requirements document. The system requirements document, is divided into three sections: general requirements, alignment description, and specific requirements. A summary of key system parameters is presented in Table 1-2.

This task also evaluated four different levitation subsystems, as well as comparing LIM propulsion with LSM propulsion. The design flow logic for the process which culminated in the selection of an EDS levitation system with a LSM propulsion system is schematically represented in Figure 1-3. The capability of a maglev system to operate with a “large air gap”, in the range of 2.5 cm, provides potential benefits, such as its ability to operate in all weather conditions, as well as being less sensitive to guideway construction tolerances. The result was the selection of permanent magnet Halbach arrays for levitation, and a guideway-mounted LSM for propulsion.

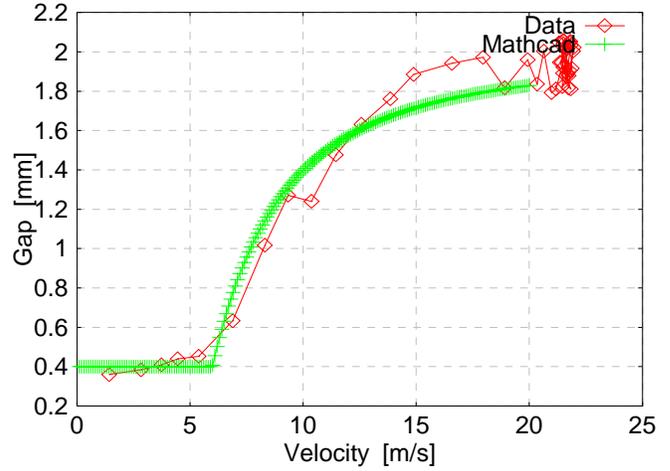
The second task “Base Technology Development” was responsible for a number of risk reduction analyses, as well as building several test articles. Examples of some of the test articles built for reducing technology development risks includes a subscale test wheel to verify levitation physics and development of manufacturing procedures for high quality solder joints in the levitation track system. The subscale test wheel and the resulting levitation test data are shown in Figure 1-4.

**Table 1-2  
Key System Parameters**

<b>System Parameter</b>	<b>Value</b>
Accessibility standards	Americans with Disabilities Act (ADA)
Weather	All-weather operation
Levitation	Permanent magnet Halbach array, passive
Propulsion	Linear synchronous motor
Operation	Fully automatic train control (driverless)
Safety	Automated train control, wraparound feature on the guideway, and restricted access to elevated guideway
Speed, maximum operational	160 km/hr (100 mph)
Speed, average	50 km/hr (31 mph)
Vehicle size	12-m (39.4-ft) long x 2.6-m (8.5-ft) wide x 3-m (9.8-ft) tall
Average power consumption	50 kW
Grade, operating capability	7% (design capability >10%)
Turn radius, design minimum	25.0 m (82 ft), design capability 18.3 m (60 ft)
Size of vehicle (passenger capacity)	AW3 (crush load) capacity: 100 passengers total
Aesthetics philosophy	Guideway will blend with and enhance the environment

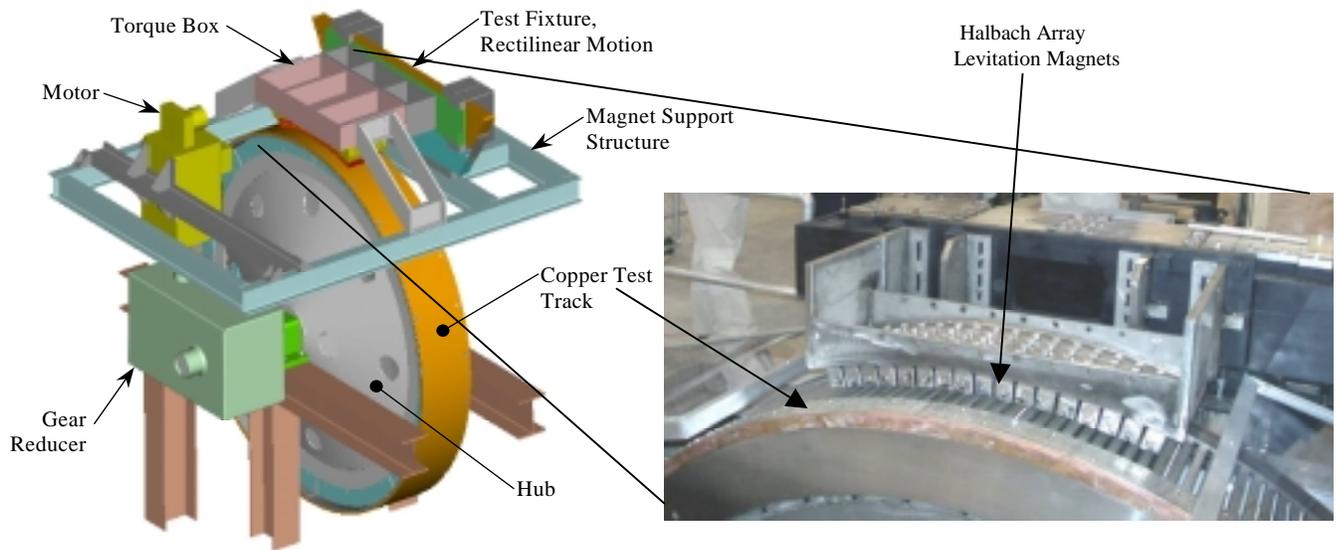


**Figure 1-3  
Design Flow Logic Used in Selecting Key Levitation and Propulsion Subsystems**



**Figure 1-4**  
**Subscale Test Wheel is a Key Example of Risk Reduction Testing**

A major effort in this phase was the design and construction of a Dynamic Test Facility. This facility consists of a 3-m (10-ft) diameter wheel, capable of rotating at speeds up to 160 km/hr (100 mph), and is intended to simulate a relative motion between the vehicle and the guideway. This facility (shown in Figure 1-5) demonstrated the levitation and lift-off characteristics representative of the full-scale magnetic levitation subsystem.



**Figure 1-5**  
**The Dynamic Test Facility is Designed to Test Full-Scale Magnetics and Dynamics**

### **1.3 APPLICATION (PRIMARY ALIGNMENT)**

In order to provide a basis for the Urban Maglev requirements, baseline design, engineering and construction schedule, and cost estimate, a primary alignment was established which was representative of a typical American city.

The Urban Maglev primary alignment considered the following:

- ÷! The ability to be constructed in an urban area with minimum impact to existing transportation facilities, buildings, and the public.
- ÷! The primary goal of connecting existing and future intermodal transportation facilities to activity centers, including commercial centers, education and cultural facilities, hospitals, sports complexes, and similar attractions.
- ÷! A minimum turn radius of 18.3 m (60 ft), which will permit the alignment to be placed in almost any urban situation and minimize impacts to existing buildings and facilities.
- ÷! A minimum sag and crest vertical radius of 1,000 m (3280 ft), which will permit the alignment to be utilized in almost all urban situations without excessive structure and vehicle costs.
- ÷! Turnouts (switches) to increase the flexibility of the alignment, permit emergency pulloffs, and permit access into maintenance and storage facilities.
- ÷! A maximum grade of 10%, which will allow installation in almost any application across the United States.

The horizontal plan and vertical profile of the primary alignment are shown below in Figure 1-6 for a 13.5-km (8.4-mile) alignment with 15 stations.



## 2. Maglev Technology Development

### 2.1 MAGLEV DEVELOPMENT STATUS ASSESSMENT

A chronology of worldwide maglev development is shown in Figure 2-1. This figure shows only those systems that completed technical verification. R&D efforts have been performed for several decades to develop maglev systems with various levitation and propulsion technologies. Many have dropped out after scale model studies and are not shown here. Some succeeded in small-scale commercial operations as public transportation systems but have since stopped operation (M-Bahn and BPM). The four maglev systems shown at the bottom of the figure are in the final stages of testing. The German Transrapid and Japanese HSST have completed verification tests and are certified for commercial operation.

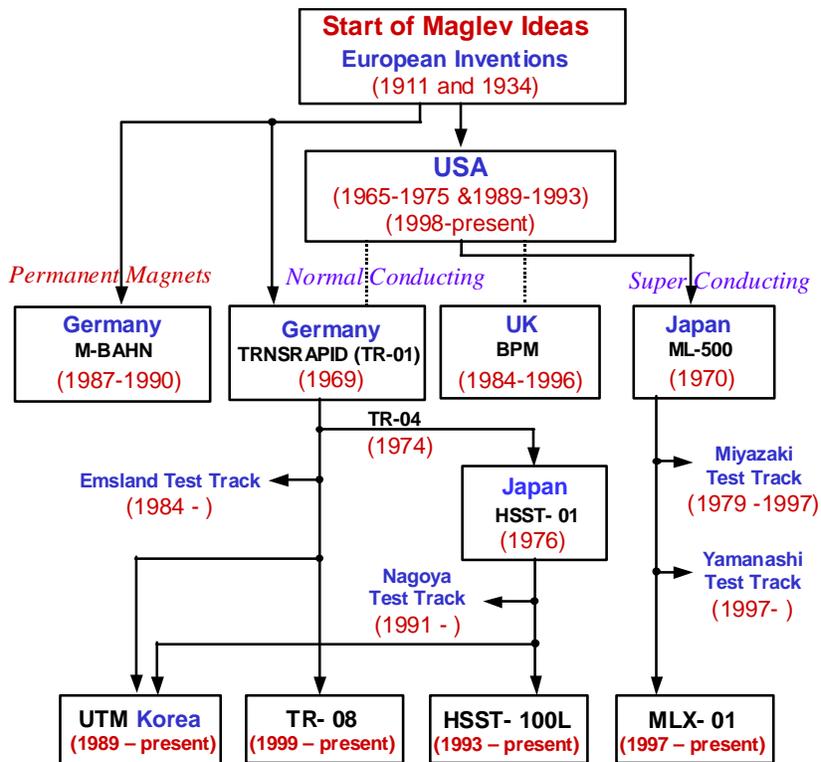


Figure 2-1  
Chronology of Worldwide Maglev Development

### **2.1.1 German Transrapid**

Transrapid began development in 1969. Since 1975, however, the name has been synonymous with German maglev systems. Transrapid is based on EMS levitation and uses a LSM for propulsion. It targets very high-speed (~450 km/hr) applications.

TR05 was the first vehicle developed using the EMS/LSM approach. It was exhibited during the International Transportation Fair at Hamburg in 1979. The TR05 was the first Maglev system approved for passenger service. Encouraged by the exhibition, the German government constructed a high-speed test track (Emsland Test Facility - TVE). TVE was completed in 1987 with a total length of 31.5 km.



**Figure 2-2  
Transrapid Test Vehicle Model TR08**

Transrapid built three test vehicles for the test track (TR06, TR07 and TR08).

Extensive testing was conducted with TR06 and TR07, accumulating over 500,000 km of test operation. TR06 attained a speed of 412.6 km/hr and TR07 reached a speed of 450 km/hr. TR08 is a prototype vehicle for commercial application.

Transrapid started its technology development without a target for commercialization, and has been in active search of an application since 1982. Domestically, Transrapid conducted an extensive study for a Berlin-Hamburg route (300 km) but it could not obtain government approval. Transrapid is now considering shorter and medium speed routes including Munich airport access. Internationally, Transrapid is the main technology option for several maglev deployment projects under consideration in the U.S. (High Speed Maglev). Construction for the Pudong airport access line from Shanghai, China, is in progress with a target operation date in 2003.

### **2.1.2 Japanese Superconducting Maglev**

In 1970, the development of superconducting (SC) EDS maglev started in Japan, only 4 years after James Powell and Gordon Danby of the USA proposed the SC maglev concept. This initial development process maintained very close ties with the U.S. The Japanese system is the only system that adopted SC magnet technology for its levitation and propulsion systems. This EDS/LSM based maglev system was developed for high-speed applications of about 500 km/hr. It uses DC superconducting EDS levitation, with on-board cryogenic equipment.



