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High Capacity Mobile Telephone

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Mobile telephone service in our country started first in Tokyo from December, 1979. NTT started a high capacity mobile telephone system service in Tokyo districts from May, 1988, and in Osaka districts from December, 1988. At present, a nation-wide service is accomplished, covering approximately 600 cities including the districts having the conventional system. The present number of mobile telephone owners amounts to 215,000 as of December, 1988.
Further, the entry of new business enterprises into the mobile telephone market started for example, Nippon Ido Tsushin Corporation started the service in 23 Tokyo areas from December, 1988. According to the revised Telecommunication Business Law (April 1, 1985), the manufacture and sales of terminal equipment have been opened, thus making it possible to offer the terminal devices which may satisfy the users' diversified needs.
From these background, our company has developed a high capacity handset and hands-free type for mobile telephone, which is designed to obtain the function to the maximum capacity as a mobile telephone, including "Perfect Function," "Ease of Operation" and "Car Matching Design."

1. Introduction

Since mobile telephone service began in December 1979 in the Tokyo Metropolitan area, the mobile telephone has increasingly become part of our everyday lives. In the meantime, the amended Telecommunication Business Law (April 1, 1985) deregulated the manufacture and sale of terminal equipment (*1), thereby opening the way to the development of terminals tailored to user needs.

The mobile telephone handset and the handsfree telephone described in this paper (hereafter collectively called a mobile telephone system) are subject to numerous design constraints, as they are installed within a car passenger compartment. Ease of installation and operation as well as aesthetic appeal are major factors to be considered in the development of a mobile telephone system. This paper presents a mobile telephone system developed to the Toyota Motor Corporation's specifications, with design emphasis on these factors.

*1 Amendments to the Telecommunication Business Law have removed prohibitions on the distribution of terminal equipment, previously the sole domain of NTT and KDD.

2. High-capacity mobile telephone system overview

Japan's first mobile telephone service commenced operation in Tokyo in December 1979. This service has since been extended to Osaka in November 1980 and to Nagoya in January 1981. Further, NTT began offering a high-capacity mobile telephone service in Tokyo in May 1988, then in Osaka in December. This service now covers about 600 cities nationwide, with as many as 215,000 subscribers as of the end of December 1988. At the present rate of progress, the number of subscribers is predicted to exceed 2 million by the year 2000. Figure 1 reviews the evolution of the mobile telephone service in Japan, including an outlook for the next few years.

The number of mobile telephone subscribers has been rising, with the major impetus to growth coming from the 23 Tokyo metropolitan wards. To meet this increase, the sphere of communication between base stations and mobile stations has been divided into small zones, each measuring from 3 km to 5 km in radius, thereby allowing more base stations to use the same frequency channels. However, since this solution to increased subscriber de-

