The MAGLEV 2000 Urban Transit System

Date of Submission
July 31, 2002

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Word Count:

Abstract:	245
Body:	2,664
Figures:	5@250-1,250
Tables:	1@250
	1@250x4-1000
Total:	5,409

ABSTRACT

MAGLEV 2000 of Florida Corporation ("M2000") has designed magnetic levitation and propulsion technology for high-speed intercity transportation systems capable of operating at speeds in excess of 300 mph. This high-speed technology can be adapted for slower speed urban transit operations where operating speeds of 30 to 120 mph will be used. This paper will discuss the MAGLEV 2000 preliminary baseline urban transit designs and the criteria that are essential for a maglev technology to operate safely and efficiently in an urban transit environment.

MAGLEV 2000 uses superconducting magnets on the vehicle, interacting with aluminum coils in the guideway for levitation, stability and propulsion. The coils are completely encapsulated in polymer concrete panels which are attached to the sides of a narrow beam guideway. The vehicle straddles the beam with a 4-6 inch gap between the guideway surface and vehicle. Propulsion is provided through the linear synchronous motor coils and powered by AC electrical current.

The large clearance between vehicles and guideway with the superconducting MAGLEV 2000 magnet system ensures low-cost guideway construction because of more leeway with construction tolerances. These large clearances allow system operations under snow and ice conditions. The magnetic switch also allows for efficient off-line stations and permits increased train frequencies and operation of express trains without delays from locally stopping trains.

Most of the components for a MAGLEV 2000 operating system have been constructed and this paper will review manufacturing techniques, operating requirements and performance results for a maglev transit project.

THE MAGLEV 2000 URBAN MAGLEV SYSTEM

The MAGLEV 2000 ("M2000") urban maglev concept described in this paper is an elevated system that will serve as an urban circulator and connect outlying suburban areas to the urban center and to other transportation hubs, such as airports and high-speed (300-mph) intercity maglev lines. It will be constructed as an elevated system with a speed capability up to 120 to 150 mph for the longer routes and 30-60 mph for the urban circulator route segments. Stations can be built off-line where needed and will be fully compliant with ADA requirements. In order for urban Maglev Systems to be widely implemented, they should satisfy the following criteria:

1. Systems must be safe and environmentally benign.
2. Capital and operating costs must be acceptable.
3. Service should be faster, more convenient, more comfortable, and lower in cost than alternative systems.
4. Construction and operation of the system should have limited impact on existing urban/suburban infrastructures.
5. Subsidization of the system should be minimal.
6. Systems should serve a wide range of locations and users in a seamless manner, with a minimum of transfers required. Connections to other modes of transport should be easy, convenient, and quick.

Although these are tough criteria to meet, the M2000 Urban Maglev System can satisfy them.

Before discussing how the M2000 system meets these criteria, it is useful to define the baseline M2000 urban maglev design that is being developed. It should be noted that this is a preliminary, not a final baseline design. However, while the parameters of the final design may be modified somewhat, it is not anticipated that they will be substantially different. For several years M2000 has been designing and constructing system components primarily aimed at the high speed (300+ mph) market. Because of this extensive work, M2000 has been able to more easily adapt the high speed designs for the lower-speed urban environment.

Table 1 summarizes the principal features of the M2000 Urban Maglev System. Compared to intercity M2000 maglev vehicles, the M2000 urban maglev vehicles will be shorter, lighter, and carry a smaller number of passengers—60 rather than 100—for example. Their maximum speed will be less, probably up to 60 mph in urban areas, with top speeds of 150 mph in less densely populated suburbs. In contrast, M2000 intercity maglev vehicles will probably operate at maximum speeds of approximately 300 mph in rural areas, reducing speed as they travel through suburban and urban areas. Figure 1 illustrates the right-of-way requirements for a 2-way guideway. The guideway can also be designed for a double track on one set of piers.

A key feature of the M2000 maglev system is the ability of urban and intercity maglev vehicles to use the same guideway. This eliminates the need to build two separate systems in urban and suburban areas, and greatly reduces construction and operating costs. It also greatly reduces disruptions to existing infrastructure, because only one guideway system needs to be constructed, not two separate ones.

This operational flexibility also provides enhanced convenience for customers, thereby reducing the need for transfers. Passengers will be able to board an urban maglev vehicle at any of the many stations in a given urban/suburban region and travel rapidly to the nearest maglev station with intercity access. There they can quickly board the intercity maglev vehicle traveling to their final destination.

The M2000 urban maglev vehicles use the same levitation and stability process that the M2000 intercity maglev vehicles use, and employ similar large clearances (e.g., 4 inches) between the vehicle and the guideway. Figure 2 shows the vehicle interface with both the narrow beam guideway configuration and a planar section. The quadrupole magnets can function equally well with coil panels placed on the sides of the narrow beam or in the horizontal or flat position on the planar section. Large clearances and inherent strong stability are vitally important for the safe operation of high-speed maglev systems. To match the safety performance of commercial airliners, for example, a maglev vehicle will have to travel for billions of miles before having a fatal accident, based on the approximately 10 million takeoffs and landings per fatal crash of an airliner. Because of the inherent safety features of the M2000 system, this goal can be achieved.