**Figure 2-3  
Superconducting Maglev Test Vehicle**

accumulated over 70,000 km of test operation by March 2000. The 3-year test results were reported to the Technical Evaluation Committee appointed by the Japanese Ministry of Transport on March 9, 2000. The evaluation found there were no fundamental problems for the system to be commercialized, but it also recommended continued testing to establish the durability and economic aspects of a commercial system. The decision on commercial implementation will be made in 2005.

In the course of development, several test vehicles were built and two test tracks were constructed: Miyazaki and Yamanashi. The Yamanashi test track is planned to be part of a commercial line (New Chuo Line), after completion of testing. The prototype vehicle MLX01 attained a maximum speed of 552 km/hr in April 1999 with a three-vehicle train and had

### **2.1.3 Japanese HSST**

HSST is the acronym for High-Speed Surface Transportation, and also the business name adopted by the HSST Corporation. HSST is a maglev system based on EMS levitation and LIM propulsion, targeting medium speed applications. Between 1990 and 1991, HSST constructed a 1500-m long track for the testing of HSST-100 vehicles. The HSST-100 targets a maximum speed of 100 km/hr.



**Figure 2-4  
Application Vehicle HSST 100L**

In 1995, a “HSST Feasibility Study Committee” consisting of scholars and public officials evaluated test results and concluded that the technology of HSST-100L was ready for commercial application. In the same period, the Japanese Ministry of Transportation evaluated the safety and reliability aspects of the system and confirmed that the system is safe and reliable for public transportation.

HSST Corporation has been seeking opportunities for commercial application of the HSST-100L since 1995. Of several candidate routes, the Nagoya Expo access line was selected for the first commercial application. The 9.2-km line, called the Nagoya Eastern Hillside Line, will be used as an access line to the 2005 Nagoya Expo. After that, it will be used as an access line to the new campus town to be built at and around the Expo site. The project will start test operation in 2004 and commercial operation in 2005.

### **2.1.4 Korean UTM**

The Korean Urban Transit Maglev (UTM), was developed for urban transit applications. UTM is a medium-speed system based on EMS levitation and LIM propulsion. In the course of development, UTM built two vehicles and a 1.3km test track. The UTM01 has been under test operation since 1997 and has accumulated over 20,000 km of test running. UTM has been looking for possible deployment routes since 1997 including the people mover systems at Incheon airport.



**Figure 2-5  
UTM Vehicles**

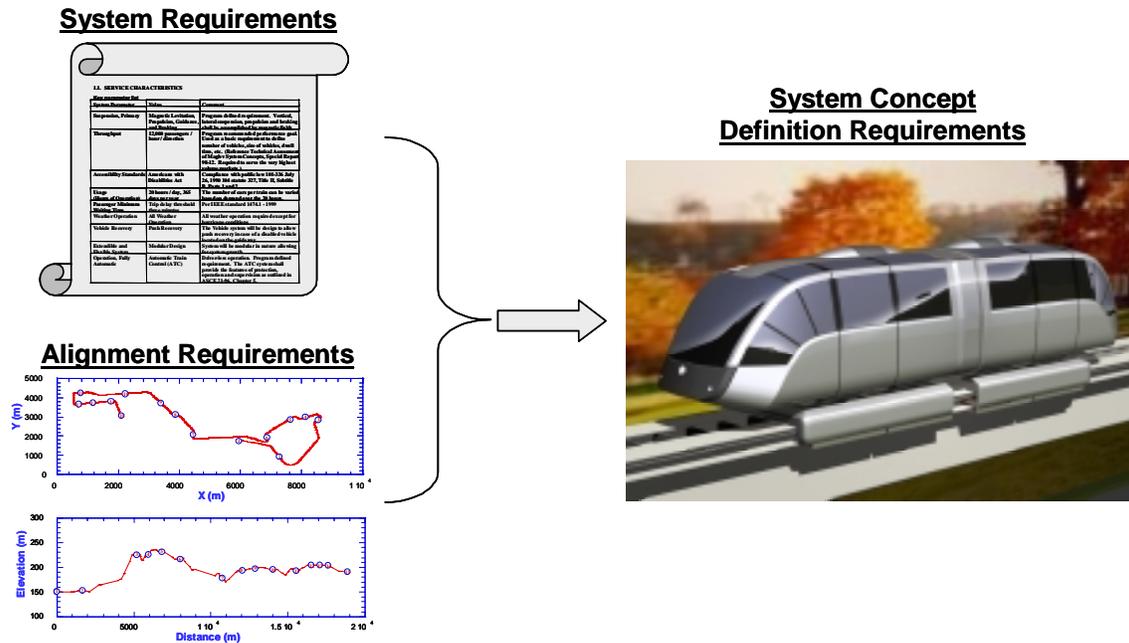
### **2.1.5 Summary**

Development of a transportation technology normally takes a great deal of time and money, mainly because it requires thorough testing to ensure public safety when implemented. The above-described programs are well on the way to demonstrating the safe nature of maglev.

A number of maglev systems are technically ready for implementation. As an example, the Transrapid series of vehicles have accumulated over 500,000 km of operation, the HSST over 150,000 km of operation, and the MLX over 100,000 km of operation. Transrapid may start commercial operation in 2003 in China. The HSST is likely to be in revenue-service in 2005. Although these systems are commendable achievements, the advances in magnet technology since their inception can lead to systems with more attractive features as demonstrated by the General Atomics team.

## 2.2 URBAN MAGLEV DESIGN REQUIREMENTS DEFINITION

In an early phase of the project, the requirements of a low-speed maglev system for an urban setting were studied and documented. This requirements document creates a common set of guidelines, which keep the design team focused during the design process.



**Figure 2-6**  
**Requirements Relationship**

The process of developing a comprehensive requirements document is an evolutionary process. In the initial stages of the program, a set of system constraints was assembled. It defined the preliminary requirements and design constraints used to develop our preliminary maglev concepts.

Next an extensive review of existing requirements, standards and reports was performed to establish a database of information to create the “General Atomics Low Speed Maglev Technology Development Program Requirements Document.” These documents included national and international standards and specifications, handbooks, reports from the FTA and others. With help from the FTA and several members of the Urban Maglev team, the documents were reviewed in detail.

In addition to reviewing existing documents, the special aspects of the Urban Maglev system and specific alignment issues were considered. From this review and many meetings and discussions between the FTA and the Urban Maglev team, a requirements document started to emerge.

The final format was organized into three separate sections:

- ÷! The **System Requirements** section contains the top-level requirements that apply to the design, construction, and operation of a maglev system.
- ÷! The **Alignment Requirements** section includes the requirements that are specific to the selected application and site of the maglev system.
- ÷! Finally, the **System Concept Definition Requirements** section includes the requirements for each of the major subsystems, which make up the maglev system.

A review of General Atomics' final Urban Maglev system baseline reveals that it meets or exceeds each of the requirements defined in the Requirement Document.

The capital system cost is often quoted for various transportation concepts in terms of cost per mile or kilometer. However, direct comparison of these numbers can be very misleading. This is due to inconsistencies in the composition of these costs. In some cases, the cost will include vehicles, stations, and commissioning. However, in most cases the cost per mile does not include these costs. The cost could be for single guideway or dual guideway. If the system uses a LIM instead of a LSM, problems in comparing the cost can occur if the vehicle is not included. The LIM concept will have power electronics and windings that are included in the vehicle, whereas the LSM concept has its power electronics and windings included as part of the guideway. However, if vehicles are included in the cost, then differences in the number and size of the vehicles can complicate this comparison. Therefore, whenever capital cost of the transportation system is quoted it must be qualified by linking it to passenger throughput, with an explanation of the basis.

A review of existing light rail and rubber tire system costs was conducted during this program. The cost estimate for an Urban Maglev system compares favorably with these systems. The results of this study are summarized in Table 2-1. Our Urban Maglev estimates were based on the costs developed from using ridership volume as a figure of merit.

In order to compare the actual system cost of at-grade rail with elevated systems, the cost of an elevated guideway was added. This added cost for the elevated guideway amounts to a total of \$21 million/mile (based on data for elevated guideways). Even with these actual costs, large variations are caused by what was included in the costs. The lower numbers tend to be for extensions to existing systems. These extensions typically do not include costs for such things as maintenance facilities, and communication and control systems, since they were constructed earlier. Light rail systems tend to have drivers, hence the communication and control systems are typically simpler and cheaper.

**Table 2-1  
Cost Summary of Current Transit Technologies**

	<b>Miles</b>	<b>Capital Costs/Mile (\$millions)</b>
<b>Light Rail*</b>		
Average	<b>19.0</b>	63.7**
Lowest	5.3	35.1**
Highest	34.5	173.0**
<b>Rubber Tires***</b>		
Average	4.3	106.8
Lowest	0.7	70.4
Highest	13.4	161.0
<b>Urban Maglev****</b>		
Low Ridership System (<1,000pphd)	8.3	20.1
Medium Ridership System (~3,000pphd)	8.3	56.3
High Ridership System (12,000pphd)	8.3	88.3

\*Based on twelve light rail systems.

\*\*Value adjusted for comparison with elevated system.

\*\*\*Based on four rubber tire systems.

\*\*\*\*pphd=passengers per hour per direction

Light rail is a very mature technology, while rubber tire and especially maglev technologies are new or developing. As rubber tire systems mature, and maglev systems are deployed, the capital costs of both should decrease to levels competitive with light-rail systems.

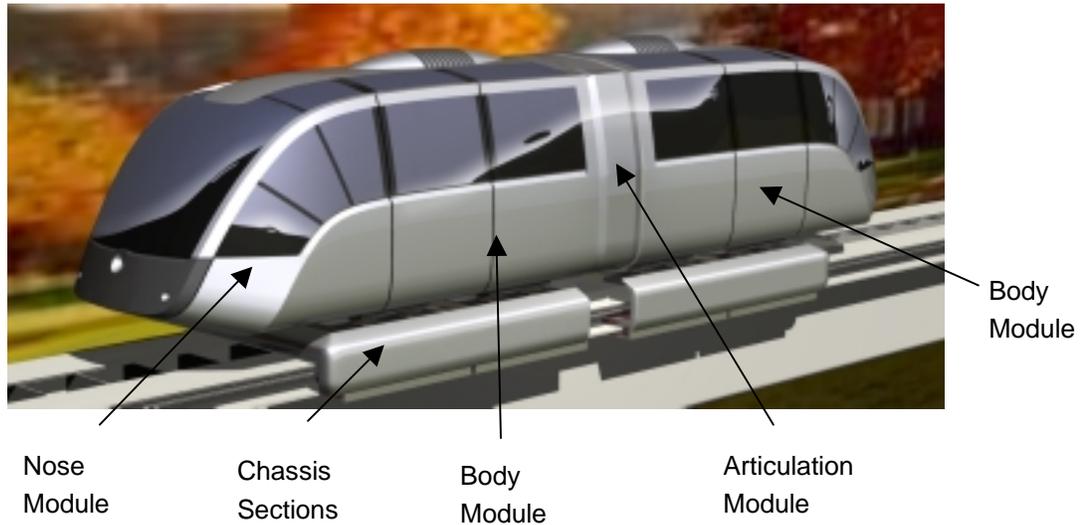
## **2.3 SYSTEM DESCRIPTION**

In the following sections the general concepts and key elements which comprise the Urban Maglev subsystems are discussed in more detail.

### **2.3.1 Vehicle**

The proposed Urban Maglev vehicle is lightweight, quiet, low-maintenance, durable, and low-cost. The 100-passenger vehicle system delivers excellent ride quality, meets safety standards, is environmentally friendly, and is aesthetically pleasing. The vehicle developed for this project is designed to meet the needs of an urban environment.