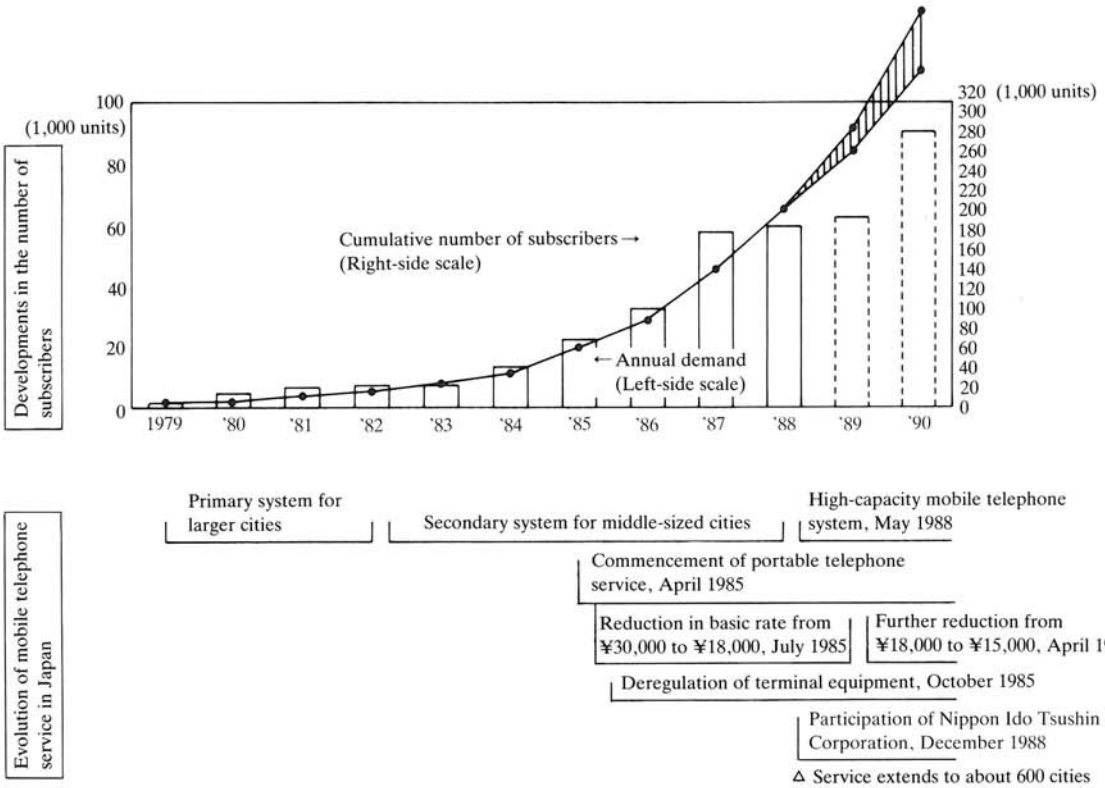

Figure 1. Forecast of mobile telephone stations

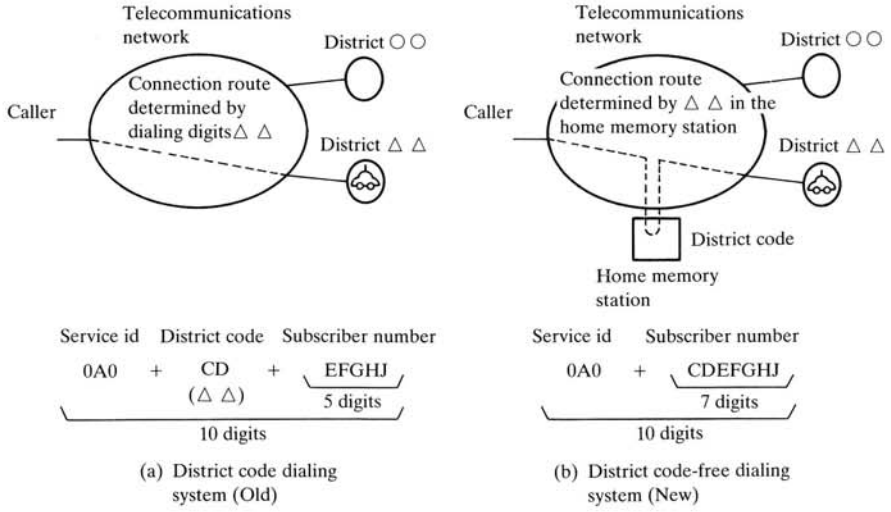

Figure 2. New and old dialing systems

mand is bound to soon reach its limits, a high-capacity mobile telephone system has been introduced to push subscriber capacity beyond its previous limits.

2.1 Expanded mobile telephone numbering capacity

With the previous dialing system, the caller to a mobile telephone had to dial the service id "030" first, followed by a two-digit district code and a five-digit remote subscriber number. Under this numbering plan, up to 100,000 subscribers could be accommodated at most. Beginning in March 1988, an alternative plan was therefore implemented. The new plan features seven-digit subscriber numbering to eliminate the need for district codes. In addition to accommodating up to 10,000,000 subscribers, this system uses "030" service id to reach subscribers 160 km or less apart, and an "040" service id to reach subscribers 160 km or farther apart. Figure 2 compares the new and old dialing systems.

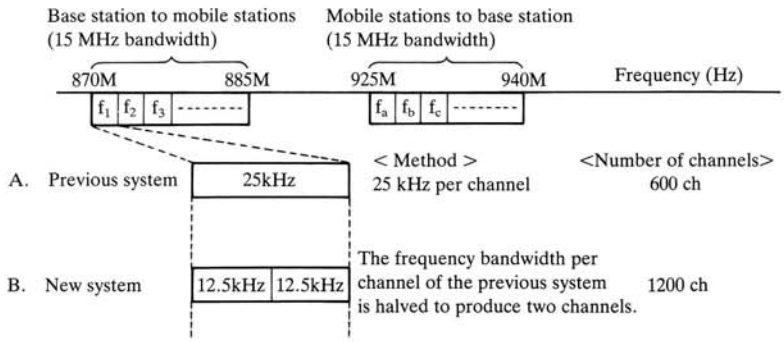

Figure 3. Narrower radio channels

Table 1. Comparisons of principal specifications

		NTT high-capacity mobile telephone system	Conventional system
Frequency band		800-MHz band	800-MHz band
Channel spacing		12.5 kHz	25 kHz
Voice signal modulation		Phase modulation	Phase modulation
Maximum frequency deviation		±2.5 kHz	±5.0 kHz
Control signals	Call origination/termination control channel	2400 bps split-phase control	300 bps split-phase control
	Speech channel	2400 and 100 bps split-phase signals	300 bps split-phase control
Diversity method		Switching diversity reception after detection	None
RF output power		Base station: 25 W max., mobile stations: 5 W max.	Base station: 25 W max., mobile stations: 5 W max.
RF output power control		Two-way adaptive output power control	Independent mobile station output power control
Voice processing (privacy feature)		Option	None