In the M2000 system, urban and intercity vehicles are automatically and passively levitated and stabilized as long as they move along the guideway by the magnetic interactions between the induced current in the guideway loops and the superconducting loops on the vehicle. If the propulsion power to the guideway is cutoff, the vehicles would simply coast to a safe low speed, a few miles mph, before coming to rest on the guideway. Figure 3 shows how the guideway coils (levitation, propulsion and stability loops) are arranged and encapsulated in a 66"x30"x2 1/2" panel. These coil panels are then attached to the guideway as illustrated in Figure 2.

M2000 urban vehicles will remain stably levitated by induction generation of guideway loop current at speeds above 15-20 mph, depending on final design parameters. At lower speeds, the vehicles can either remain levitated by applying electric power to the guideway loops, or come down on auxiliary wheels, or a combination of the two methods, with powered levitation on some portions of the guideway and wheels on other portions. For example, an option is to use powered levitation on the slow speed portions of the guideway leading into and out of stations, with support by wheels when stationary at the stations. Figures 4 and 5 illustrate the transition between the narrow beam guideway and the planar section that is used for switching onto stations.

The power requirements for the powered loops are modest, on the order of 30 to 40 kilowatts. The power would be applied for only a few seconds as the M2000 vehicle glided into and out of the station. The stationary period for loading/unloading passengers at the station would be a few minutes. From the energy point of view, the energy used for the powered loops would be negligible.

The combination of large physical clearance between the vehicles and the guideway – 4 inches or more – as compared to the fraction of an inch for attracting electromagnetic maglev systems, plus the unmatched inherent strong vertical and lateral stability of the M2000 design, all contribute to making it the safest possible maglev design. No conceivable external force – winds, curves, etc. – could overcome the very strong stability of the M2000 vehicle which can withstand external forces of 2 g or more without contacting the guideway.

In addition to strong inherent stability and large physical clearance, the M2000 urban system will have continuous real-time monitoring of all portions of the guideway to detect hazardous objects, shifts in position of beams and piers, changes in the inductance/resistance of the guideway loops, and so forth.

Meeting the very stringent safety standards that will be mandatory for future U.S. maglev systems before they can be implemented will involve very extensive testing of prototype systems. Failure to meet safety standards would be catastrophic for implementation, therefore satisfying safety needs is given the highest priority on the list of criteria presented earlier. The M2000 system has been designed to maximize safety performance, and in our view, can meet the very stringent safety requirements that will be imposed.

Maglev systems, in general, are environmentally benign. They emit no pollutants, are much quieter than other modes of transport, e.g., autos and trucks, light and heavy rail, airplanes, etc., and by using elevated narrow beam guideways, minimize impact on the surrounding landscape. A major feature of the M2000 system, the quadrupole magnet, minimizes magnetic field strengths in the passenger cabin that do not exceed the natural environmental value, in contrast to the Japanese maglev system, which has several times Earth value.

The M2000 systems, both urban and intercity, are designed to have low capital and operating costs. The M2000 guideway beams and piers are prefabricated and mass-produced in factories and transported by road, rail, or the maglev system itself to the erection site. Expensive field construction, a major problem for the Japanese maglev system, is virtually eliminated in the M2000 design. Moreover, the large physical clearance of 4 inches between vehicles and guideway in the M2000 system considerably reduces guideway cost by allowing greater construction tolerances for the guideway beams and piers. A key reason why the German Transrapid guideway costs 40 million dollars or more per mile is the very small clearance, 3/8ths of an inch, between the vehicles and the guideway. In order to operate safely at high speeds, the Transrapid guideway has to be built to extremely tight tolerances, and designed so that real world effects on the guideway, such as temperature changes, icing, snow, ground settling, etc., do not cause operational or safety problems. Transrapid uses servo-controls to successfully manage the small gap and the Shanghai Transrapid line has used laser surveys to meet the precise construction tolerances that will be required for a Transrapid operation.

In our view, small clearance maglev systems that operate at a fraction of an inch clearance, whether they are electromagnetic or use permanent magnets, will be difficult and expensive to construct and operate, particularly in areas that are subject to ice and snow. The M2000 system, with its large clearance and narrow beam construction, has been designed to operate efficiently in all regions of the U.S., regardless of their weather and ice/snow conditions.

Guideway prototype components for the M2000 system – levitation, propulsion, and stability loops, reinforced concrete beams, along with encapsulation and formation of loop panels – have been fabricated and tested at full scale. Based on this fabrication experience and detailed cost analyses, the projected capital costs for a 2-way M2000 guideway for intercity applications is 11 million dollars per mile. This includes fabrication of the beams and piers, transport to the construction site, grading, footings, erection and assembly, installation of electronics and power cables, and monitoring systems. This is a greenfield cost, and does not include land acquisition, modifications to existing infrastructure, and special conditions like tunnels, etc.

Detailed cost projections that maximize the economics associated with urban applications have not yet been made of the M2000 guideway costs. Urban M2000 vehicles will weigh about half as much as the intercity vehicles, and therefore the guideway beams and piers can be substantially lighter, significantly lowering the cost of the guideway.

