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The development of a cost-effective automatic train protection system for safety operation on suburban lines in the Tokyo metropolitan area

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Abstract

In East Japan Railway Company(JR East), the ATP system based on the transponder technology is applied to upgrade the safety on commuter lines in the Tokyo metropolitan area since 1989. This ATP system was named ATS-P(the Automatic Train Stop with on-board Pattern) in Japanese National Railway. This ATS-P performs the wayside-to-train communication by the transponder technology. The coded message transmitted from a ground coil enables the on-board devices to perform a continuous supervision of the train speed. The lines equipped with the ATS-P system accounted for 706 kilometers as of December 31,1995.

Applying the ATS-P to moderate traffic lines, it would be necessary to develop a cost-effective on-board equipment and wayside equipment. In February,1994 authors decided to develop the wayside equipment of such a system at first and named the developed unit the ATS-$P_{(N)}$ in October,1995.

ATS-$P_{(N)}$ also uses the transponder technology and especially makes full use of the ground coils without power supply cable. The ATS-$P_{(N)}$ system is constructed of several ground coils and relay-modules to change the train control telegrams according to signal indications.

It's really significant that the ATS-$P_{(N)}$ system is simpler than the ATS-P ground system. So, the total cost of ATS-$P_{(N)}$ is less than 50% of the ATS-P ground system. The ATS-$P_{(N)}$ will be applied on two conventional lines in 1997.

1 ATS-P system[1)]

Transponders are generally used as repeating devices in communication satellites and for identifying an aircraft. But as shown in Fig.1, it serves as a digital communication device for sending and receiving information between ground coils and on-board coils.

Some transmission specifications for the transponder are illustrated in Table 1. The fixed information such as a station name, etc., can be transmitted using

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electromagnetic waves from an on-board coil as energy. The transmission of electromagnetic waves from the train transmitter to ground devices is known as the energy transmission. ATS-P uses a transponder to enable the ground-to-train communication of a large quantity of information.

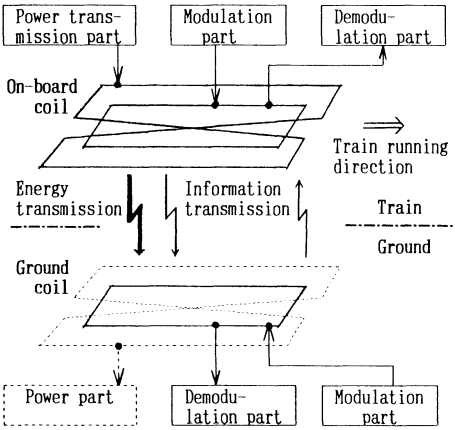

Fig.1 Transponder configuration

Table 1 Transmission specification of transponder

Items		Frequrecy and etc.
Information transmission	Ground → train	1.7MHz (FSK modulation)
		64 kbit/s
	Train → ground	3.0MHz (FSK modulation)
		64kbit/s
Energy transmission	Train → ground	245kHz

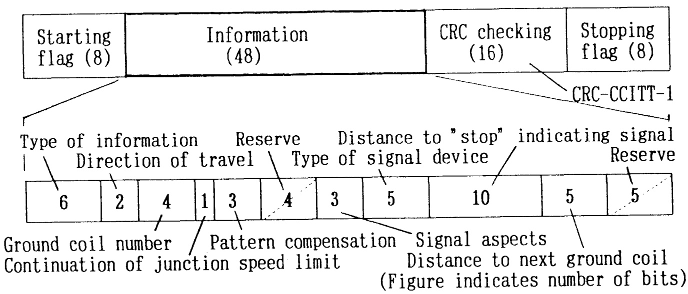

Fig.2 Telegram configuration of ATS-P system

Fig.2 shows the format of a telegraphic message transmitted from ground to train in ATS-P system. All figures there indicate the numbers of bits. The transmission of the message from ground to train uses an 80-bit telegram format with 16 bits for CRC detection, 8 bits for flag, and the remaining 48 bits for the information. 10 bits are used for the information of the distance to a stop indicating signal. Setting 1 bit for 4 meters, therefore 10 bits indicate from 0 meter to 4092 meters.