To meet low-cost and lightweight requirements, the Urban Maglev vehicle is modular in design, as shown in Figure 2-7. The modular approach also offers maximum deployment flexibility. The Urban Maglev vehicle will be constructed of two body modules, one articulation module, and two nose modules to create a vehicle which is 12-m (39.4-ft) long by 2.6-m (8.5-ft) wide and 3-m (9.8-ft) tall.



**Figure 2-7  
Maglev Vehicle**

Under each body module there are chassis modules that provide levitation, propulsion, guidance, braking, and a secondary suspension. Each chassis is split into two sections to negotiate super-elevated curves. The split chassis also allows use of fixed instead of deployable landing wheels, thus minimizing cost and complexity while increasing safety and reliability.

The LSM propulsion system utilizes two chassis-mounted permanent magnet Halbach arrays, interacting with guideway-located windings. Since the active component of the motor is in the guideway, heavy on-board power conditioning equipment for propulsion is not required. Power pickup is required to provide only ~20 kW of housekeeping power.

The levitated vehicle is equipped with three separate braking systems, as required on light-rail vehicles. They are the dynamic LSM service brake, an electromechanical friction service brake, and a permanent magnet fail-safe emergency track brake. Each system will provide up to 0.2 g deceleration. The two friction brakes will react against the steel top surface of the guideway LSM supporting member. Brake operation is unaffected by vehicle weight variations.

The Urban Maglev vehicle is fully automated and driverless. Automatic train control (ATC) and automatic train protection (ATP) is provided by car-borne, wayside, and centrally located sensors and computers.

The aesthetics of the vehicle are designed to project a pleasing, futuristic image that matches the technology. Large, wraparound windows provide a sense of openness and connection with the environment. The vehicle is equipped with HVAC, communications and control, public announcement system, lighting system, passenger comfort features, safety equipment, and doors. Important features that govern the vehicle design include:

- ÷! Passenger interface features and human factors which include such items as: overall styling and aesthetics, large window sizes and good lighting, threshold heights, door and aisle widths, seat width and comfort, handrail locations, rainwater diversion, climate control, ADA requirements, noise transmission, and ride quality. The seating will be designed to meet system owner/operator requirements.
- ÷! Safety concerns, such as overall vehicle strength and fatigue resistance, emergency egress openings, resistance to projectiles, crashworthiness, protection against trip and slipping hazards, vehicle-to-vehicle gap protection, protection against pinch points of any kind, and fire resistance as required by National Fire Protection Association (NFPA) 70 and 130.
- ÷! Operation and maintenance concerns, such as durability, corrosion resistance, clearances, lifting points, equipment access (including access to mounting points), ease of repair and cleaning, and appropriate allowances for wear and deterioration such that the design life is achieved.
- ÷! Environmental operating conditions of the deployment site which shall not cause undue degradation or loss of performance to the vehicle. The vehicle shall have a 30-year design life.

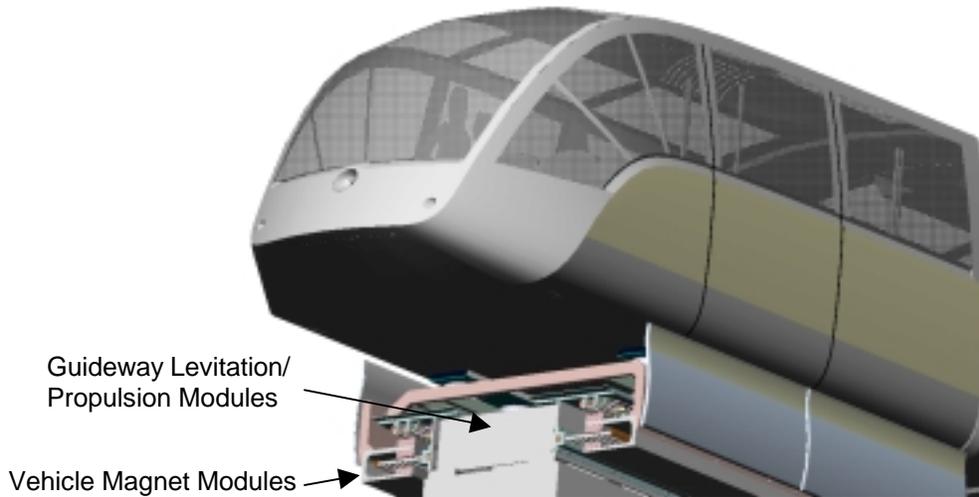
### **2.3.2 Magnet Systems**

The Urban Maglev vehicle hovers above the guideway, supported, aligned and propelled by magnetic forces, with no physical contact. This non-contact feature eliminates contact friction, providing a smooth, quiet ride. With the absence of contact friction, the component wear is virtually eliminated, resulting in an efficient system with significantly reduced maintenance costs as compared to wheeled systems.

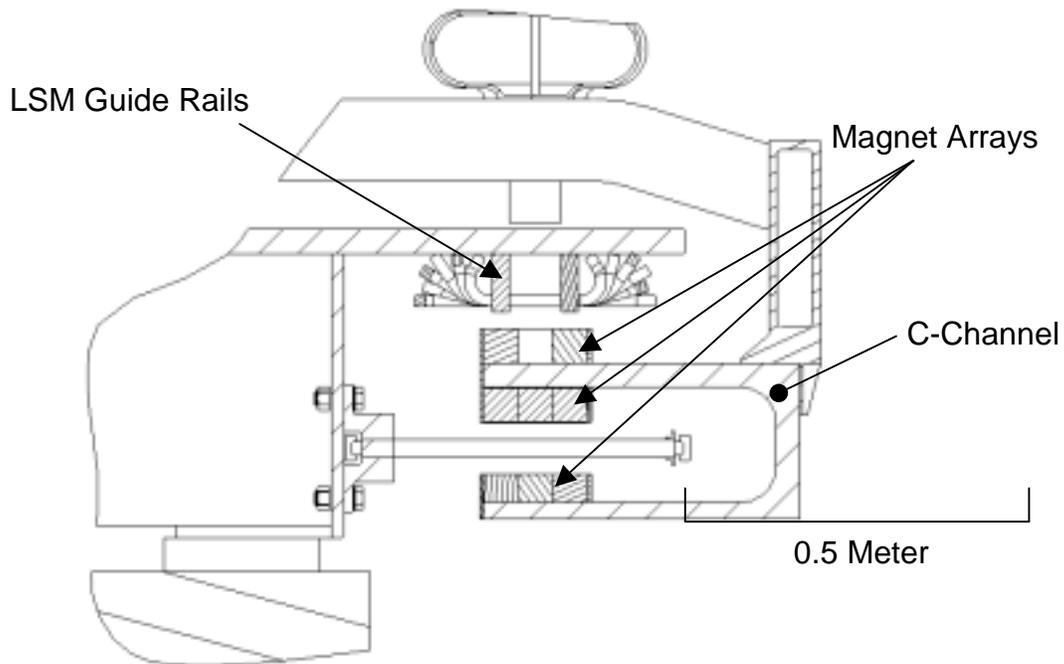
The magnet systems include the vehicle magnet modules and the guideway levitation/propulsion modules (Figure 2-8). The system is inherently safe with its wraparound vehicle design, and passive and stable levitation/guidance system provided by permanent magnet arrays.

The vehicle magnet modules include guidance/propulsion system magnets and levitation system magnets. These magnets are designed to be packaged as assemblies and are supplied to the vehicle manufacturer for integration with the vehicle.

The guideway/levitation modules include the levitation track, LSM propulsion coils, and associated support structure (Figure 2-9). These module designs will be interfaced with the energy supply system for integration with the propulsion system.



**Figure 2-8**  
**Vehicle on Guideway**



**Figure 2-9**  
**Cross-section of Magnet System Assembly**

### **2.3.2.1 Vehicle Magnet Modules**

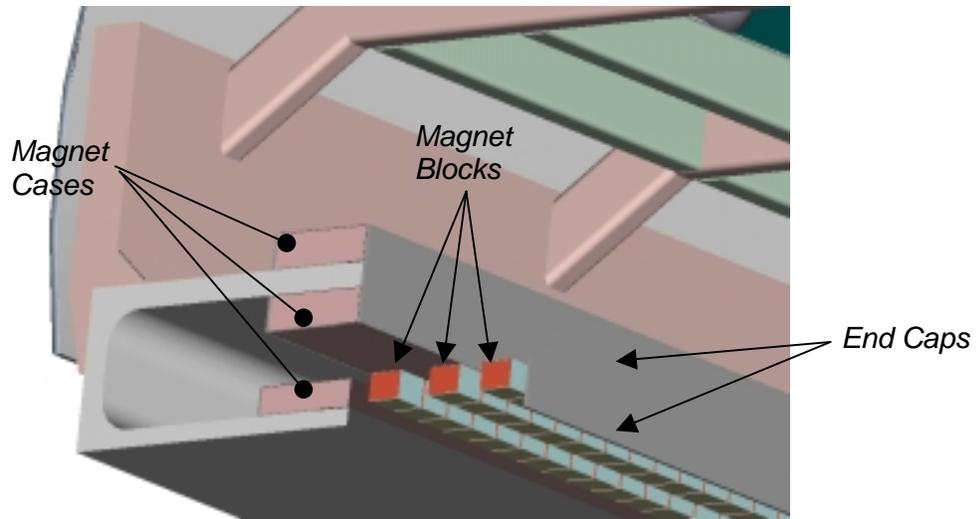
An attribute of the Urban Maglev system is the simplicity and efficiency of the design. The system is passive in nature, meaning that achieving levitation requires no control systems to maintain system stability. Second, the system uses permanent magnets, which are more efficient in their size to field strength ratio than electromagnets, and require no power systems to operate. This yields a system that is much less complicated, less expensive, and more widely adaptable than other maglev systems.

Permanent magnets, in a configuration called a Halbach array, provide increased magnetic field strength for levitation, guidance and propulsion of the vehicle. Originally conceived for scientific experiments and named after inventor Klaus Halbach, Halbach arrays concentrate the magnetic field on the active side, while canceling it on the opposite side. This magnet arrangement, along with other design features of the Urban Maglev system, results in very low magnetic fields in the passenger compartment. In fact, the fields are much lower than other transportation systems that use conventional electric motors.

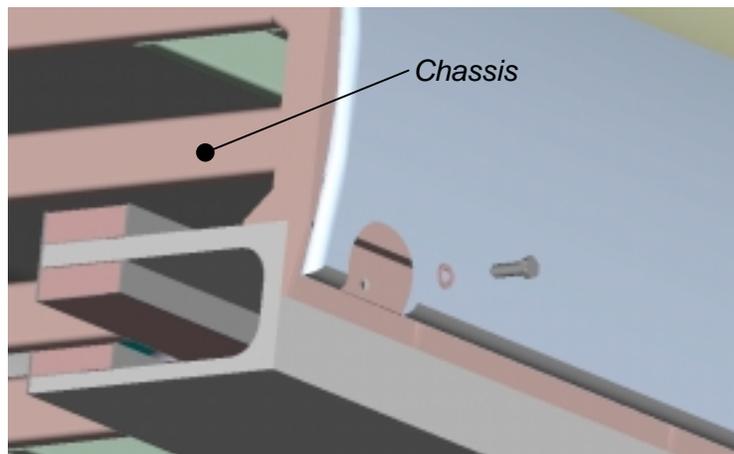
Permanent magnets are widely used in commercial application. For example, the average computer system (PC, printer, monitor) contains over 40 magnetic components. The number increases as more peripherals are added, such as a second CD-ROM drive, DVD drive, and a scanner or laser-jet printer. Also, large quantities of permanent magnets are produced each year for such things as adjustable speed drives, stepper motors, and starters.