Moreover, because the M2000 urban vehicles will be much lighter and travel at considerably lower speed, the power and energy for acceleration and cruising will be much less. At a cruise speed of 60 mph, for example, the power to overcome aerodynamic drag on a M2000 vehicle is small, only about 40 kilowatts. At 150 mph, aerodynamic drag power is substantially greater, approximately 600 kilowatts.

Including I^2R losses in the guideway and propulsion loops, together with on-board refrigeration and "hotel" power, the total energy consumption per vehicle mile is approximately 3 kilowatt hours at 60 mph and 6 kilowatt hours at 150 mph. Assuming a 50 passenger loading and 6 cents per kilowatt hour (the average cost in the U.S. for electrical power), the typical passenger traveling at 60 mph would pay about 0.35 cents per passenger mile; while if he or she traveled at 150 mph, the energy cost would be 0.7 cents per passenger mile. The other operating costs for maintenance, personnel and vehicle amortization also appear very low.

The M2000 vehicles would be computer-controlled from a central traffic control facility. In effect, the system could be operated without the need for on-board operating personnel. However, the system operation would probably want on-board personnel for passenger comfort and security. Access and fare collection would probably be by metro card (or equivalent), or turnstiles.

Based on studies for intercity MAGLEV 2000 systems, total operating cost per passenger mile for urban M2000 systems should be less than 3 cents per passenger mile. At this level, fare box revenues would clearly cover operating costs, and payback some portion of capital costs. As to whether revenues could fully payback all costs – something that almost never happens with existing transport systems—that would depend on ridership and the total mileage for the particular urban maglev system.

Turning to the third criteria, the urban/suburban M2000 system will be faster and more convenient than the alternative systems like buses, subways, and light rail, since it will travel on elevated guideways. The M2000 system does not conflict with city traffic, like on-grade buses and light rail, nor require long multi-car trains like subways. The M2000 vehicles can travel either as individual or coupled units, depending on the number of riders served on the route, and can flexibly accommodate changes in ridership patterns.

As discussed above, operating costs will be less than those for alternative systems. The capital cost of a M2000 system will be far less than that of a subway, which costs hundreds of millions dollars per mile, and significantly less than that of light rail, which typically necessitates substantial costs due to modifications to existing infrastructure.

Turning to the fourth criteria, the M2000 narrow beam guideway is highly adaptable to existing infrastructure. It needs very little field construction, has a minimal land footprint – a couple of square yards every 100 feet or so, for the piers – is easily banked to accommodate curves to follow exiting rights-of-way, can readily pass over or under existing structures, and can be quickly erected and assembled into an operating system with minimal construction delays (see Figure 4). The Las Vegas monorail, currently under construction, is a good example of how quickly a pre-fabricated elevated structure can be erected and with minimal impact on existing urban structures.

This contrasts with alternative transport systems like subways and light rail, which require extensive field construction, cause major local disruption, and take a long time to complete.

Turning to the fifth criteria, because of its low capital operating costs, M2000 systems will require substantially less subsidization than alternative transport options, as discussed above.

Finally, with regard to the sixth criteria, M2000 urban/suburban maglev systems can be seamlessly connected to high-speed M2000 intercity maglev systems. Both vehicles can use the same guideway structure; urban M2000 maglev vehicles can transport passengers from all parts of the urban/suburban region to a number of stations that are connected to the high-speed intercity maglev network. This enables the passenger a short "across the platform" walk to board a vehicle traveling at 300 mph to a destination hundreds of miles away. The urban/suburban maglev lines also can readily connect to airports, conventional rail stations, and major highways. Studies of the M2000 system for the interstate highway network indicate that M2000 guideways can utilize the existing rights-of-way along highways without any major conflicts, so that integration with highway interchanges and airports would be easily accomplished. Figure 5 illustrates the transition between the narrow beam and planar sections. This guideway configuration will be used where vehicles exit the main guideway to stop at off-line stations or for branch lines. This same configuration is used to re-enter the mainline from a station or branch line.

Table 2 summarizes the performance of the M2000 urban/suburban maglev system as it relates to the six criteria discussed above.

The planned test in Titusville, Florida of the M2000 vehicle will provide a realistic demonstration of a vehicle that will be quite close in length, weight, and passenger capacity to the baseline M2000 vehicle for urban/suburban applications. Results from the test in early 2003 will enable the final design of the M2000 revenue vehicle and guideway for an actual urban/suburban maglev system.