As shown in Fig.3, the ATS-P system is composed of both ground devices and on-board devices. The ground devices in each block consist of one encoder and several repeaters with each ground coil. The encoder transmits the telegraphic messages on the current status of the signal indication to each repeater by FSK(Frequency Shift Keying)-MODEM at 1200bit/s. The repeater sends at 64kbit/s repeatedly the telegraphic messages received from the encoder to a train through a ground coil by FSK modulated signal. And it sends at 1200bit/s the telegraphic messages received from a train through a ground coil, to the encoder. One encoder and each repeater

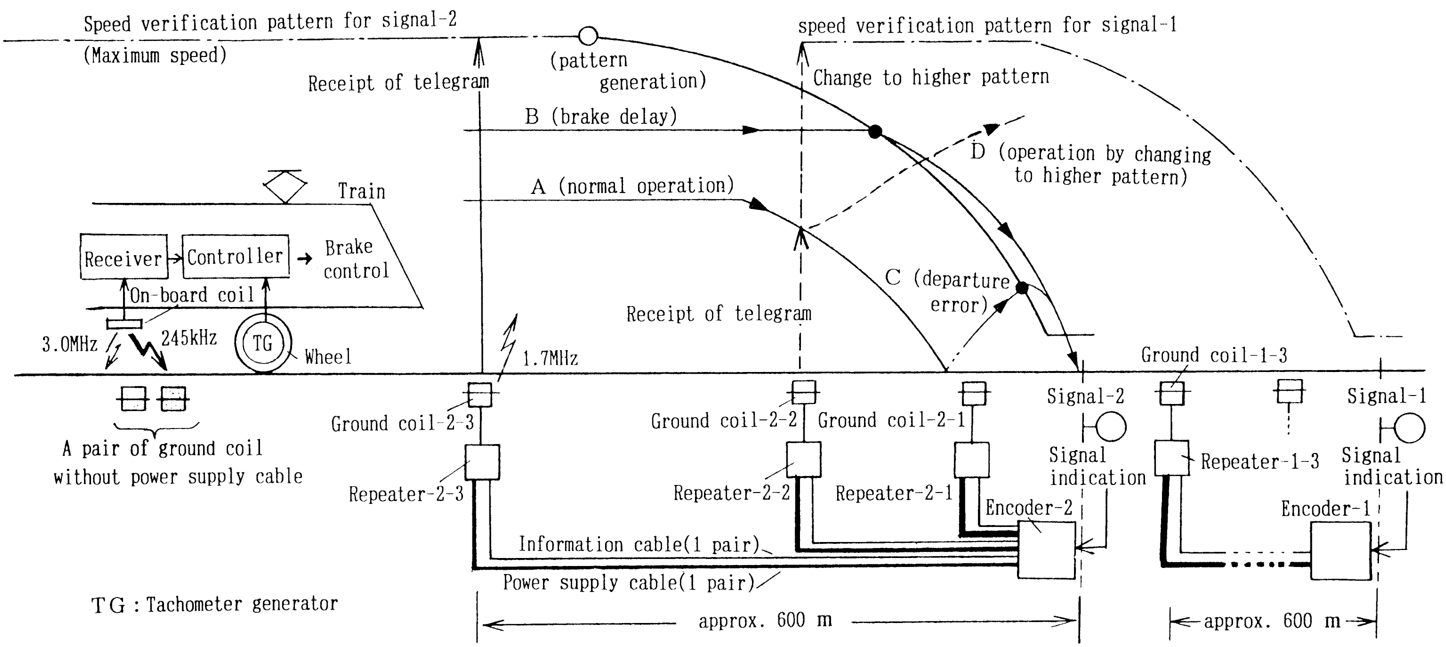

Fig.3 Configuration and operation of ATS-P system

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are connected by a pair of cables for information and a pair of cables for power supply individually.

And there are a pair of ground coils whose power is supplied by the energy transmission from an on-board coil, for sending the fixed information such as the "speed limit at a curve".