2.2 Expanded subscriber support capacity

Mobile telephones operate in the 800 MHz band, using from 870 MHz to 885 MHz to communicate from base stations to mobile stations, and from 925 MHz to 940 MHz to communicate from mobile stations to base stations. According to the previous system, each of these 15 MHz bandwidths was divided into 600 channels of 25 kHz each. The high-capacity mobile telephone system halves this frequency bandwidth per channel to 12.5 kHz to create 1,200 channels. Figure 3 shows how radio channels have been narrowed in the new system.

2.3 Higher quality and functional enhancements

New techniques have been developed to achieve higher product quality to match the broader system capacity. One is diversity, whereby the signal in each channel is received by two antennas to enable the selection of either of the two signals having a higher field intensity. This method is most efficient in urban areas where there is much reflection of signals by buildings. Even with this method, however, successful signal reception could be impaired by increased radio frequency interference. To protect against this condition, the diversity method is complemented by interference detection/channel switching. When signal reception in one channel is poor, communication is switched to another channel in the same zone which has less interference. As the mobile station moves from one zone to another, the base station transmits a channel switch signal to the mobile station. This signal is transmitted at frequencies outside the voice band to eliminate the "beep" noise which occurs when the channel is switched. Another enhancement offered by the high-capacity system is voice processing (privacy feature option). Table 1 compares the principal specifications of NTT's high-capacity mobile telephone system and the conventional system.

3. Development goals

Because the mobile telephone is installed within the passenger compartment, it must meet three essential goals specifically aimed at lessening the driver's workload - ease of operation, functionality, and aesthetic appeal. The development of the

mobile telephone system has been specifically geared to achieve these goals.

1) Ease of operation

Call originating procedures have been simplified to enable the subscriber to easily and safely originate calls while driving.

2) Functionality

The noise level within a car varies with traffic density, cruising speed, open or closed windows, and many other conditions. The handset telephone has a common control for the receiver volume, speaker volume, and ringing tone to ensure good speech quality under passenger compartment noise conditions. The handsfree telephone has directional microphones to lessen blower noise and howl.*2

3) Aesthetic appeal

Colors and geometry matching the car interior have been selected.

*2 Howl

A singing or wailing sound caused by acoustic feedback from the speaker to the microphone.

Table 2. Handset telephone specifications

No.	Item		Specification
1	Rated voltage		DC + 13.2 V
2	Operating voltage		+10 V – +16 V
3	Ambient temperature		−20°C – +65°C
4	Storage temperature		−30°C – +80°C
5	Power consumption		300 mA or less (0.25 W voice output)
6	Mounting location		In the passenger compartment
7	Dimensions		71 (W) × 200 (D) × 74 (H) mm
8	Weight	Dial control	240 g
		Cradle	365 g
9	Sound transmitted to radio communications equipment		70% modulated by radio communications equipment at −10 dB
10	Sound received from radio communications equipment		70% modulated by radio communications equipment at −15.5 dB

0 dB = 0.775 Vrms

Figure 4. Outer view of handset telephone

4. Equipment summaries

4.1 Equipment features

4.1.1 Handset telephone

1) All controls and indicators are located on the handset for ease of operation.
2) A large LCD keeps the driver informed of the present status of the mobile telephone system. It shows the dialed number and various operation states. Bright LEDs keep the user visually informed of power, lock, and out-of-zone conditions. The LCD and the key area are backlighted for night operation. The cradle is illuminated by an LED to help the user to replace the handset.
3) Function (F) keys execute special functions. Often used keys are larger than other keys.

4.1.2 Handsfree telephone

1) Calls are originated simply by pressing speed dialing switches.
2) An automatic level control (ALC) minimizes the effects of level variations in the telephone line. A directional microphone cuts acoustic coupling between the speaker and microphone and also reduces vehicle noise. The microcomputer-controlled howl canceller, the directional microphone, and the ALC make handsfree conversation possible.
3) One speaker of the audio system is used during call origination, termination, and speech. Other speakers in the car are turned off to prevent the car radio or music system from interfering with the call.