LIST OF TABLES AND FIGURES

TABLE 1

Features of the M2000 Urban Maglev System

<u>Vehicle</u>	
Passenger Capacity	60
Weight (loaded)	15,000 kilograms
Physical Levitation Gap (vehicle/guideway)	10 centimeters (4 inches)
Length	20 meters
Width	3.3. meters
Cabin Height (Maximum Interior)	2.5 meters
Seating Capacity	4 seats/row, 15 rows 2 lines of longitudinal seating
Doors	Center doors on each side
Bags/Luggage	Overhead racks; underseat
Speed (maximum)	150 mph Suburb 60 mph Urban
Minimum Speed for Levitation	0 mph
Acceleration (maximum)	0.2 g
Deceleration (maximum normal) (emergency)	0.25 g 0.4 g
Stopping Distance (normal) @ 60 mph (emergency)	180 meters (600 feet) 90 meters (300 feet)

TABLE 2

M2000 Maglev System Performance As Related To Six Major Criteria For Urban/Suburban Transport Systems

Evaluation Criteria	M2000 Maglev System Performance
1. System Safety and Compatibility with Environment	1. The M2000 System is designed with the paramount goal of safe operation. Its safety features include: a) Large physical clearance (≥ 4 inches) between vehicles and guideway b) Automatic, inherent levitation and stability as long as vehicle is moving along the guideway c) Capability to coast to a safe, low speed stop if the propulsion power to the guideway were to fail d) Strong, inherent lateral and vertical stability (~ 2 g) against external forces such as winds, curves, etc. e) Continuous, real-time monitoring of the guideway to detect hazardous objects, displacements of beams and/or piers, changes in loop inductance/resistance, etc. f) Multiple independent superconducting magnets on vehicle – no single point failures possible g) High stabilized, very well cooled superconducting magnets h) Very low external noise levels from moving vehicles i) No pollutants emitted – electronically powered j) Superconducting quadrupole magnets result in natural Earth type magnetic fields in passenger cabin k) Minimal land impact – small footprint for guideway piers

TABLE 2 (continued)

M2000 Maglev System Performance As Related To Six Major Criteria For Urban/Suburban Transport Systems

Evaluation Criteria	M2000 Maglev System Performance
2. Acceptable Capital and Operating Costs	2. The M2000 costs are acceptable and generally lower than those of alternate options: a) Cost per mile of guideway (2-way) will be lower than the detailed cost projections developed for M2000 intercity maglev, which are ~ 11 million dollars, and which are based on fabricated prototype components; M2000 urban vehicles, beams and piers are lighter than intercity M2000 ones; less power needed in guideway b) The large physical clearances, ≥4 inches, between M2000 vehicles and guideway does not require the expensive construction and tight tolerances that is needed for small clearance (3/8th inch) electromagnetic and permanent magnet maglev systems c) M2000 guideway costs are reduced by prefabrication of beams and piers in mass production factories d) Large clearance M2000 systems will be much cheaper and easier to operate in regions with ice and snow than small clearance systems e) Energy costs for M2000 urban/suburban maglev systems are well below 1 cent per passenger mile e) Total operating costs will be less than 3 cents per passenger mile—will not have to be subsidized

TABLE 2 (continued)

M2000 Maglev System Performance As Related To Six Major Criteria For Urban/Suburban Transport Systems

Evaluation Criteria	M2000 Maglev System Performance
3. Fast, convenient, lower cost, Comfortable service	3. M2000 Maglev systems have potential for much better service than alternate transport options: a) Travel on elevated guideways does not conflict with existing surface travel is fast, and not held up by traffic congestion, signals, etc. Will be much faster than buses, light rail and subways, which cannot achieve high-speed b) Multiple maglev stations for easy convenient access. Travel on Individual vehicles, not long trains like subways—more frequent service c) Much lower capital cost than subways, lower capital costs than light rail, and lower operating costs than alternate options (less operating personnel) d) Much more comfortable ride than subways, light rail and buses.
4. Limited Impact of Construction and Operation On Existing Infrastructures	4. M2000 System designed for minimal impact: a) Prefabricated guideway beams and piers quickly erected and assembled, with minimal disruptions and delays. b) Elevated guideway construction very flexible and adaptable to existing rights-of-way c) Minimal land footprint – typically a couple of square yards every 100 feet

TABLE 2 (continued)

M2000 Maglev System Performance As Related To Six Major Criteria For Urban/ Suburban Transport Systems

Evaluation Criteria	M2000 Maglev System Performance
5. Subsidization of the system should be minimal	5. M2000 Urban/suburban maglev systems will not require a lot subsidization: a) Operating costs are low, ~ 3 cents per passenger mile, compared to alternate options b) Guideway capital costs are relatively low d) Ridership potential is good, due to greater speed and convenience, and the more comfortable ride of maglev
6. Integration with other systems and Modes of Transport	6. M2000 offers opportunity for very convenient and efficient intermodal integration: a) M2000 urban/suburban maglev system will integrate seamlessly with high-speed intercity M2000 systems b) M2000 stations can be easily located at airports, highway interchanges, and RR stations to integrate with other modes of transport. Can readily adapt to existing rights-of-way along highway and RR tracks.