The on-board devices consist of a receiver to detect and decode the telegraphic messages received through an on-board coil, and a controller to activate the brake by comparing the on-board speed verification pattern and the practical train speed from the tachometer-generator(TG).

The ground devices and the on-board devices are both the products of microelectronics. The encoder, the receiver and the controller are composed of so called fail-safe microcomputers.

The specific primary objectives which ATS-P is designed to achieve are prevention of accidents due to a stop signal violation and over speeding at places such as turnout or curves. Fig.3 shows an outline of the operation of this system. There is the ground coil-2-3 at any point 600 meters ahead of the signal. When the signal-2 is indicating 'stop', the ground coil-2-3 sends the "distance to the signal-2" to the train and the controller generates a speed pattern when the train comes up to about 600 meters before the signal.

After the pattern has been generated, the train speed is compared with the pattern speed continuously and the brake is automatically activated if the train speed is higher than this pattern speed. The train is thus brought to a stop before the stop signal-2.

In Fig.3, A is the train movement in normal operation, B is the case when the application of the brake is late, and C is the case of a mistaken departure of the train. When the indication of signal-2 changes from "stop" after the pattern has been generated,the on-board pattern must be renewed so as not to decrease the transportation efficiency. D shows this case. If the train continues to run farther on the line,the train will receive new information such as "the distance to the stop indicating signal-1" from ground coil-2-2. So, the "distance to stop signal" will be lengthened to renew the speed verification pattern. When this occurs, the braking action will cease even if the brake is being applied.

2 Construction and Function of ATS-$P_{(N)}$

Almost all of trains in the Tokyo Metropolitan area and its outskirts have been already equipped with ATS-P on-board devices, because they go into the ATS-P sections. So,JR-East intends to reduce the construction cost of the ATS-P ground system. The basic points required of new ATS-P, named ATS-$P_{(N)}$,are equal safety to ATS-P, low cost, no remodeling of ATS-P on-board devices, and accommodation for the operation at 160 km/h or less.

Fig.4-a) shows the standard construction of the ATS-P ground system and the distance information transmitted from each ground coil . This distance information is changed according to the signal indications.

In JR, generally, the existing ATP system named ATS-S(Standard) is also in service on the ATS-P operating lines. The ATS-S ground coil is controlled by the relay HR.