The magnet blocks consist of neodymium-iron-boron (NdFeB) rare-earth permanent magnets. The magnet blocks are subdivided into subassemblies that are loaded into the magnet cases, as shown in Figure 2-10. The top set of magnet blocks interacts with the LSM to provide guidance and propulsion. This arrangement, combined with the LSM rails, provides the passive guidance force to keep the vehicle aligned to the guideway. In each subassembly the magnet blocks are placed with their magnetization vectors in the same direction and are contained in a welded, aluminum container. Along the length of the Halbach array, the magnetization vectors rotate in steps of 45 degrees per magnet container subassembly. This rotation of the magnetization vectors provides the Halbach effect, as discussed above, that concentrates the magnetic field lines to increase the lift forces.

To complete the assembly of the Halbach arrays, the channels are then mounted to the chassis supports with removable fasteners, as shown in Figure 2-11.



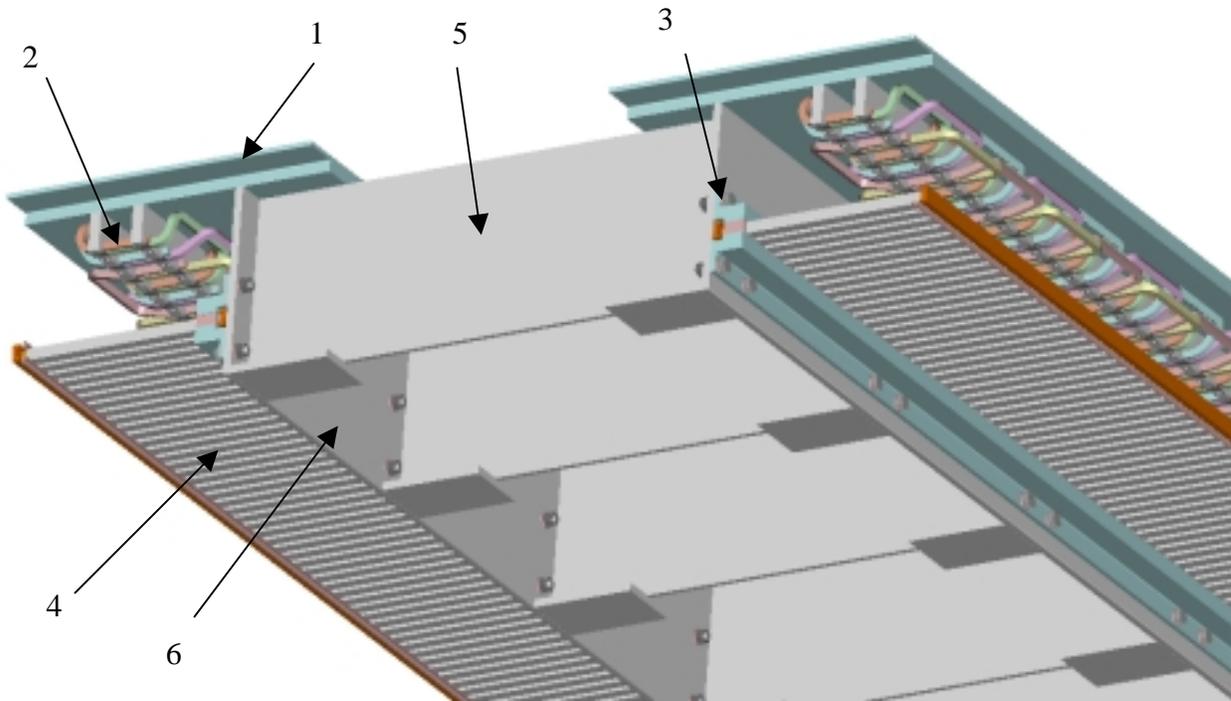
**Figure 2-10**  
**Magnets Inserted into Containers**



**Figure 2-11**  
**Magnet Module Assembly to Vehicle Chassis**

### **2.3.2.2 Guideway Levitation/Propulsion Modules**

As illustrated in Figure 2-12, the guideway module assembly consists of two carbon-steel guideway top plates (1). These plates carry both the LSM assembly (2) and provide the landing surface for the station/emergency wheels. Also, the guideway levitation/propulsion module consists of two stainless steel angle brackets (3), which support the track assemblies (4). Both the LSM top plates and the angle brackets are interconnected with stainless steel guideway frames (5). Running the length of the module on both sides are two stainless steel guideway side plates (6), which are welded to the guideway frames and provide the mounting surface for the track assemblies.



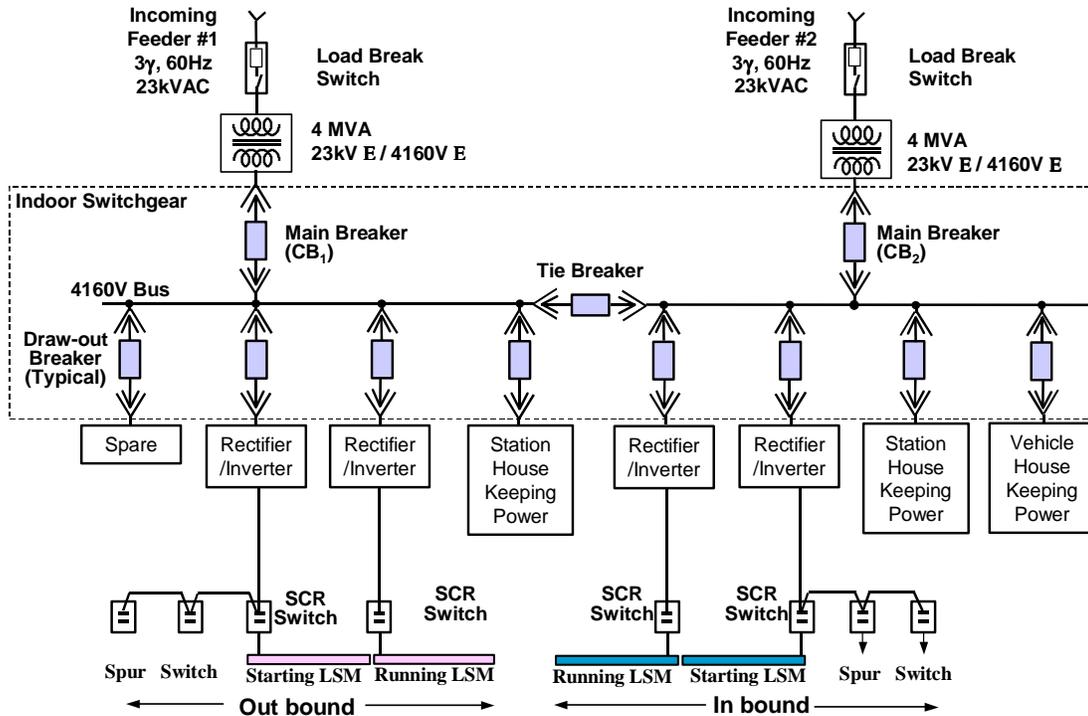
**Figure 2-12**  
**Guideway Levitation/Propulsion Modules**

As the levitation Halbach arrays, which are attached to the vehicle, move above and below the track, electric currents are induced in the track. The interaction of these currents with the magnetic fields, generate the lift forces.

The propulsion system consists of propulsion magnets on the vehicle, the LSM windings on the guideway, and propulsion power supply system in the station building. The propulsion thrust is generated by the LSM from the interaction between induced traveling waves in the winding and the magnetic field generated by the propulsion magnets. The traveling magnetic waves are generated and the speed of the vehicle is controlled by the propulsion power supply system.

### **2.3.3 Power Conditioning and Distribution**

This section presents an overview of the energy supply systems for the Urban Maglev system. Figure 2-13 presents a high-level diagram of the major elements of the system. The main function is to provide power to the vehicle(s) both for propulsion and housekeeping (air conditioning, lights, communication, etc.), to the stations (lights, elevator, etc.), and to the maintenance facility (crane, tools, etc.). The power inverters used to power the track for vehicle propulsion are housed in the stations. This provides a protected, controlled environment for the power equipment, and provides easy access for maintenance.



**Figure 2-13  
High Voltage Distribution Layout**

### 2.3.3.1 Input Power Substation

The Urban Maglev system is assumed to utilize two 12 kV primary power sources (from separate generating stations where possible). The two-source scheme provides additional reliability so that system disturbances or storms are not apt to affect both utility primary sources. This system consists of two primary loops with two three-phase transformers connected on the loop, providing power to each of the two primary loops. Each primary loop is operated such that one of the loop sectionalizing switches are kept open to prevent parallel operation of the sources.

### 2.3.3.2 Maintenance Facility/Station Metal-Clad Switchgear

This system uses duplicate sources from the existing distribution power supply point utilizing two main breakers and a tiebreaker. The two main breakers and tie-breaker will be electrically interlocked to prevent closing all three at the same time and paralleling the sources. Upon loss of voltage on one source, an automatic transfer to the alternate source line will be used to restore power to all station primary loads. This arrangement permits quick restoration of service to all loads when a primary feeder fault occurs by opening the associated main and closing the tiebreaker.

If the loss of secondary voltage has occurred because of a primary utility feeder fault with the associated primary feeder breaker opening, then all secondary loads normally served by the faulted utility feeder would have to be transferred to the opposite utility primary feeder. This

means each primary utility feeder conductor must be sized to carry the combined load of both sides of all the secondary buses it is serving under secondary emergency transfer. If the loss of voltage was due to a failure of one of the utility transformers in the station double-ended switchgear, then the associated primary fuses would blow, thus taking only the failed utility transformer out of service. Then only the secondary loads normally served by the faulted transformer would have to be transferred to the opposite utility transformer.

In either of the above emergency conditions, the in-service utility transformer and the metal-clad switchgear will have to have the capability of serving the loads on both sides of the tiebreaker. For this reason, the service utility transformers will have an equal power MVA rating on each side of the station's double-ended switchgear where the normal operating maximum load on each transformer is typically  $2/3$  base nameplate MVA rating. The utility transformers will be furnished with fan-cooling and rated for lower than normal temperature rise such that under emergency conditions they can carry on a continuous basis the maximum load on both sides of the secondary tiebreaker. Because of this spare transformer capacity, the voltage regulation provided by the double-ended switchgear will increase reliability.

### **2.3.3.3 Power Distribution**

Metal-clad switchgear (Figure 2-14) with vacuum breakers (Figure 2-15) provides centralized control and protection of the medium-voltage power equipment that serves the passenger station's motors, feeder circuits, and transmission and distribution lines. The metal-clad switchgear offers a total design concept of cell, breaker, and auxiliary equipment, that can be assembled in a two-high breaker arrangement. A one-high cell or breaker arrangement can be furnished if required.



**Figure 2-14**  
**Metal-clad Switchgear**



**Figure 2-15**  
**Vacuum Breaker**

Maintenance requirements are minimized by the use of enclosed long-life vacuum interrupters. When maintenance or inspection is required, the component arrangements and drawers allow easy access. The lightweight switchgear simplifies handling and relocation of the breakers. The above switchgear meets or exceeds all applicable ANSI, NEMA, and IEEE design standards.

#### **2.3.3.4 Operating Facility Equipment**

Unitized dry-type power centers are self-contained, metal-enclosed unit substations especially designed to supply and distribute low-voltage power (120/208 V and 277/480 V) from medium-voltage feeder conductors. These power centers (Figure 2-16) will supply power to the elevator, escalator, exhaust fans, communication system, lighting fixtures, and convenience receptacles.



**Figure 2-16**  
**Unitized Power Center**

#### **2.3.3.5 Propulsion Block Equipment**

The power inverter (variable frequency drive) is used to change a DC input voltage to a symmetric AC output voltage and current of desired magnitude and frequency for LSM drives. The propulsion block design architecture uses a four-quadrant inverter, which provides regeneration and dynamic braking capabilities to other inverters. The DC voltage bus ties together in the inverter lineup; any excess energy will be dumped to a resistive load-bank. The resistive load-bank is sheet metal encased with damper motor and fans. During summer operation the excess heat flows to the roof exhaust fan. In winter operation the resistive load-bank provides supplemental heat to the data/communication and station equipment rooms. The

variable frequency drive control software communication capabilities enables the drive to be integrated into a supervisory control and data acquisition (SCADA) system.