4.2 Equipment specifications

4.2.1 Handset telephone specifications

Figure 4 shows the handset telephone. Table 2 summarizes its specifications.

Figure 5. Outer view of hands free telephone

4.2.2 Handsfree telephone specifications

Figure 5 shows the handsfree telephone. Table 3 summarizes its specifications.

4.3 Equipment functions

4.3.1 Handset telephone functions

Table 4 lists the functions of the handset telephone.

Table 3. Handsfree telephone specifications

No.	Item		Specification
1	Rated voltage		DC + 13.2 V
2	Operating voltage		+10 V – +16 V
3	Ambient temperature		−20°C – +65°C
4	Storage temperature		−30°C to +80°C (other than microphones) −30°C to 100°C (microphones)
5	Power consumption		300 mA or less (0.25 W voice output)
6	Mounting location	Telephone computer	Trunk
		Microphone	Passenger compartment
		Speaker selector relay	Passenger compartment
		Telephone switches	Passenger compartment
7	Dimensions	Telephone computer	57 (W) × 212 (D) × 60 (H) mm
		Microphone	82 (W) × 70 (D) × 18 (H) mm
		Speaker selector relay	30 (W) × 65 (D) × 25 (H) mm
		Telephone switches	23 (W) × 65 (D) × 43 (H) mm
8	Weight	Telephone computer	530 g
		Microphone	26 g
		Speaker selector relay	148 g
		Telephone switches	53 g
9	Sound transmitted to radio communications equipment		Standard modulation by radio communications equipment at −10 dB
10	Sound received from radio communications equipment		Standard modulation by radio communications equipment at −15.5 dB

Table 4. Handset telephone functions

Function	Description
Speed dialing	Dials programmed telephone numbers with shorter digit sequences. Twenty speed dialing codes (from 00 to 19) can be stored in memory.
On-hook dialing	Permits the subscriber to originate calls without having to lift the handset.
Speaker reception	Allows the subscriber to listen to calls without having to lift the handset.
Redialing	Redials the last number dialed.
Scratchpad memory	Allows the user to get directory assistance and write a telephone number to memory during a call.
Dial number display	Displays telephone numbers as entered.
Dial lock	The dial, once locked, permits call origination only when the correct password is entered.
Transmitter muting	The mute key mutes the transmitter.
Answer hold	When the subscriber cannot answer an incoming call, pressing the end key places the call on hold.
Local number display	Displays the local telephone number.
Illuminated dial on/off	Turns the display and dial surface backlighting on or off.
Key tone on/off	Turns the key-press confirmation tone on or off.
Silent incoming calls	Suppresses the ringing tone from the speaker when a call is received.
Call duration display	Displays the duration of each call.
Voice processing on/off	Turns optional voice processing on or off.
Displayed telephone number transmission	Transmits the displayed telephone number.
System selection	Allows selection between an IDO line and an NTT line when IDO radio communications equipment is used. (This feature is exclusive to Toyota and requires licensing by NTT.)

4.3.2 Handsfree telephone functions

Table 5 lists the functions of the handsfree telephone.

Table 5. Handsfree telephone functions

Function	Description	Remarks
Speed dialing	Permits dialing of programmed telephone numbers by pressing speed dialing switches. Two telephone numbers can be programmed.	Feature exclusive to Toyota
Audio mute	Mutes audio when the handsfree telephone is used.	Feature exclusive to Toyota
Handsfree or handset operation selection	Selects handsfree or handset operation	
Receiver volume control	Controls the sound level of the receiver.	
Howl cancellation	Cancels howl by monitoring the audio signal level to automatically control amplifier gain.	

Table 6. Division of dial control cradle functions

Dial control	Cradle
Key entry	Radio communications equipment interface
LCD readout	Master-slave telephone control
Key entry confirmation tone output	Buffering of serial data input/output to and from the dial control
Serial data input/output to and from the cradle	Transmitter voice buffering and mixing
Transmitter and receiver voice mute	Receiver voice buffering
Receiver and speaker sound selection and volume control	Constant voltage