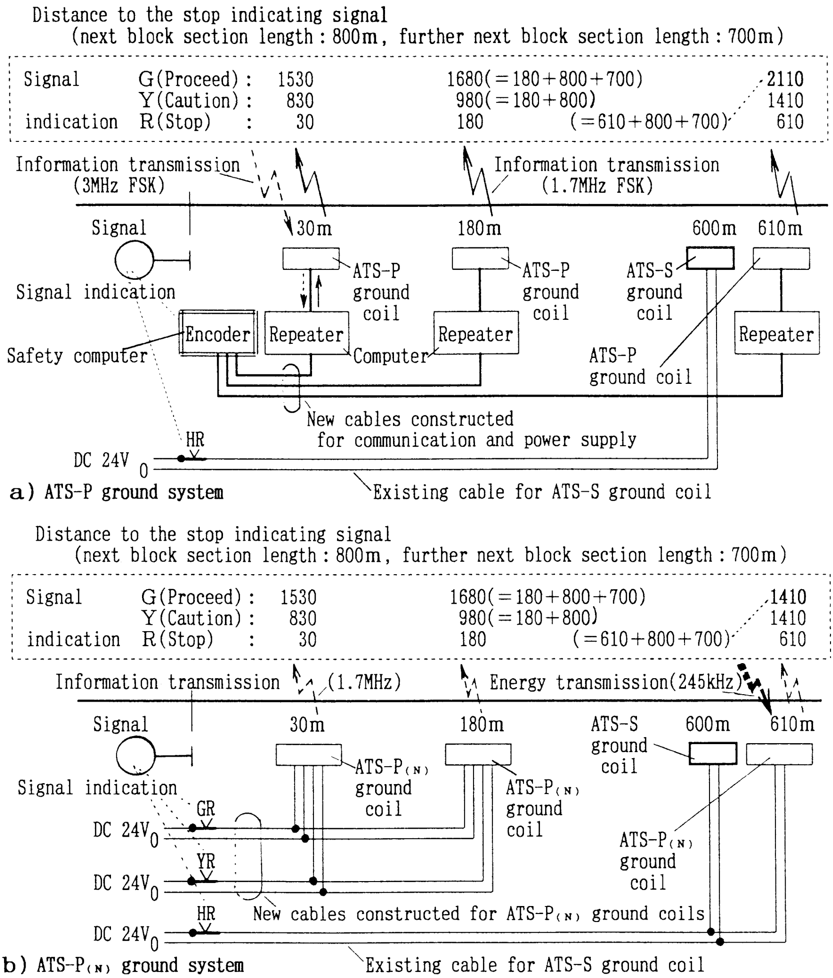

Fig.4 Comparison of ground system between ATS-P and ATS-P(N)

Table 2 Status of relays according to signal indications

Signal indication	Status of relays		Comment	
G(Proceed)	GR ↑ :GPR ↑	HR ↑	R ↑ : Relay operation	R ↓ : Relay non-operation
Y(Caution)	YR ↑ :YPR ↑		R Switch on	R Switch off
R(Stop)	GR ↓ :GPR ↓ YR ↓ :YPR ↓	HR ↑	R Switch off	R Switch on

Table 2 shows the operation of relays and the status of those contact points. When the signal indication is "G"(proceed) or "Y"(caution),the contact point of relay HR is made and the ATS-S ground coil resonates with 105kHz. When the signal indication is "R"(stop),the contact point of HR is broken and the ATS-S ground coil resonates with 130kHz. When a ground coil is in the coupling with an on-board coil, the ATS-S ground coil shifts the oscillation frequency of the ATS-S on-board coil from 105kHz to 130kHz at signal indication R.

Fig.4-b) shows the standard construction of the ATS-$P_{(N)}$ ground system and the distance information transmitted from each ground coil. This ATS-$P_{(N)}$ is composed of some ground coils without power supply cable (called $P_{(N)}$ ground coil) and the control unit with relays. The ground coil has some telegraphic messages in it and each message corresponds to the signal indication. This telegraphic message includes the distance information from the ground coil to the stop indicating signal. The format of this message is the same as shown in Fig.2. The selection of the telegraphic messages to be transmitted to the trains depends on the signal indication.

To cite the case in Fig.4-b) as a typical example, $P_{(N)}$ ground coils are located at 610m,180m and 30m away from the signal respectively. Although it is necessary for the 30m-coil and the 180m-coil to be provided with newly installed relays GR and YR and cables, it is not necessary for the 610m-coil, because the existing relay HR and cable for the existing ATS-S is applicable to the 610m-coil without change. This saves the construction cost, as compared with ATS-P ground system.

The 610m-coil has two telegraphic messages for signal indication Y(caution) and R(stop). A 180m-coil and a 30m-coil each have three messages according to signal indications G(proceed), Y and R.

When the signal indicates R, each coil allows a train to run farther beyond 30m, 180m, 610m, respectively, each of which means the distance from the ground coil to the signal. If this signal turns to Y, the next signal will indicate R. So, next block section length (in this case, 800m) would be added to that distance.

When this signal indicates G, the further next signal might be R, then the further next block section length (in this case, 700m) should be add more. But the 610m-coil could give only the distance in case of caution (i.e. 1410m) while this signal indicates G.

Excepting the distance information in the 610m-coil at signal indication G, the distance information of ATS-$P_{(N)}$ is similar to one of ATS-P at any signal indication.

3 Functions of a Ground Coil

Fig.5 shows the circuits of the $P_{(N)}$ ground coil, which selects the telegraphic message according to the signal indications and transmits it using the energy from a train. This $P_{(N)}$ ground coil, which has three messages, is composed of a power receiver antenna , and rectifier circuits, and relay circuits for selecting one suitable message, and an OR logic circuit, and a circuit which converts the message from parallel to serial data formula, and a transmitter circuit, and an information sender antenna, and so on.