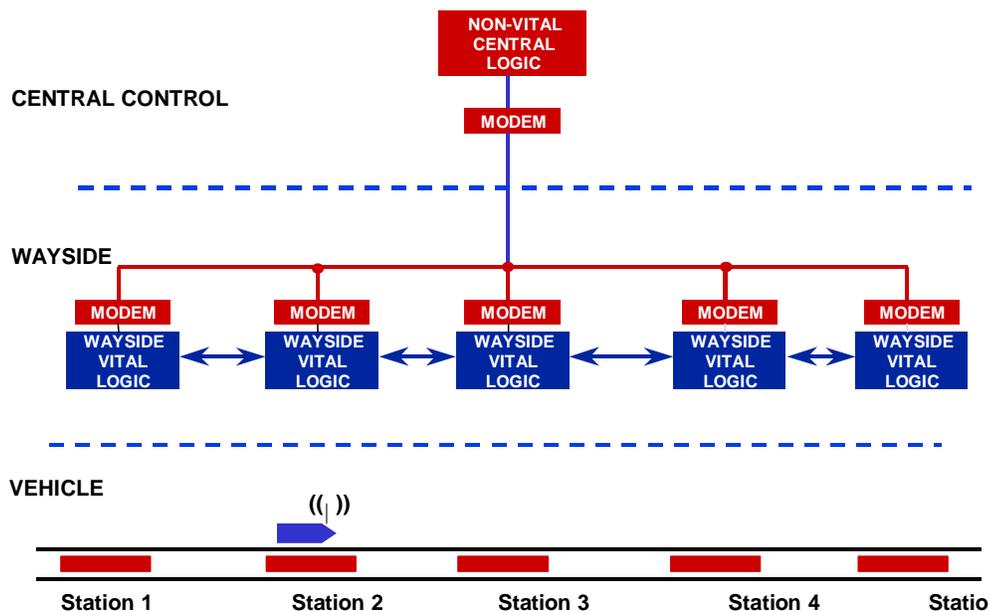
Standard I/O has 24 digital inputs and 16 digital outputs, 4 analog inputs, and 4 analog outputs. The output waveform generated by a multilevel inverter requires minimal filtering. The output current total harmonic distortion will be less than 3%. By reducing the number of power switching devices and using minimal filtering, a high converter efficiency of 98%, and an overall drive efficiency (including input transformer) of greater than 96.5%, is achieved.

### 2.3.3.6 Wayside Equipment

A feed-through three-phase reversing two section (forward and reversing) silicon controller rectifier power switch provides the power and isolated low voltage control from the output of the variable frequency drive to the LSM propulsion blocks. The superstructure propulsion blocks are a passive system such that power is provided to the LSM propulsion block only as the vehicle approaches and passes over that specific LSM propulsion block.

## 2.3.4 Operation, Command, and Control Systems

The baseline architecture for the automatic train control (ATC) system consists of three major components as shown in Figure 2-17. These three components are labeled: wayside, vehicle, and central. This general architecture conforms to a typical train control philosophy. The ATC system uses distributed, vital, and non-vital processor logic.



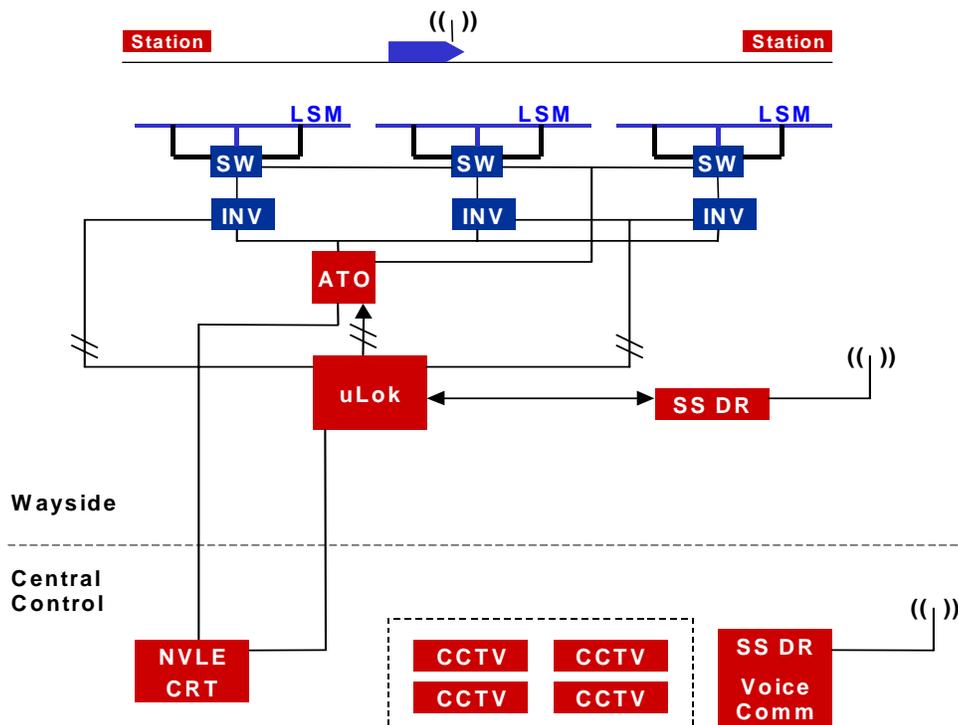
**Figure 2-17**  
**Train Control**

The central control is located at one site and is non-vital. Communications to the distributed wayside devices is through serial links. Each vital wayside processor communicates to a vehicle via data radio. With multiple vehicles operating on the system, an independent train location system is provided via each train inductively shunting the Audio Frequency AF900 track circuits distributed along the guideway.

The equipment onboard the vehicle measures the vehicle's true speed and calculates its location on the guideway. This information is transmitted to a local zone vital train control processor (via data radio) that in turn communicates this data to the zone control inverter by a serial interface. The communications between the vehicle, the vital train control processor, and the zone inverter provides the necessary feedback to ensure each vehicle is following the correct speed profile permitted in a particular zone on the guideway.

### 2.3.4.1 Station Equipment

The typical train control system layout is shown in Figure 2-18. Each LSM located on the guideway is defined as a zone. There is an inverter that supplies energy to each LSM. If multiple vehicles operate on the system, each zone would have two or three inductive track circuits. These track circuits detect the presence of a maglev vehicle.



**Figure 2-18**  
**Train Control System**

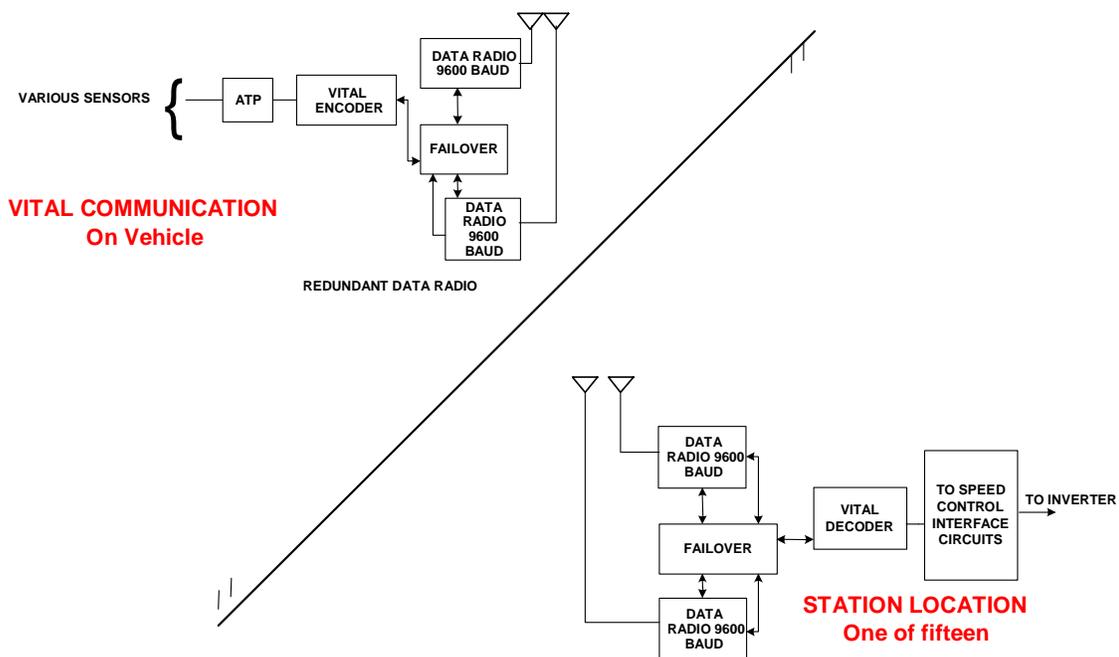
When a vehicle is traversing a control zone, the vehicle communicates its location and speed information to the station equipment via data radio. This communication is bidirectional and is vital. With multiple vehicles, the wayside also detects the presents of a train via the inductive track circuit. These devices provide the closed loop for vitality in locating each vehicle on the system.

Microlok II ( $\mu$ Lok) is a vital processor that communicates with the vehicle and determines if the vehicle is traveling faster than permitted. If the vehicle is traveling faster than permitted (overspeed), the Microlok II system requests that the applicable inverter be shut down.

The automatic train operation (ATO) device controls the inverter so that the vehicle follows a fixed profile as it traverses the guideway.

### 2.3.4.2 Vehicle to Wayside Communications

The block diagram shown in Figure 2-19 illustrates the communications between the vehicle and wayside zone controller. Vital data (e.g., the vehicle's true speed, location, etc.) between the vehicle and wayside is via a data radio. Vitality is obtained using encoding techniques: cyclical redundant code, event numbers, and time stamps. As described elsewhere, this function is backed up via the inductive track circuits.



**Figure 2-19**  
**Vital Communications**

A second communication system (via a second data radio) permits the central dispatcher to view and communicate with passengers on each train.

### 2.3.4.3 Automatic Train Operation (ATO)

The vehicle is passive in that its motion is controlled by the guideway and not by devices onboard the vehicle. The guideway is organized into zones. An inverter controls each zone. Each zone inverter determines the motion of the vehicle via a LSM. Therefore, the zone inverter controls the vehicle's physical motion (i.e., acceleration, deceleration, speed regulation, etc.).

The information collected by each sensor is used to calculate the vehicle's true speed, acceleration ( $''$ ), and position as it traverses a zone. A separate CPU, operating at a clock speed of 100 MHz performs these calculations. An additional processor is used to generate the correct profiles (speed, acceleration, etc.) for each train that is traversing its control zone.

### 2.3.4.4 Central Office

A block diagram of the central office is shown in Figure 2-20.