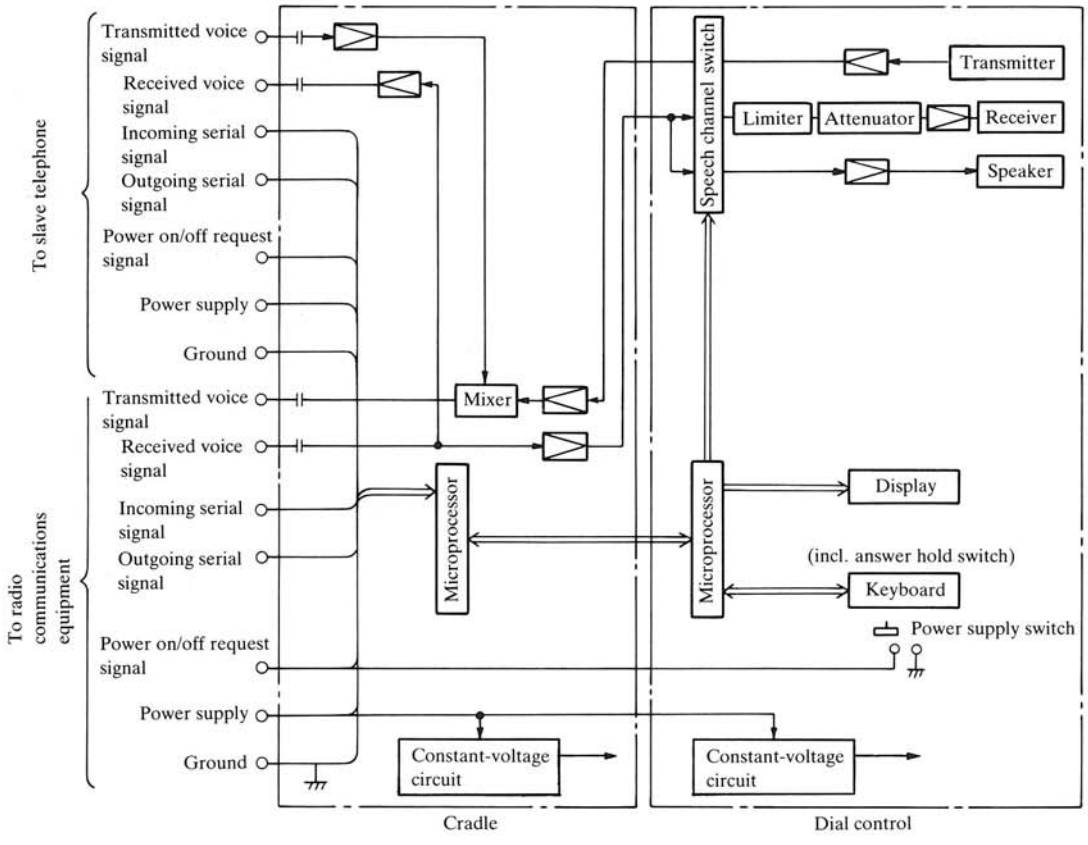

Figure 6. Handset telephone

Table 7. Arrangement

Item	Description
Master-slave telephone system	Potential for expansion allows the handset to be used as a master or slave telephone. An amplifier is inserted to keep transmitter and receiver signals from being attenuated.
Watchdog timers	The dial control and the cradle incorporate a watchdog timer circuit each to prevent program overruns.
Prevention of excessive acoustic impact	A limiter is inserted between the speech channel switch and the receiver to protect the receiver against excessive acoustic impact.
Shared variable resistor	A shared variable resistor controls the sound volume of the receiver, speaker, and ringing tone.

5. Design characteristics

5.1 Handset telephone arrangement and operation

The handset telephone is separated into two blocks: the dial control handset and the cradle. Each of these blocks houses a single-chip microprocessor for compact geometry and added reliability. CMOS ICs widen the operating temperature range and noise margin and cut power consumption.

Figure 6 is a block diagram of the handset telephone. Table 6 summarizes the dial control and cradle function. Table 7 describes the arrangement of the handset telephone.

1) Compact, lightweight geometry

Compact, lightweight geometry results from a simplified internal structure, effective use of internal space, and component materials selection with regard to thickness and other properties.

2) Car mount design

The mobile telephone is subject to different mounting constraints as compared with a subscriber telephone. The structural design of the handset telephone makes it adaptable to any type of car, permitting it to be installed in cramped spaces without interfering with the driver. It is designed to match the vehicle interior.

3) Ease of operation

The following features make the handset telephone easy to use while reducing its geometry and weight:

① A large LCD displays dialed numbers in two lines of six and four columns for ease of reading. The 10-column readout displays a sequence of 16 numeric characters stored in memory, higher-order size characters first, lower-order ten characters next.

② Call origination is as easy as pressing speed dialing switches.

③ Both the key panel and the LCD are backlighted for visibility and ease of operation at night.

④ The less frequently used power switch and the sound volume control do not protrude to prevent accidental operation.

4) Lock and unlock mechanism of the dial control

Figure 7 shows the lock and unlock mechanism of the dial control. Table 8 compares the lock and unlock mechanisms of the high-capacity handset telephone and the conventional handset telephone.