When signal indicates G in Fig.5, as in this case relay GR is in operation and relay YR is not, then only the contact point of relay GPR is made, and the telegram for G is sent to the transmitter. In case of Y, relay YR is in operation and relay GR is not. Then only the contact point of relay YPR is made and the contact point of relay GPR is broken. So, the telegram for Y is sent to the transmitter.

When the signal indication is R, both GR and YR are not in operation. Because of non-excitation of GPR and YPR, the telegram for R is sent then to the transmitter.

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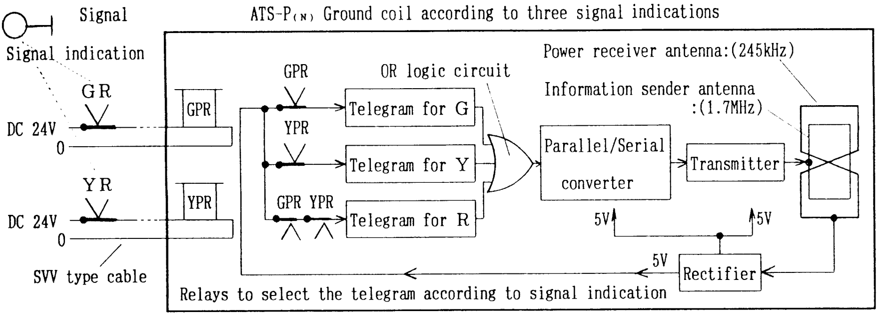

Fig.5 Structure of an ATS-P$_{(N)}$ ground coil

The relays in a ground coil are supplied with DC 24V by the voltage converter located near the signal. To isolate the lightning-surge voltage, this DC voltage is not used as the power source for other circuits in the ground coil but used for the relays selecting messages according to the signal indications. The inexpensive SVV type cable is applicable for supplying DC voltage to the coils.

The ATS-P on-board coil radiates the electromagnetic energy with 245kHz. The ground coil is fed by this energy coming from the on-board coil. While the ground coil is coupling with the on-board coil, the power receiver antenna catches the electromagnetic energy. The received energy is converted and smoothed to DC 5V. This DC 5V is the power source for the circuits in the ground coil. Only while the DC 5V is fed, only one message selected by the relay logic is sent to the transmitter through the OR circuit and the amplifier, and modulated with 1.7 MHz to FSK signal, and transmitted to the train from the information sender antenna. The message composed of 80 bits is transmitted successively and repeatedly while the power is supplied from the power receiver antenna.

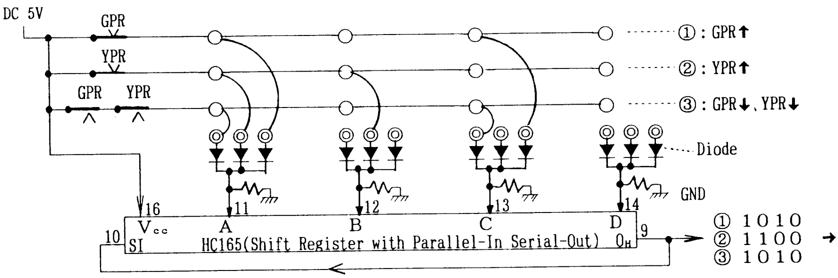

Fig.6 Circuit diagram to set up telegrams and transform parallel to serial

This FSK signal from a ground coil is captured by the receiver through the on-board coil and demodulated to a telegraphic message. This message includes the information about the distance to stop indicating signal and it is available for train control.

As an example,Fig.6 shows a circuit composed of the message setting and selecting circuit, the wired OR circuit and the parallel/serial converting IC. The telegraphic message setting pins ○ for logical "1"s of three signal indications are allocated on the DC 5V power lines beyond the selection circuit with relay GPR and YPR. Input terminals A ,B ,C and D of HC165-IC are connected to DC 0V(GND) through electric resistance. Therefore, when all input pins ◎of a terminal D are not connected to any setting pin ○, the logical input to that terminal is always "0". As an example of ①,the bit-sequence of a telegraphic message is set as "1010" when only a relay GPR is operating, the input pins ◎ of two input terminals A and C are connected to the pin ○ on the highest line.