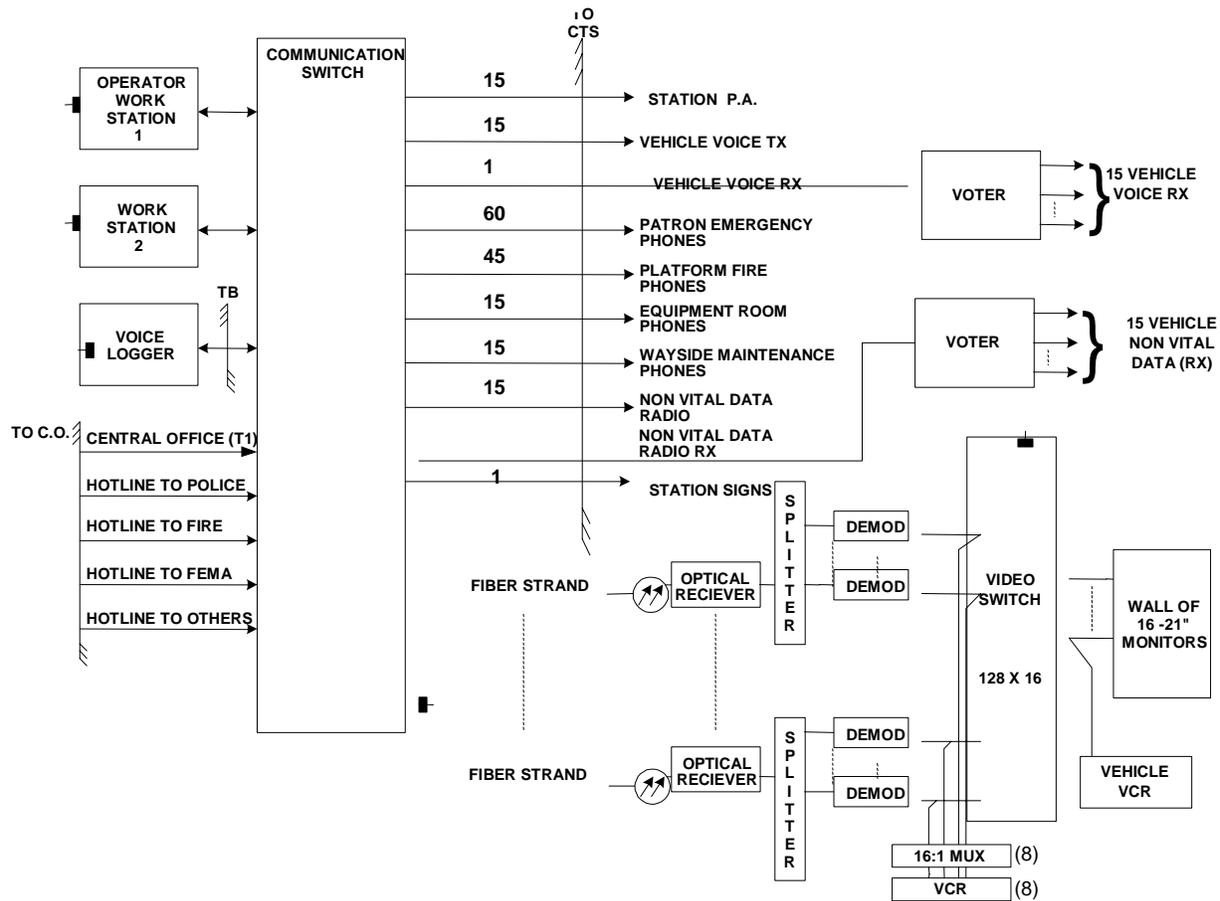


Figure 2-20  
Central Office

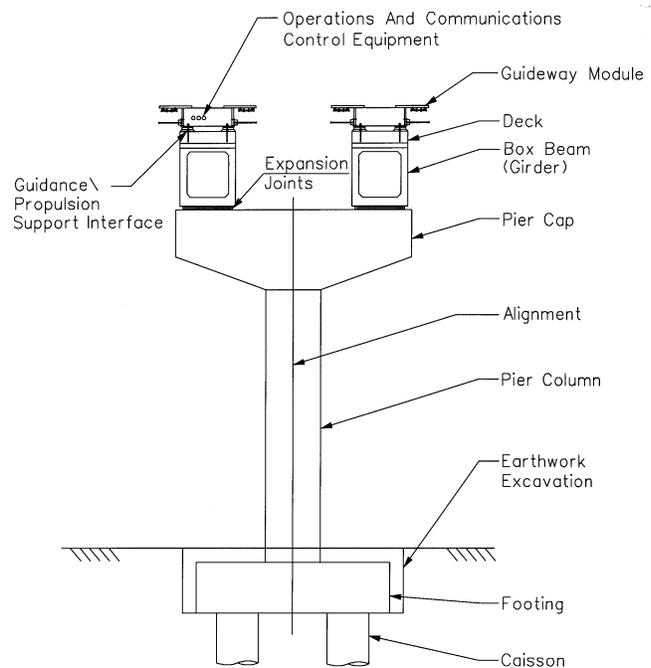
From central, vehicles will be automatically routed through the system. The central dispatcher also has the ability to view and talk to passengers on each vehicle traversing the system.

In addition, a dispatcher at central has the ability to view each station platform by CCTV.

Also, all voice communications via telephones located at all stations and control rooms are routed through the central control room. This function includes telephones and hand-held radios for maintenance personnel.

### 2.3.5 **Guideway, Civil Structures, and Right-Of-Way/Corridor**

An Urban Maglev system is composed of key guideway components which support the vehicle, magnet modules, power systems, and operating and communications control systems, and transport the vehicle to key activity centers throughout the urban area. These components include the alignment itself, the guideway superstructure, substructure, expansion joints and bearings, and switch supporting structure. The Urban Maglev system also includes civil structures that facilitate use of the guideway and operation of the system. These include stations, the operations/maintenance facility; and right-of-way/corridor elements that permit and complement construction of the guideway (right-of-way, utility relocations, roadway modifications, landscaping, demolitions, and environmental mitigation). Together, these components must be designed and constructed to meet the requirements of an Urban Maglev system that mandates economical, efficient construction and minimum disturbance of existing facilities.



**Figure 2-21  
Guideway Components**

These basic requirements include:

- ⇨! Locate the guideway in public right-of-way, to minimize costs and environmental impacts.
- ⇨! Elevate the guideway, to minimize costs and impacts, permit continued use of the area beneath the guideway, and to provide greater safety, security, and lower cost when compared to guideways placed in tunnels.
- ⇨! Accommodate tight turn radii, which will enable the guideway to fit into urban areas with a minimum of impacts and displacements.

- ±! Connect key activity centers and intermodal transportation facilities to reduce congestion and promote maximum usage.
- ±! Minimize impacts to existing facilities both during and following construction.
- ±! Incorporate aesthetics and landscaping to blend with or complement the environment of the surrounding area through which guideways and stations are located.

Following is an overview of the various components that comprise guideway, civil structures, and right-of-way/corridor components, and a discussion of features that enable the system to meet the basic design requirements.

### **2.3.5.1 Earthwork**

The primary earthwork for the construction of the maglev guideway is the excavation and backfill required to construct the footings, including the installation and removal of all required shoring.

To construct each footing, a pit will be excavated 300 mm (12 in.) beyond the edges of the footing. The depth of the excavation will match the depth of the bottom of the footing and will equal the thickness of the footing plus the depth of the original overburden.

Steel trench boxes are fabricated out of plate and structural shapes with inside dimensions that match the width and length of the footing and depth of the deepest excavation. This allows the boxes to function as both shoring and formwork for each footing.

At each footing, the trench box is placed in the excavated pit, its inside surfaces are coated with a bond breaker, the reinforcement cage is installed, and the box filled with concrete. When the concrete has cured, the trench box is loosened from the footing and removed for reuse on another footing. Then the footing is backfilled, graded, and seeded.

### **2.3.5.2 Substructure: Piers, Footings, and Caissons**

The substructure of the maglev guideway consists of three components: the piers, footings, and caissons.

Cast-in-place concrete T-shaped piers constructed out of circular columns and hammerhead caps support the guideway box beams. Cast-in-place rectangular footings, each supported by four caissons, support the piers. The caissons are drilled shafts filled with concrete. The caissons and piers are constructed out of normal weight Class A concrete while the footings are constructed out of normal weight Class AAA concrete.

### **2.3.5.3 Superstructure**

The guideway superstructure consists of two components: (1) the box beams and (2) the levitation, guidance, and propulsion (LGP) modules. One box beam provides a single-track guideway. Two adjacent box beams provide a dual-track guideway.

The precast prestressed concrete box beams with cast-in-place composite concrete decks support the levitation, guidance, and propulsion modules that the maglev vehicles ride on. The box beams and the decks are constructed out of high-strength, structural lightweight concrete.

### **2.3.5.4 Expansion Joints and Bearings**

The guideway is designed for linear expansion and contraction by being attached to the pier at one end and released at the other end. Alternating attachments are repeated at each subsequent beam. Both ends of the beam bear on a 75-mm (3-in.) thick elastomeric pad.

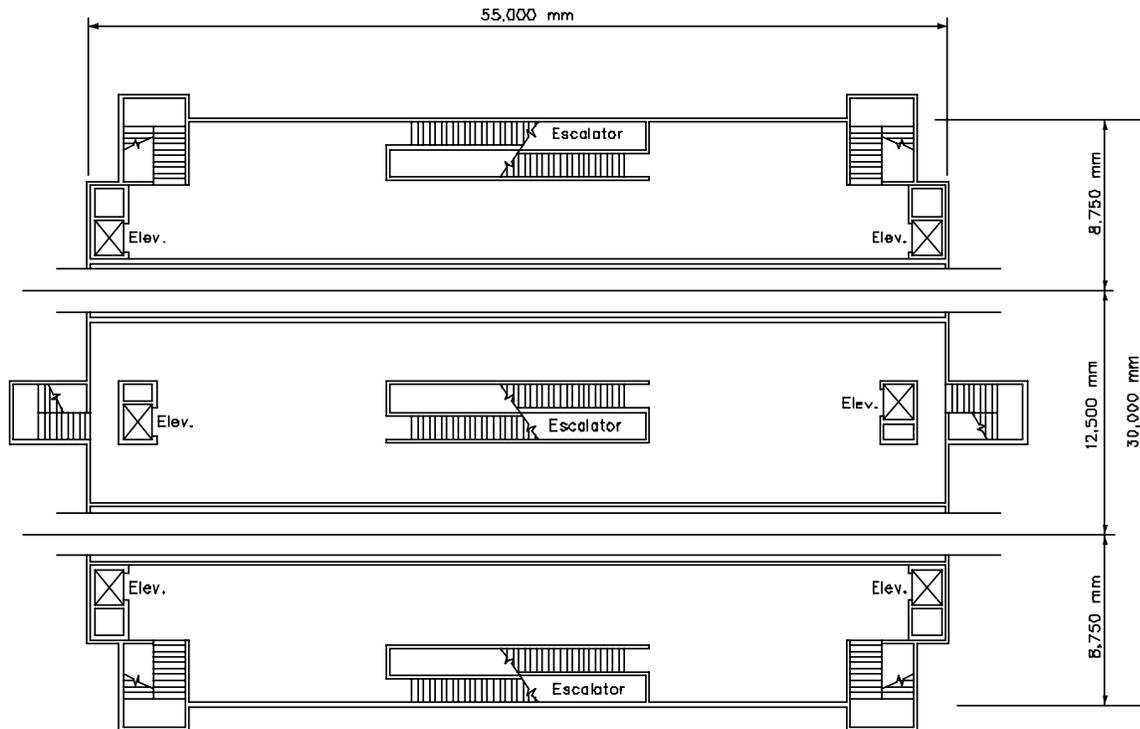
### **2.3.5.5 Guidance/Propulsion Interface**

The typical LGP module carries the vehicle and has Litz wire assemblies to provide levitation and LSM winding to provide propulsion. The modules are shop-fabricated and consist of a carbon-steel top plate, stainless steel side plates, 26 stainless frame plates, and 52 laterally slotted stainless bearing plates. Each bearing plate is attached to a longitudinally slotted stainless steel sole plate. The sole plates are anchored to the guideway with galvanized carbon-steel threaded rods and supported by nonshrink, nonmetallic epoxy grout.

The modules are aligned by adjusting them longitudinally using slots in the sole plates, laterally using slots in the bearing plates, and vertically using leveling, locking and clamping nuts. All adjustments are within "3-mm (1/8-in.) tolerance.

### **2.3.5.6 Stations**

The typical Urban Maglev guideway incorporates passenger stations that are 55-m (180-ft) long and 30-m (98-ft) wide. The stations accommodate two four-vehicle maglev trains spaced 12.5 m (41 ft) apart, one inbound and one outbound. They have one inboard loading platform and two outboard unloading platforms (Figure 2-22).