An important improvement in the present handset telephone is that the dial control is easily replaced by pressing it into the cradle from above, and that it can be detached simply by lifting it from the cradle. This improvement has been realized by analyzing and adjusting the structure, shape, and spring constant of the claw. The dial control has been adjusted for an unlocking force of 800 gf ± 200 gf to keep the handset in position even under vibration or impact and also to make locking and unlocking easy.

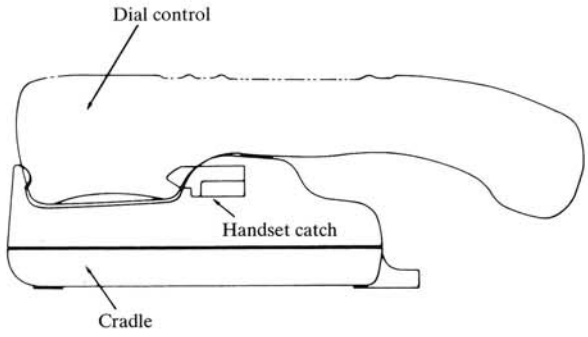

Figure 7. Lock and unlock mechanism

Table 8. Comparison of lock and unlock mechanisms (in Fujitsu TEN products)

	Conventional handset telephone	High-capacity handset telephone
Locking method	Insert the front part into position and press the back.	Press from above.
Unlocking method	Press a release lever.	Lift.
Control lock position	Holds the transmitter and receiver.	Holds both ends of the receiver.

The present structural modification allows the dial control to be locked in position by pressing down on it from above; This eliminates the need, associated with the previous type of handsfree telephone, to first insert the front of the handset into position and then press the back into place. Further, it can be conveniently unlocked without pressing a release lever.

5.2 Handsfree telephone arrangement and operation

The components of the handset telephone comprise a telephone computer (in the trunk), a microphone (above the steering column housing), speakers (which are also used for the radio or music system), a speaker selector relay, telephone switches (center panel), and an answer hold switch (center panel). This enables the driver to make a call without having to lift the telephone handset. For circuit simplicity, calls are originated with the handset by merely pressing the speed dialing switches. Telephone numbers are programmed by using the dial control of the handset. Figure 8 is a block diagram of the handsfree telephone. Table 9 summarizes the functions of its components.

5.2.1 Howl cancellation

The handsfree telephone features a scheme of transmitted/received voice selection. The received and transmitted voice signals are read into the microcomputer for averaging (after A/D conversion), so that the received and the transmitted voice signal, whichever is weaker, is reduced. This prevents the speaker output from being fed back to the microphone in such a way as to cause howl. Allowing for internal noise, the transmitted voice signal is reduced while the received voice signal is present, regardless of the levels of the received and the transmitted voice signals. Figure 9 shows the principle of operation of the howl canceller.

5.2.2 Microphones

The handsfree telephone uses two microphones. Front-to-back bidirectivity with a front to side level difference of 10 dB or more (300 Hz to 3 kHz) is achieved by using the microphone phase difference, which is the difference in time sound takes to travel from the source to the microphones. Sensitivity to the speakers and blower is lowered to lessen howl caused by acoustic coupling. The microphones are