FIGURE 1

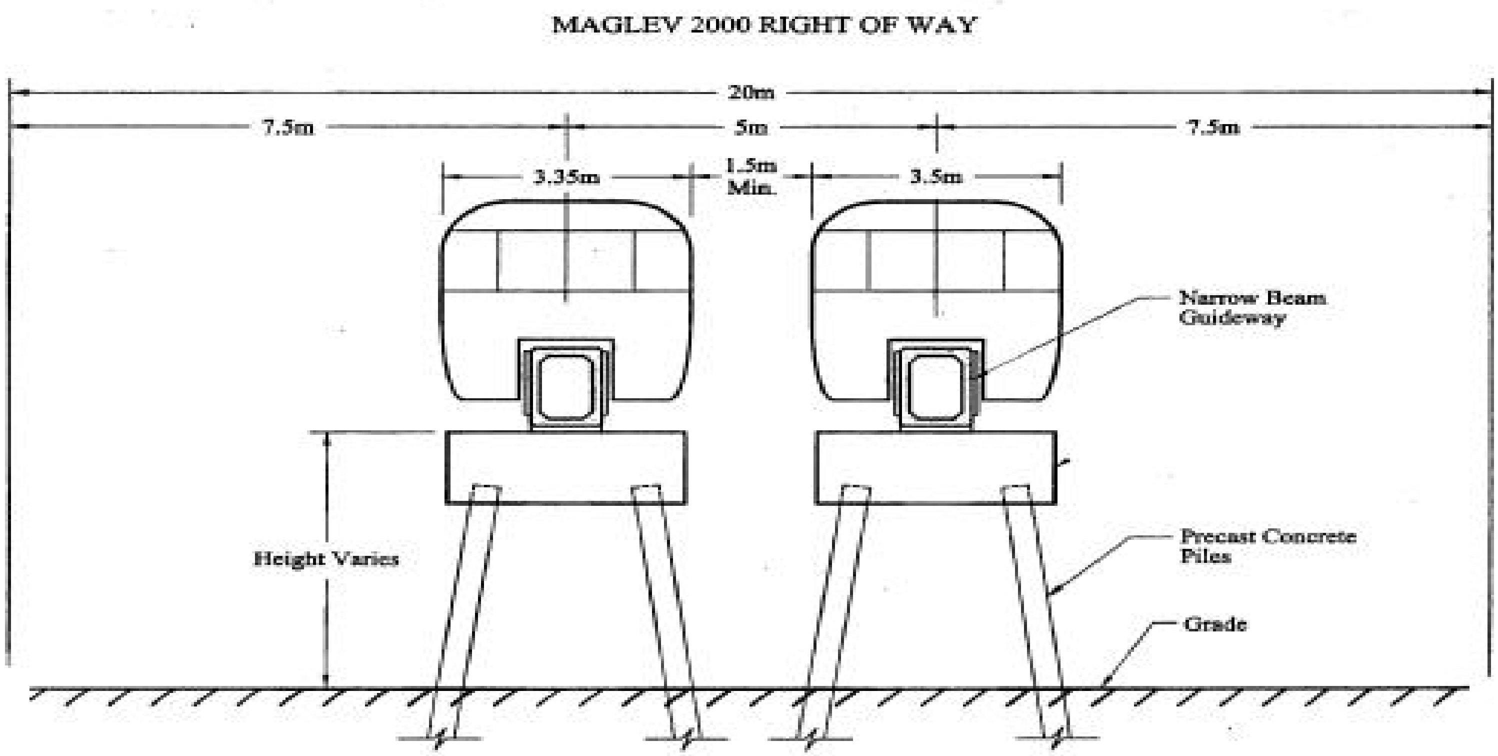

MAGLEV 2000 RIGHT OF WAY
20m
7.5m
5m
7.5m
3.35m
1.5m Min.
3.5m
Narrow Beam Guideway
Height Varies
Precast Concrete Piles
Grade