**Figure 2-22  
Passenger Stations**

Each station has two levels. The upper level is a passenger circulating and waiting area incorporating the loading and unloading platforms. This level is served by a combination of six stairwells, six escalators and six elevators. It is covered but not completely enclosed because the ends of the station have four openings to allow the trains to move in and out of the station.

The lower levels are also passenger circulating and waiting areas; served by a similar combination of six stairwells, six escalators and six elevators. It includes storage, maintenance and equipment rooms to support the escalators and elevators along with the guideway power supply and telecommunications hardware. Even though this level is completely enclosed, it is not heated or cooled. However, it has an air intake and exhaust system for the power supply equipment room and an air conditioner and a fire suppression system for the telecommunications equipment room.

The exposed superstructure for the upper and lower levels consists of pre-fabricated steel columns and beams supporting cast-in-place concrete floors, masonry walls and glass windows. The substructure consists of cast-in-place spread footings supported by drilled concrete caissons. The passenger station's superstructure and substructure is completely independent of the guideway's superstructure and substructure. The stations are designed to aesthetically complement or match the architecture of the surrounding residential, academic or business communities.

### **2.3.5.7 Operations and Maintenance Facility**

The typical Urban Maglev guideway requires at least one operations and maintenance facility. It is placed in a location that facilitates the maintenance of the vehicles, the operating systems and the guideway and house the communications and control center. The facility has a total of 3,600 square meters (39,000 sq ft) of maintenance, office space, and storage. The building has six distinct functional areas:

- ≠! **Cleaning and Inspection Areas** – This area consists of, as a minimum, two guideways each with side and center platforms that allow cleaning and subsequent inspection of two vehicles. The inspection area has two levels to allow for the concurrent inspection of the vehicle and its magnet assemblies, and to permit minor vehicle repairs.
- ≠! **Vehicle Repair Areas** – This area consists of, as a minimum, two guideways. One 15-ton overhead crane is provided at each guideway for the purpose of lifting vehicles off the guideway, or lifting the vehicle body off its chassis.
- ≠! **Component Repair Areas** – This area consists of, as a minimum, two workshops, one for each guideway. It is the facility where major vehicle components, such as the magnet assemblies and suspension systems, can be removed and repaired. Two 2-ton jib cranes are provided at each guideway for the purpose of handling heavy components.
- ≠! **Administrative Offices** – Administrative offices are established for the System Manager, the Operation and Maintenance Managers, and the IT Manager, at a minimum. The Communications and Control center is located in the same area as the administrative offices.
- ≠! **Storage Areas** – Storage areas are provided for cleaning and maintenance supplies, vehicle car parts such as the door assemblies, and magnet and suspension assembly components.
- ≠! **Vehicle Storage Areas** – Outside storage areas are maintained for vehicles that are not needed during off-peak hours. All other vehicles are stored at the passenger stations.

The operations and maintenance facility is designed to complement or match the architecture of the surrounding business community.

### **2.3.5.8 Right-of-Way**

An essential requirement for the Urban Maglev system is that it be constructed largely within the public right-of-way, i.e., along existing streets, highways, or freeways, within parking or shoulder areas, sidewalk areas, medians, or if space is available, in the area between the roadway template and the right-of-way line. Meeting this requirement results in minimization of costs (right-of-way acquisition costs are not required), minimization of time delays (right-of-way acquisition, a process which sometimes requires extensive time, is not required) and minimization of public opposition and the time required for the environmental process (displacements and environmental impacts are minimized).

In some instances, it is not possible to stay totally within existing right-of-way, and some acquisition is required. In those instances, it is necessary to follow normal procedures to define right-of-way required, and follow normal right-of-way acquisition procedures.

### **2.3.5.9 Utility Relocations**

Utility relocations are a costly and time-consuming component of transportation projects. Utility relocations for an urban maglev project should be minimized to the greatest extent possible to reduce construction costs and to expedite construction of a maglev system. The elevated nature of the guideway alignment, together with the flexibility of span lengths and pier placement help reduce utility impacts. (Piers are placed to avoid utilities wherever possible.) However, since construction is taking place in public right-of-way, some utility impacts are unavoidable.

Extensive utility location and coordination activities are conducted during the design process, followed by close coordination with utilities during construction. An underground utility location consultant is utilized to accurately locate underground utilities, and overhead utilities are located by survey and their identification coordinated with the utilities. The guideway must be designed to avoid utility impacts, if feasible. For utilities requiring relocation, utility relocation design is conducted by the involved utility company, followed by identification and assignment of responsibility for costs, and ultimately, relocation. Relocation must be scheduled to avoid delays to the guideway construction, and continuous coordination must be conducted throughout the relocation process.

### **2.3.5.10 Roadway Modifications**

Roadway modifications occur when the maglev alignment is constructed within existing public right-of-way and the template of streets, highways, and freeways (where possible, the guideway is constructed within public right-of-way, but outside of the roadway template). Roadway modifications are minimized to the greatest extent possible to minimize costs, and disruptions to the public. Minimization occurs by placing the guideway piers in median or shoulder areas, or in parking or sidewalk sections. Generally, roadway modifications will consist of:

- ÷! Removal and replacement of sidewalk, curb, and roadway sections at pier and station locations.
- ÷! Removal and replacement of drainage facilities.
- ÷! Removal and relocation of signing, lighting and traffic signals.

Impacts to large structures such as bridges are avoided by adjustment of the alignment if at all possible.

The design and construction of roadway modifications are coordinated closely with local public works officials to meet their approval. Approval must be obtained far in advance of construction.

### **2.3.5.11 Landscaping**

Landscaping is conducted along the Urban Maglev alignment to compliment the guideway, and reduce visual impacts and associated objections to the guideway. Landscaping consists of the following (subject to cost constraints and feasibility).

- ÷! When the alignment is constructed within the limits of city streets, planting boxes are constructed at pier locations. The planting boxes can include flowers, shrubs, perennials, and such.
- ÷! Reseed disturbed areas.
- ÷! Plant flowers and shrubs where the alignment traverses unpaved areas.
- ÷! Plant flowers and shrubs at all stations

Landscaping details are presented at public meetings prior to construction. Details are closely coordinated with the local municipality, and approved by them prior to construction.

### **2.3.5.12 Demolitions**

Demolition of existing facilities (and associated right-of-way acquisition costs) are avoided to the greatest extent possible as an aid to minimizing costs, facilitating construction, and reducing project schedule.

The Urban Maglev guideway is designed to minimize the demolition of existing structures such as offices, stores, classrooms, apartments and homes. The alignment is based on a route that least disrupts the business, academic and residential communities along the guideway. The key features of the Urban Maglev system, such as small turning radii, steep grades, and single tracks, are used to adjust the alignment to avoid the demolition of buildings.

When demolition is necessary, environmental investigations are required during the design process to identify and quantify hazardous wastes. Permits are obtained from the local municipality, and the demolition is closely coordinated with the municipality and utility companies.

### **2.3.5.13 Environmental Mitigation**

Environmental mitigation is conducted for all impacts identified in the mitigation section of the Environmental Impact Statement. Due to the urban nature of the alignment, impacts to wetlands, forestlands, agricultural lands, and wildlife are minimal or non-existent (note that a major design requirement is to minimize environmental impacts by judicious placement of the alignment, avoiding parks, historic structures, and such). Air and noise impacts do not occur, due to the low noise level of the Urban Maglev, and general reduction of traffic and associated noise and

emission impacts. The two impacts which will likely require mitigation are hazardous waste and viewsheds.

Hazardous waste is located during the environmental and design process, and the alignment relocated, if possible to avoid impacts. If relocation is not possible, the type, extent, and classification of wastes is identified, and the waste removed to an approved site during construction. (Waste removal is only required at pier or station locations.)

Viewshed impacts are mitigated by constructing an aesthetic guideway and piers, and by giving appropriate aesthetic treatment such as facings, form liners, etc. to guideway, and piers, and by landscaping where feasible. Details are developed utilizing input from the public and the residents of the community where the guideway is located. Input will be obtained during the environmental process, with additional input obtained during the design process.

# 3. Maglev Commercialization

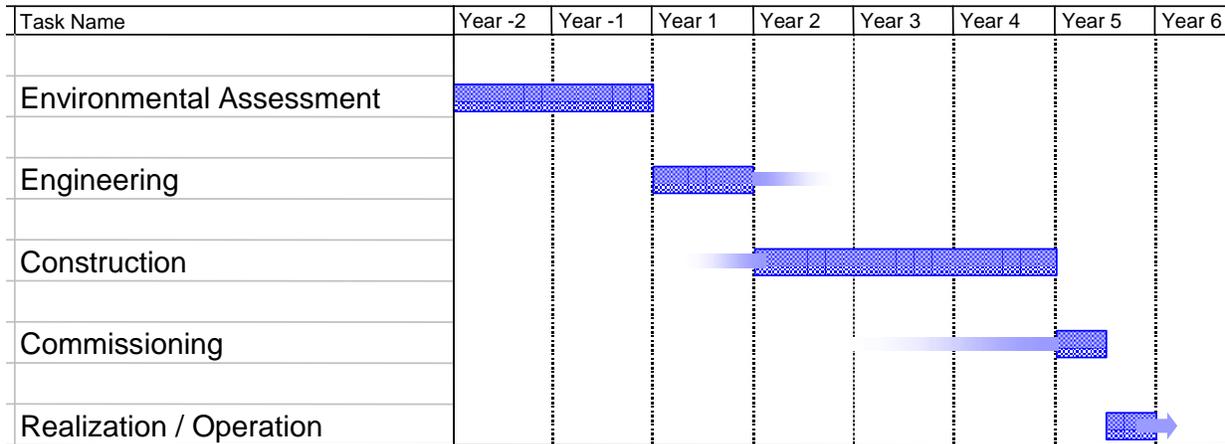
## 3.1 ENGINEERING AND CONSTRUCTION SCHEDULE

One of the key activities of this project was the development of a detailed engineering and construction schedule for a typical Urban Maglev system. The critical assumptions are provided below:

1. Concept is defined and ready for deployment.
2. Prototype testing is complete.
3. System meets criteria of the requirement document (e.g., 12,000 passengers/hour/direction, primary alignment, driverless, etc.).
4. Site-specific engineering is a primarily a one year activity, with some tasks extending into the second year.
5. Construction is a three-year activity that begins one year after commencement of site-specific engineering.
6. Commissioning is a six-month process after completion of construction.
7. Manufacturing capacity generally exists to achieve the construction schedule.
8. System will be operated in a typical fashion (e.g., reduced performance in non-peak hours, etc.).
9. Topology includes 5 off-line sidetracks/10 turnouts (switches).
10. System includes 62 propulsion blocks on the mainline.
11. No property acquisition is required since alignment is in the public right-of-way.

A summary level schedule is shown in Figure 3-1.

It should be noted that one activity, the Environmental Impact Statement (EIS), is typically required to be essentially complete prior to funding of a project. The EIS could take as long as two years to complete. On the engineering and construction schedule the EIS is shown as occurring in Year Minus 2 and Year Minus 1 prior to project start. Site-specific engineering starts in Year 1, and construction starts in Year 2. Commissioning is a six-month activity commencing in Year 5.



**Figure 3-1  
Master Schedule – Urban Maglev Primary Alignment**

### 3.2 TRANSPORTATION SYSTEM TOPICS STUDY

The FTA is funding development of a magnetic levitation technology that is a cost-effective, reliable and environmentally sound transit option for urban mass transportation.

A successful maglev urban transportation system requires: (a) a purpose and need for the system; (b) selection of the mode for the situation; (c) ownership of the system by an entity; (d) public involvement; (e) funding of the system either public and/or private; (f) passengers; (g) costs that are comparable to existing modes; (h) intermodal connections; and (i) time for development and testing of the system. In addition, maglev-specific advantages need to be considered. For example, maglev offers environmental advantages, as well as the opportunity to provide the most direct route possible, hence minimizing cost.