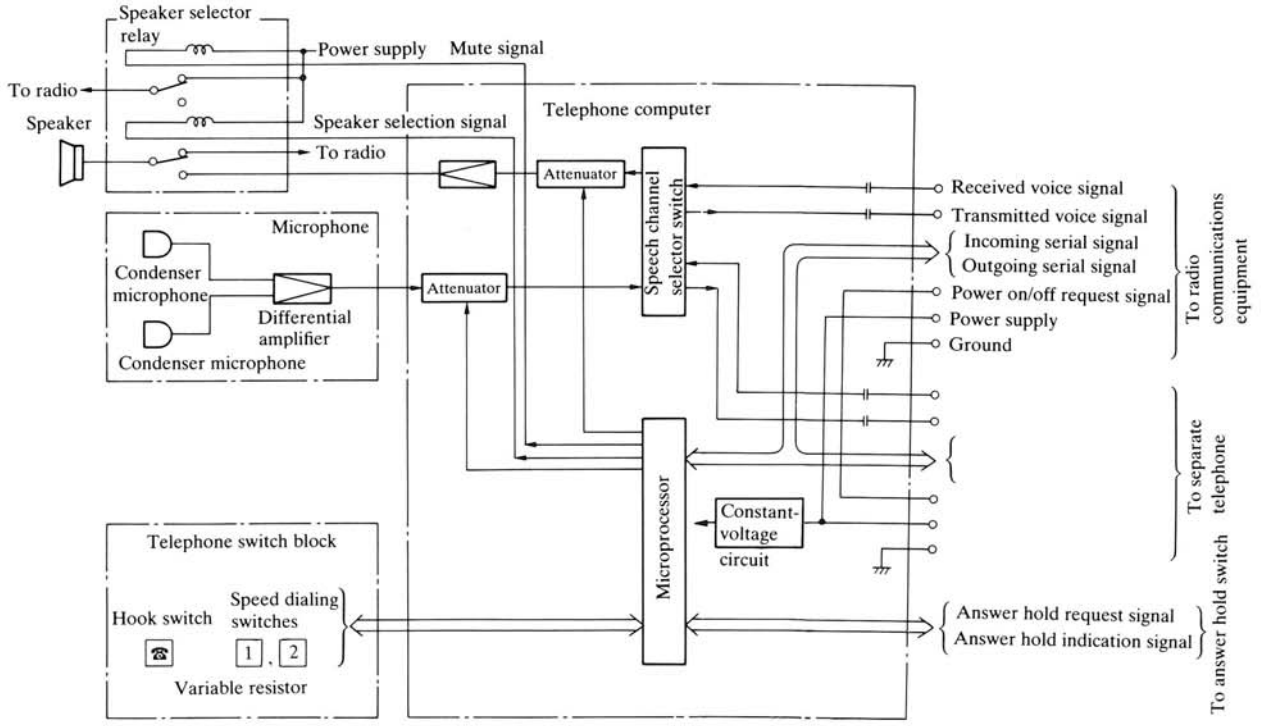

Figure 8. Handsfree telephone

Table 9. Functions of handsfree telephone components

	Function
Telephone computer	• Controls the handsfree telephone system with call origination signals generated by telephone switches to establish communication with radio communications equipment. • Transmits mute signals (audio off signals) and speaker selection signals to the speaker selector relay when the handsfree function is used. • Selects handsfree or handset operation. • Controls microphone input level and speaker output level. • Cancels howling caused by acoustic feedback from speaker to microphone.
Microphone	• Sends voice signals to the telephone computer. • Provides front-to-back bidirectivity.
Speakers	• Reproduce called party's voice, dial tones, ringing tones, etc.
Speaker selector relay	• Switches the speaker from the automobile radio/music system to the telephone system on receipt of mute or speaker select signals from the telephone computer.
Telephone switches	• Send incoming calls, on-hook signals (hook switch), and speed dialing signals (with two types of speed dialing switches) to the telephone computer. • Provide a variable resistor to control the speaker sound volume.
Answer hold switch	• Directs the telephone computer to output an answer hold signal to the radio communications equipment when the called party cannot answer the incoming call. (The exchange directs an announcement to the caller, informing the caller that the call cannot be answered.)

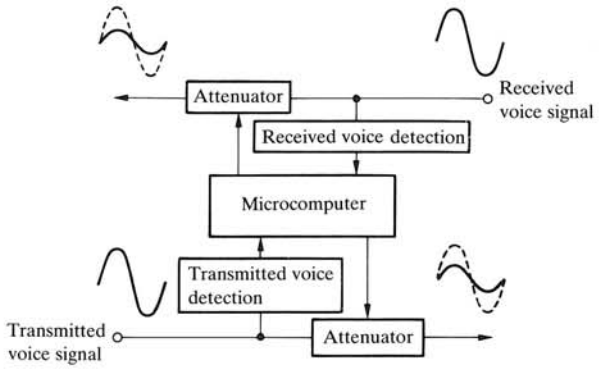

Figure 9. Principle of home canceller

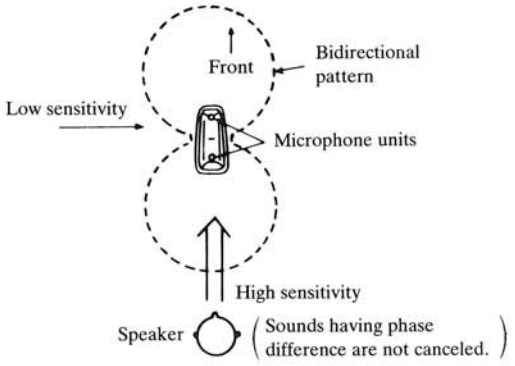

Figure 10. Principle of directional microphones

mounted above the steering column housing. They are made of heat-resistant ABS to withstand temperatures of up to +100°C.

Figure 10 shows the principle of operation of the directional microphones. Figure 11 shows their frequency characteristics.

5.2.3 Handsfree and handset mode speech selector function

Selection of handset and handsfree operation is done by pressing the hookswitch in the telephone switch block, by lifting the dial control, or by pressing the start key, whichever action occurs later.

Figure 12 is a diagram of state transitions between handsfree and handset operation.