FIGURE 2

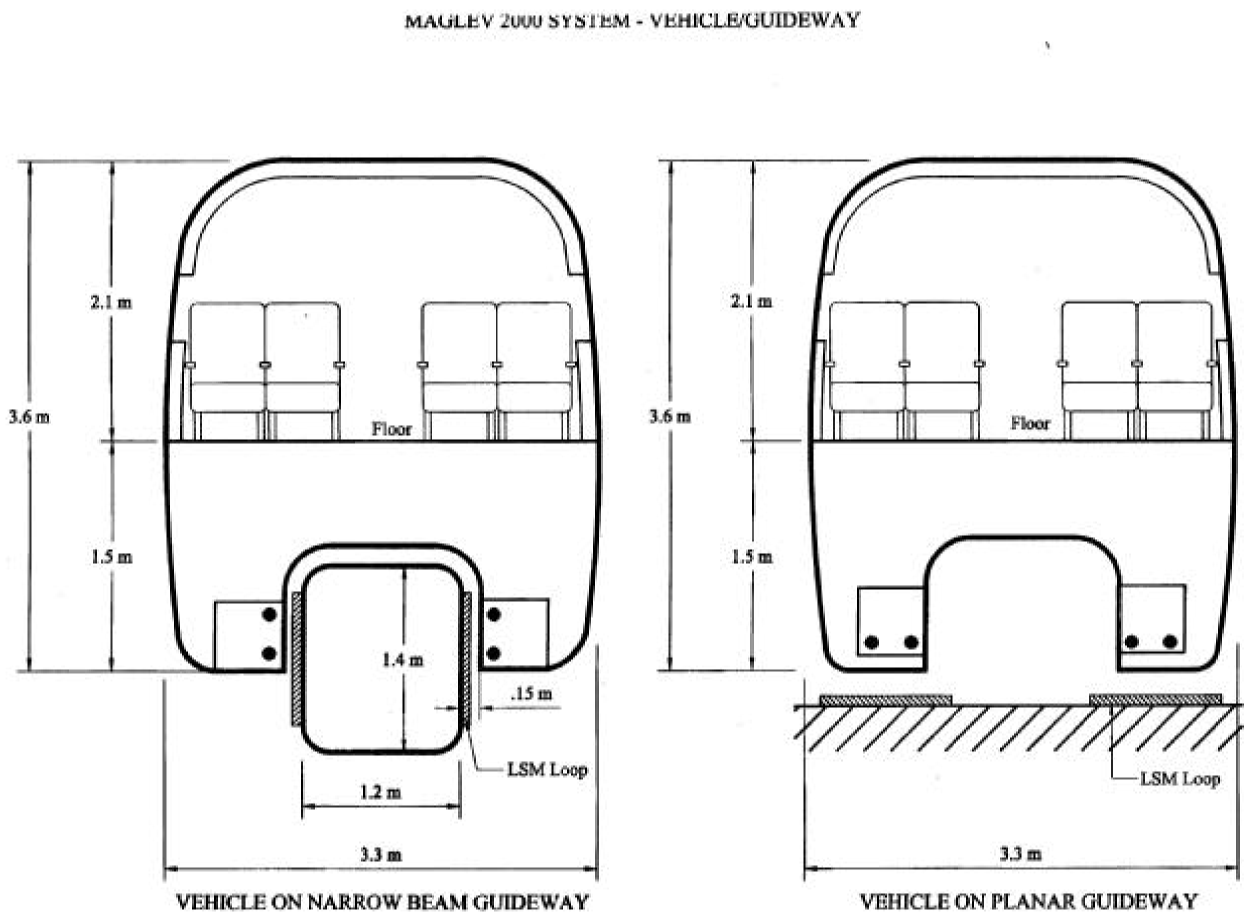

MAGLEV 2000 SYSTEM - VEHICLE/GUIDEWAY
2.1 m
3.6 m
Floor
1.5 m
1.4 m
.15 m
LSM Loop
1.2 m
3.3 m
VEHICLE ON NARROW BEAM GUIDEWAY
2.1 m
3.6 m
Floor
1.5 m
LSM Loop
3.3 m
VEHICLE ON PLANAR GUIDEWAY