A magnetic levitation system must be proposed, designed and perceived by the community as a transportation system. The maglev system must serve a purpose and resolve a transportation need. Proposing a maglev system based on technology alone will not serve that purpose.

Four major categories of challenges have been identified to bridge the gap between concepts to market for a magnetic levitation transportation system. These challenges need to be overcome for a maglev system to function in an urban transportation setting.

#### **Financial**

Financing presents the challenging issue of how to fund the project. In order to establish financing, a realistic financial plan must be prepared and cost estimates for design, capital and operating costs must be accurately estimated. The project could fail if the ability to estimate and control costs are lost.

To initiate a new untried transportation system entirely through the private sector involves capital costs and high risks that few investors are willing to take. Government support and innovative financing strategies are generally required in the development of major transportation systems.

## **Political**

Any transportation project must have a strong project champion. This project sponsor must take possession of the project and be willing to work from design to implementation of the system. There must be strong and effective leadership to develop and maintain project consensus.

A project sponsor must be identified who will operate and maintain the system. It could be the same project sponsor that championed design and construction.

The project must be carried out with the involvement of public interests. This should include federal, state, regional and local agencies, elected officials, community and business interests and citizens groups. Involvement by outside parties should be early in the development of the project and needs to include those affected by the project during construction and operation. Without public support, the project may not materialize.

## **Technological**

During development of a system concept for maglev deployment, an important decision is whether a particular technical concept is too risky or too immature to employ. Tradeoff analyses can be used to evaluate this decision. Technical concepts can be rated on a scale of risk and maturity.

New technologies are inherently viewed as start-of-the-art and not necessarily practicable. In order for a maglev system to operate successfully and be perceived as reliable by the general public, the technology has to be stable and proven. This requires a committed long-term view of the project and a well-planned demonstration effort.

A maglev system should have the ability to accommodate future growth in ridership. Without this ability, the maglev system may prove to be unreliable and outdated.

## **Market**

To become a contender for deployment as a major transportation system, a maglev system needs to be perceived as reliable, convenient, safe, frequent, comfortable and available.

One of the concerns of passengers that may need to be addressed is the possibility of stray magnetic fields. Although the intensity of magnetic fields of maglev systems are low, passengers may need to be reassured of this concern. If passengers perceive a safety issue, ridership may suffer. In the General Atomics Urban Maglev system, passengers will be exposed to magnetic fields that are less than those to which passengers are exposed on light rail systems.

In order to attract passengers, the service must provide comparable trip times (frequency of service) and fares to other modes of transportation; otherwise, passengers will continue to use existing modes.

In summary, a magnetic levitation system must be proposed, designed and perceived by the community as a transportation system. The maglev system must serve a purpose and resolve a transportation need. Proposing a maglev system based on technology alone will not serve that purpose. The project could be perceived as a novelty or, worse, a waste of money. The transportation need of the community and the purpose served should play a role in the selection of the technology, not the other way around.

### **3.3 COMMERCIALIZATION PLAN**

In the 20<sup>th</sup> century urban areas grew in part because cities were able to rise vertically with development of elevators. It is envisioned that in the 21<sup>st</sup> century, cities will be able to move sideways more effectively with the Urban Maglev system. This system will provide urban commuters, workers, students and shoppers with an alternative means of transport, one that is more attractive than the bus, subway, railroad, or automobile.

#### **3.3.1 *Characteristics of the Commercialization Plan***

The commercialization of Urban Maglev systems requires consideration of five major elements:

- ÷! The market demand
- ÷! Technological advantages
- ÷! Cost considerations
- ÷! Financing
- ÷! Development process

#### **Market Demand**

Fundamental to commercialization of any maglev transportation system is an analysis of the need and market demand for a fixed guideway transit system. Such an analysis requires an understanding of the transportation needs of the community.

## **Technological Advantages**

Of key importance to the market and the selection of a maglev technological solution to solve a transportation need are the following factors:

- ÷! Quiet operation.
- ÷! Minimal air pollution, as a result of the vehicle being electrically powered.
- ÷! Fewer mechanical parts and lack of friction thus reducing maintenance costs.
- ÷! Rapid acceleration and deceleration with linear motors resulting in increased average speed.
- ÷! Steep grade-climbing capability.
- ÷! Tight turn-radius capability.
- ÷! All-weather operation without the need to heat the guideway.
- ÷! Low cost operation due to driver-less technology.
- ÷! Safe operation because guideways are grade-separated, which eliminates traffic conflicts and at-grade crossing accidents, which result in safer operation and greatly reduce insurance costs.
- ÷! Lower life cycle costs than conventional transportation systems.
- ÷! High-tech image promotes the city as a high-tech center.

## **Cost Considerations**

An Urban Maglev system has a number of construction cost advantages over existing technology. It has the ability to make tighter turns, negotiate steeper grades, and operate more effectively in inclement weather conditions. Additionally, it can do all of this while making little or no noise. In the case of Light Rail Transit (LRT), the alignment of the route is often dictated by its limitations in these areas, thus forcing route designers to take a less efficient approach. Frequently, if an LRT system were to be constructed along a urban route instead of an elevated maglev system, a significant portion would need to utilize "cut and cover" or tunnel construction methods. The cost estimate for these construction techniques ranges from \$200 million to \$400 million per mile. All in all, the construction costs of the Urban Maglev can be substantially less than the costs of a LRT system along the same alignment.

Some agencies have reported finding that increasing and/or unreasonable operations and maintenance (O/M) costs for public transportation systems were having a near-bankrupting effect on these systems. Looked at in this light, the O/M cost advantages of an Urban Maglev system become very important. The primary O/M cost advantage is that the vehicle does not ride on wheels and has very few moving parts. Not only does this in itself save money, but it also allows the system to be less prone to break down, thus decreasing overall maintenance costs.

Commercialization of Urban Maglev requires a financing mechanism that includes private, local, state, and federal government investment. To achieve these goals, broad political and public support is needed. Commercialization of Urban Maglev also requires the cooperation of an end user and operator. Frequently, this will require the formation of a public-private partnership. Full cooperation of local, state, and federal governments is required in order for such a public-private partnership to succeed.

### **3.3.2 *Potential Future Urban Maglev System Markets***

Urban Maglev systems, because of their signature characteristic of no noise, can be utilized in congested urban settings. Larger cities, such as New York, Los Angeles or Philadelphia would perceive a large advantage from this “stealth” characteristic. Urban Maglev systems can also be used to connect such venues as airports, colleges and universities, hospitals, convention centers, sports and entertainment facilities and shopping centers with large, accessible parking facilities. Many transit agencies have expressed an interest in maglev technology.

#### **Parks**

Potential markets include park facilities in urban areas. An Urban Maglev system could connect these urban recreation areas with remote parking, so as to alleviate the urban parking burden.

The United States National Park System is experiencing severe auto and bus overcrowding. Air pollution in these once pristine areas is a growing problem. With appropriate engineering and design, a maglev system can be constructed to blend into the surroundings and be completely silent. An aesthetically pleasing guideway and column design with no noise or air pollution may provide an exciting and compelling marketing story for a maglev system application in our national parks.

#### **Universities and Colleges**

Many universities and colleges need a modern transportation system, which would link student housing, recreation, parking, education and college town activity. The environmental and economic advantages of maglev may lend themselves to solutions to transportation and parking problems at these schools.

### **3.3.3 *Engineering and Environmental Impact Statement Work***

An Urban Maglev system development requires that an engineering and environmental analysis be done in regard to the following issues:

÷! Public safety.

÷! Permitting requirements.

- ÷! Neighborhood acceptance.
- ÷! Ridership volume and usage profile.
- ÷! Economic benefits of development at the stops and along the route.
- ÷! Commissioning with state and local agencies.
- ÷! Comparison to existing light rail and rubber tire transportation systems.

### **3.3.4 Role of Public Transit Agencies**

Urban Maglev system owners and developers must work closely and coordinate activities with the county, city and state governments as well as public transit agencies regarding the following issues:

- ÷! Design requirements.
- ÷! Inter-modal integration with existing bus and light rail systems.
- ÷! Environmental assessment.
- ÷! Ridership studies.
- ÷! Route alignment.
- ÷! Maintenance and operation planning.
- ÷! Approval Plan development.

### **3.3.5 Necessity for a Test Facility**

Development of an Urban Maglev transportation system requires a physical starting point, meaning that a test facility should be constructed as soon as possible. The test facility must be designed to validate computer simulation, mathematical modeling and prototype testing previously undertaken.

The test facility would:

- ÷! Demonstrate the chassis and vehicle level performances including levitation, propulsion, guidance and control.
- ÷! Demonstrate transportation system reliability.
- ÷! Test operation of the vehicle on a grade.
- ÷! Complete all testing and integration of communication, signaling and safety systems.
- ÷! Test vehicle operation in tight turns.

The success of the testing program will provide additional evidence of the capital, operating and maintenance cost advantages for an Urban Maglev system. Private contractors will therefore have more confidence in providing firm, guaranteed price contracts for construction. The operating and maintenance cost information will similarly provide greater confidence in enabling private contractors to enter into long-term operating and maintenance contracts.

### **3.3.6 *Administrative Steps Needed to Develop an Urban Maglev System***

The administrative steps needed to develop an Urban Maglev system are:

- ÷! Complete analysis of demonstration facility testing.
- ÷! Complete all private contracts and financial guarantee agreements.
- ÷! Complete EIS work and/or obtain local political and agency approval.
- ÷! Establish an ownership structure for the Urban Maglev system.

## 4. Conclusion

The General Atomics Low Speed Urban Maglev Technology Development Program has resulted in a system that is a cost-effective, reliable, and environmentally sound transit option for urban mass transportation.

The General Atomics Urban Maglev system represents refinements that evolved from the maglev technologies developed by the United States, Germany, Japan, and Korea over the last three decades. We have developed a system that offers great simplicity in its design, operation, and capabilities:

- ÷! The vehicle glides silently on an elevated guideway 6 m (20 ft) or more above at-grade traffic and pedestrians.
- ÷! The elevated guideway, with an entirely passive levitation system and wraparound vehicle structure, results in an extremely safe form of transportation.
- ÷! The vehicle cannot be derailed and is inherently safe if propulsion power is ever lost.
- ÷! Because the vehicle has no moving parts in its levitation and propulsion system, the reliability is very high and maintenance costs are very low.
- ÷! Quiet, efficient operation offers numerous long-term benefits, including environmentally friendly transportation, and low operational maintenance.
- ÷! The ability of the vehicle to negotiate a 18-m (60-ft)-radius turn and climb grades greater than 10%, coupled with its quiet operation, provide planners with great flexibility in selecting the alignment that can most efficiently and cost-effectively serve urban areas.
- ÷! The modular guideway construction approach will minimize disruption of traffic, acquiring rights-of-way, as well as needed environmental impact assessment.
- ÷! The modular construction also allows easy system expansion, including the operation of additional vehicles as passenger throughput requirements increase with time.
- ÷! The Urban Maglev system offers many benefits on quality of life both during construction and daily operation.

Our team's vision is that this work will form the seed, not only for fostering economic development in an emerging new transportation system industry, but will also pave the way for implementation of a viable Urban Maglev system which solves a real transportation need in an American city. We look forward to the next step of prototype subsystem development leading to deployment of a full-scale project.

## 5. List of Acronyms

AC	alternating current
ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
ATC	automatic train control
ATO	automatic train operation
ATP	automatic train protection
CCTV	closed-circuit television
CPU	central processing unit
DC	direct current
EDS	electrodynamic suspension
EMS	electromagnetic suspension
FTA	Federal Transit Administration
EIS	Environmental Impact Statement
HVAC	heat, ventilation and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
LGP	levitation, guidance, and propulsion
LIM	linear induction motors
LRT	Light Rail Transit
LSM	linear synchronous motors
NdFeB	neodymium-iron-boron
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
O/M	operations and maintenance
R&D	
SC	superconducting
SCADA	supervisory control and data acquisition
UTM	Urban Transit Maglev