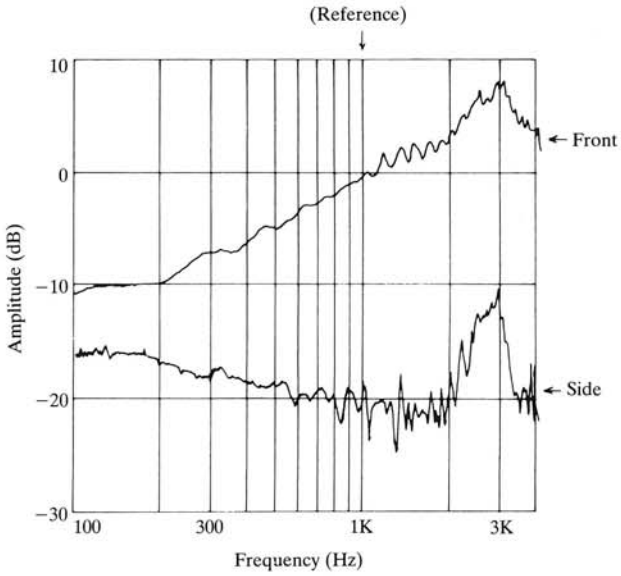

Figure 11. Directional microphone frequency response

6. Conclusion

The preceding discussion outlined the features and design characteristics of a high-capacity mobile telephone handset and a handset telephone developed with particular emphasis on ease of operation. Voice dialing, a possible future development,

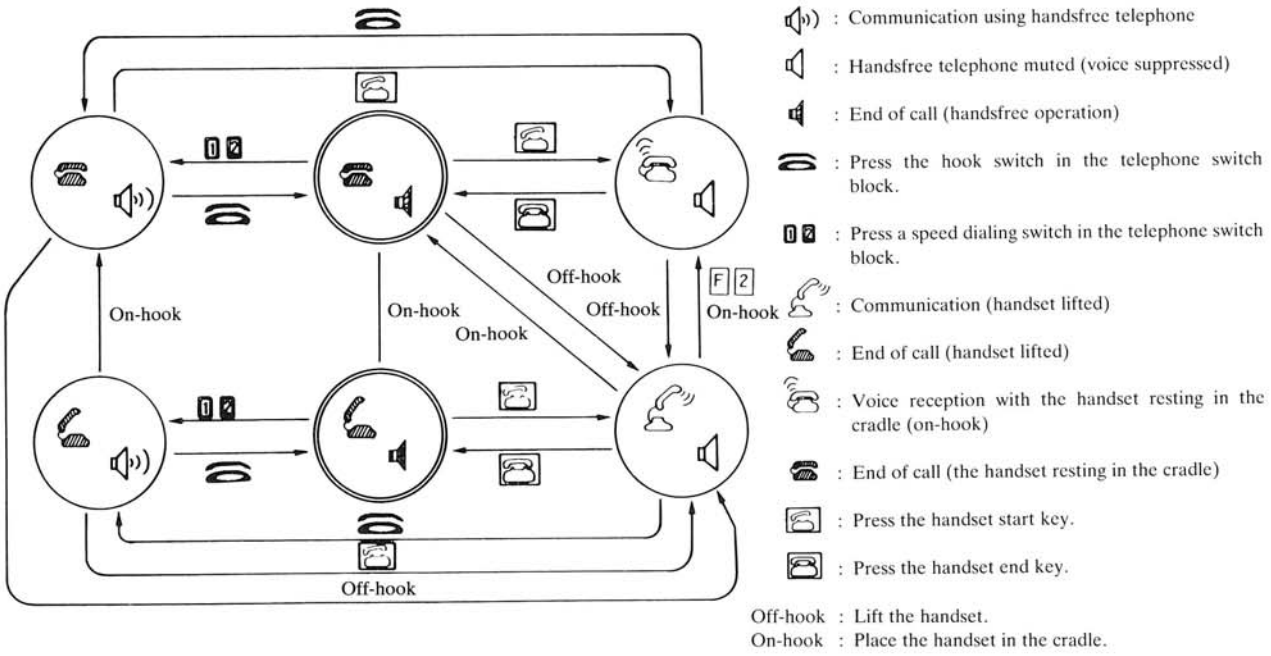

Figure 12. Handsfree/handset telephone communication switching status transition

may further enhance operating ease. The mobile telephone could also be developed into a data terminal sharing operation keys with other car-mounted equipment (such as a fax unit) or be merged with audio equipment in a single housing.

The authors are committed to developing easier-to-use mobile telephone handsets and handsfree telephones.

We thank all concerned for their cooperation in the development of this mobile telephone.

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