FIGURE 3

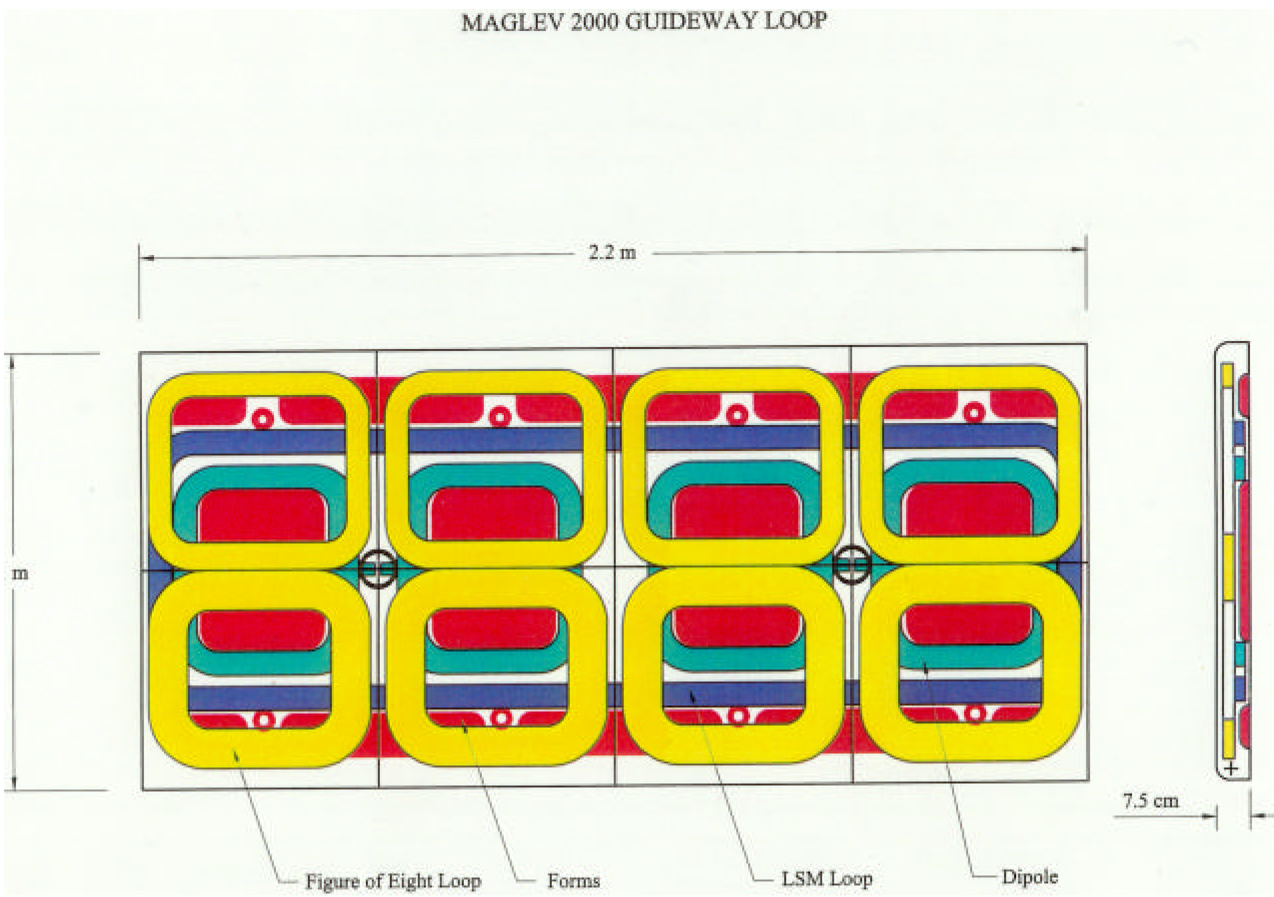

MAGLEV 2000 GUIDEWAY LOOP
2.2 m
m
7.5 cm
Figure of Eight Loop
Forms
LSM Loop
Dipole