To select one message from three telegraphic messages, the wired OR circuit with a set of three diodes is used. When the DC 5V power is applied to the setting circuit and HC165-IC,the serial bit-sequence of ①, ② or ③ is transmitted from the output terminal O_H. It's clear that the message setting and wired OR circuits for four signal indications are easily constructed in accordance to the one in Fig.6.

4 Characteristics of ATS-$P_{(N)}$ Ground Coil

Fig.7 shows the setting of an $P_{(N)}$ ground coil on a sleeper. The shape of $P_{(N)}$ ground coil is 220mm long and 380 mm wide. In order not to hinder the maintenance wagon tamping the ballast between sleepers, the $P_{(N)}$ ground coil would be set upon the sleeper wholly inside of its surface.

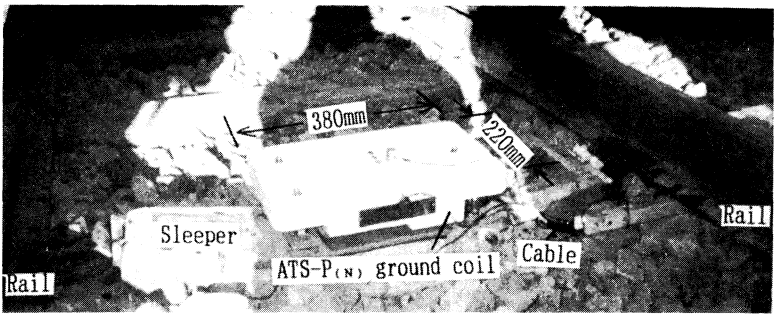

Fig.7 ATS-$P_{(N)}$ ground coil set on sleeper

This shape of $P_{(N)}$ ground coil can transmit the telegraphic message more than four times to a train running at 160km/h. ATS-$P_{(N)}$ and ATS-P ground systems are equivalent in the ground-to-train transmission characteristics. Then this shape of ATS-$P_{(N)}$ is applicable to the section where trains run at 160 km/h.

Fig.5 shows the $P_{(N)}$ ground coil at three signal indications(G,Y,R). In this ground coil, three telegraphic messages for each signal indication are installed and each message is formed in proportion to HDLC telegraphic forms.

The effects of break down or short circuit between wires in the SVV type cables are discussed for this $P_{(N)}$ ground coil. Table 3 shows the relation between activation of relays and the selected messages under break down of wires. When the wires exciting relay GPR or YPR are broken down, all telegraphic messages are normal ones or ones according to R(stop).

Table 3 Selected telegrams under the break down of wires

Status of relays		Selected telegram	Judgment
GPR	YPR		
↓(brake down)	↑	Telegram for Y	Normal
↓(brake down)	↓	Telegram for R	Safety output
↑	↓(brake down)	Telegram for G	Normal
↓	↓(brake down)	Telegram for R	Safety output
↓(brake down)	↓(brake down)	Telegram for R	Safety output

Table 4 Selected telegrams under the short circuit between wires

Status of relays		Selected telegram	Judgment
GPR	YPR		
↑(Short circuit by YPR wire)	↑	Telegram for G and Telegram for Y	Safety output (CRC check error)
↑	↑(Short circuit by GPR wire)	Telegram for G and Telegram for Y	Safety output (CRC check error)

And when DC 24(V) power supplier breaks down, it seems that the telegraphic message according to R is selected similarly to the break down of all wires. Table 4 shows the relation between the activation of relays and the selected messages as under the short circuit to other wires. When the wires exciting relay GPR or YPR are shorted to one another, all of the telegraphic messages which are selected by logic circuits in the ground coil are normal ones or ones including CRC check error. When both of GPR and YPR relays are activated simultaneously, both of telegraphic messages according to G(proceed) and one according to Y(caution) are selected at the same time and the composed telegraphic message is transmitted. But the on-board receiver detects the CRC error in this telegraphic message and doesn't adopt the message for train control. In this case, the train operation doesn't go smooth, but the safety of train operation is assured.