FIGURE 4

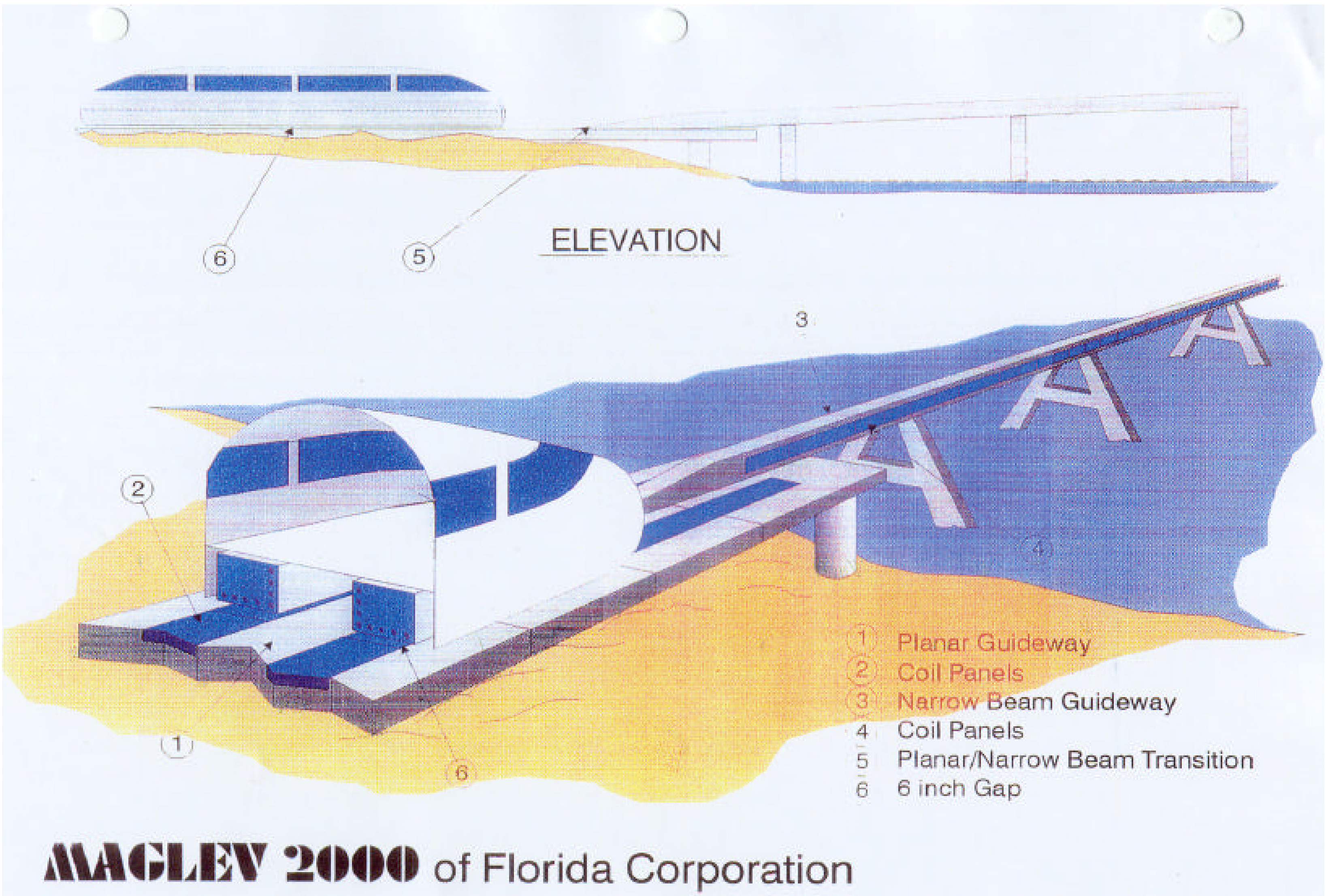
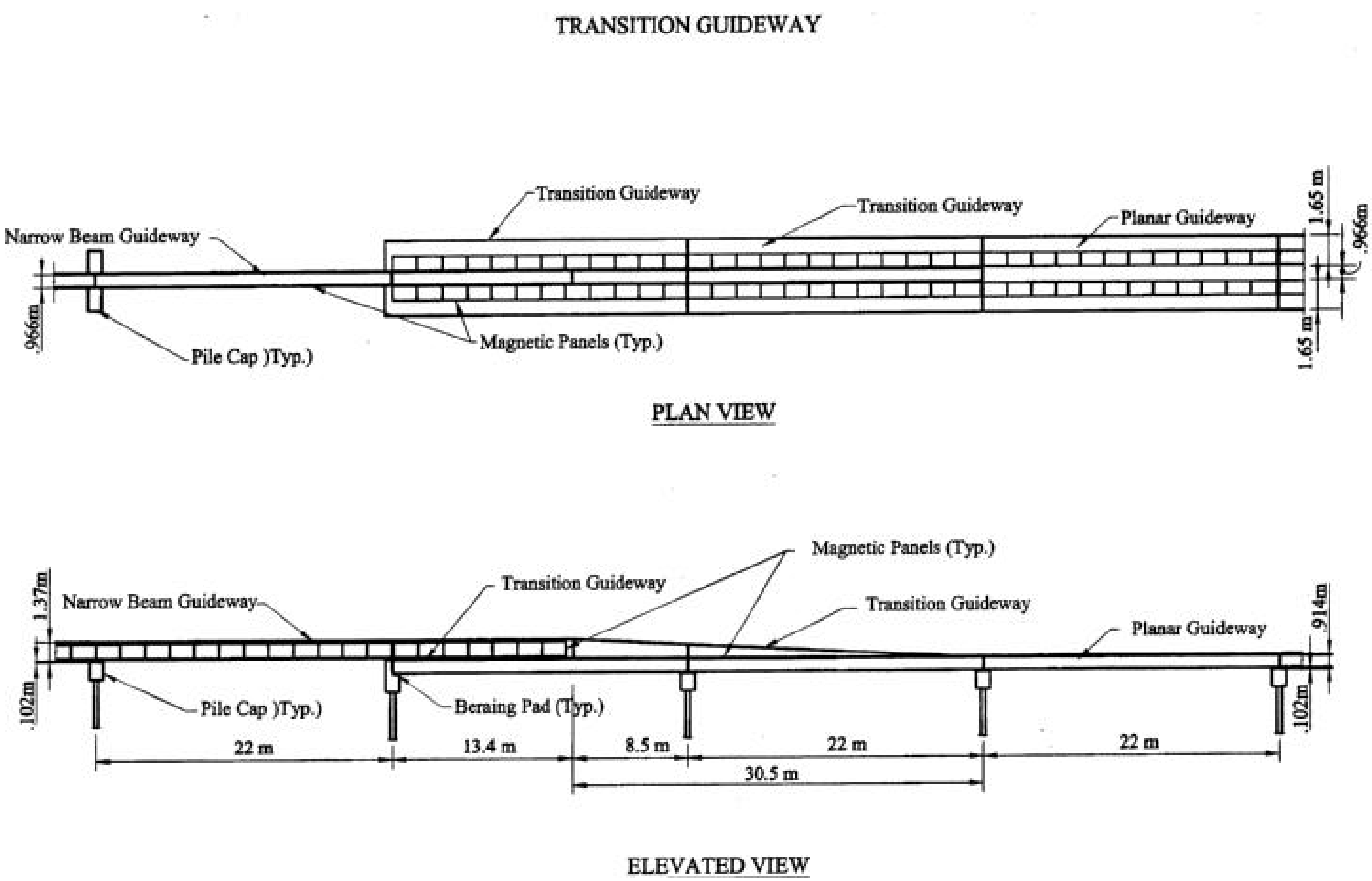

ELEVATION
6
5
3
2
4
1
6
1 Planar Guideway
2 Coil Panels
3 Narrow Beam Guideway
4 Coil Panels
5 Planar/Narrow Beam Transition
6 6 inch Gap
MAGLEV 2000 of Florida Corporation

FIGURE 5


TRANSITION GUIDEWAY
Transition Guideway
Transition Guideway
Planar Guideway
Narrow Beam Guideway
1.65 m
.966m
.966m
Pile Cap)Typ.)
Magnetic Panels (Typ.)
1.65 m
PLAN VIEW
Magnetic Panels (Typ.)
Transition Guideway
Transition Guideway
Narrow Beam Guideway
Planar Guideway
1.37m
.914m
.102m
Pile Cap)Typ.)
Beraing Pad (Typ.)
.102m
22 m
13.4 m
8.5 m
22 m
22 m
30.5 m
ELEVATED VIEW