In JR East,the ground coils without power supply cable for ATS-P were introduced since 1989, amounting to 553 sets as of April,1993. The MTBF(Mean Time between Failure) of one of these ground coils is estimated at more than 6.6×10^6 (Hour) based on the practical operating results. As the component in the $P_{(N)}$ ground coil is the same as the one in a ground coil without power supply cable and additional relays and telegraphic message setting circuits, the MTBF of one $P_{(N)}$ ground coil is guessed as about 4.3×10^6 (Hour). Because the $P_{(N)}$ ground coil operates only in coupling with the on-board coil, the total operating time of this ground coil is very short. As almost the whole period after its installation is non-operating, that may be equated to a period of preservation. So, the extremely great MTBF comes from by an extremely short activation time.

Fig.8 shows the cost comparison between the ATS-P and the ATS-$P_{(N)}$ in Fig.4. The laying costs of crossing pipe under rails and the cost of testing and others are same between ATS-$P_{(N)}$ and ATS-P. But, the cost of equipment and construction of ATS-$P_{(N)}$ is extremely reduced to about 27.8% comparing with 77.8% for ATS-P. So, the total cost of $P_{(N)}$ ground system is reduced to half that of the ATS-P.

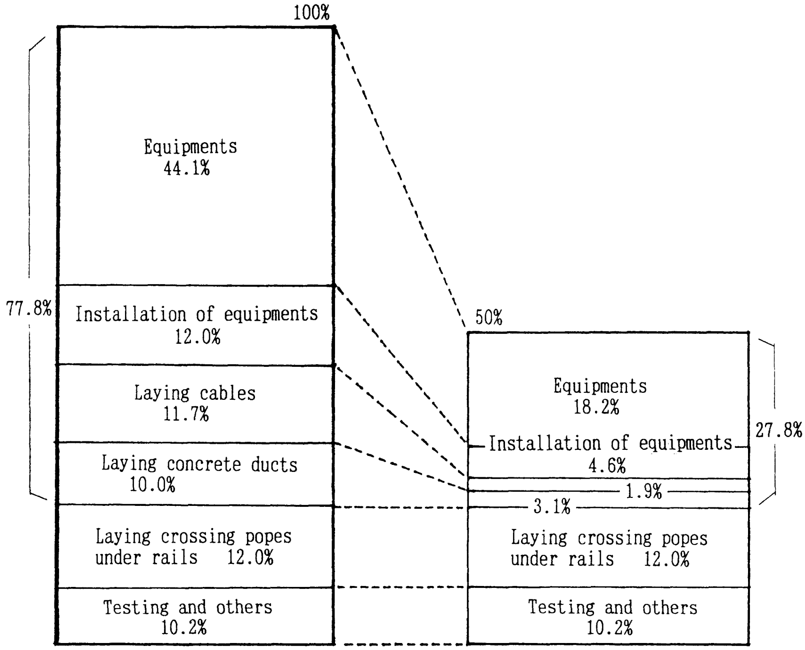

Fig.8 Cost comparison between ATS-$P_{(N)}$ and ATS-P ground system

5 Conclusions

Our aims about ATS-$P_{(N)}$,that is, equal safety to ATS-P, low cost, no remodeling ATS-P on-board devices, and accommodation for the operation at 160 km/h or less have all been achieved. And the ATS-$P_{(N)}$ is so cost-effective compared with ATS-P ground system that the ATS-$P_{(N)}$ ground system is scheduled for installation on two conventional lines in the Tokyo metropolitan area in 1997.

Reference

1. Miyachi, M.. The Development of the Speed Verification Type ATS with Transponder, *Quarterly Report of Railway Technical Research Institute,* pp.103-106, Vol.29, No.3, Japan, 1988.