DEVELOPMENT OF COMPUTER-CONTROLLED ONE-CHIP CAR TUNER IC

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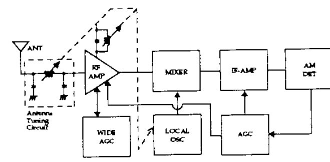
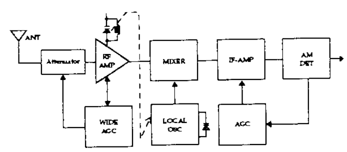
ABSTRACT
We have developed a computer-controlled, one-chip car tuner IC that features an FM single-IF diversity and AM Up-conversion system.
This paper mainly describes the features and technological advantages of the AM Up-conversion tuner system block that operates under computer control. The results of field testing have confirmed that the new one-chip IC with a built-in AM Up-conversion system satisfies the tuner specifications of automakers.

1. Introduction
The increasing use of electronic devices has been remarkable in automobiles. And it has enhanced automotive amenity while improving device performance. Car audio devices and systems are also offering improved its performance and more functions at an accelerated rate. To meet such requirements, we have developed a one-chip car tuner IC which enables an optimum signal receiving system to be constructed for AM/FM car tuners. The new one-chip IC includes all FM stereo tuner functions for single-IF diversity, as well as an AM Up-conversion tuner. The BUS interface and DAC circuit are provided on this chip, and the sensitivity in each function block and DAC output voltage are controlled through software. This new one-chip requires fewer peripheral components than a conventional tuner system consisting of several IC chips, and thus it will enhance tuner reliability, save more space, and reduce production costs. In addition, this IC can optimize reception parameters to improve performance through software. Specifically, the software architecture that improves tuner performance is an important feature of this new one-chip IC. And we have fully used available software to fabricate the AM Up-conversion tuner system. This paper also describes the AM-Up conversion tuner block in this IC that has the AM automatic tracking system.

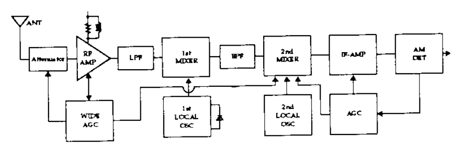
2. Conventional AM Tuner IC Systems



(a) μ-tuning system (Manual tuning)



(b) Single superheterodyne (Electrical tuning)



(c) Double superheterodyne (Electrical tuning)

Figure 1 Block Diagram of AM Tuner Systems

Figure 1 shows AM car tuner systems for comparison. The electronic tuning-type AM tuner uses a detuning system without the antenna tuning circuit employed by the μ-tuning system (manual system figure 1-(a)). This is because the corresponding antenna tuning circuit cannot cover the AM receive band due to the limited capacitive change ratio of the varactor diode (even when using the diode for variable tuning), from the standpoint of antenna load capacity.
Thus, the following problems may occur when using AM electronic tuning:
(1) Lower usable sensitivity than that of the μ-tuning system due to the detuned antenna
(2) Deteriorated cross-modulation characteristic due to the detuned antenna

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(3) Deteriorated cross modulation and possible blocking oscillation caused by the non-linearity of the varactor diode

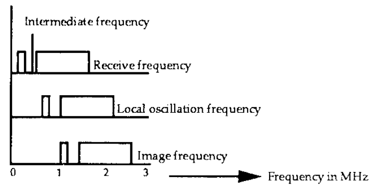
The cross-modulation characteristic is the most important consideration for AM tuners built under the tuner specifications of automakers.

Existing electronic tuning AM tuner IC systems can be divided into two types:

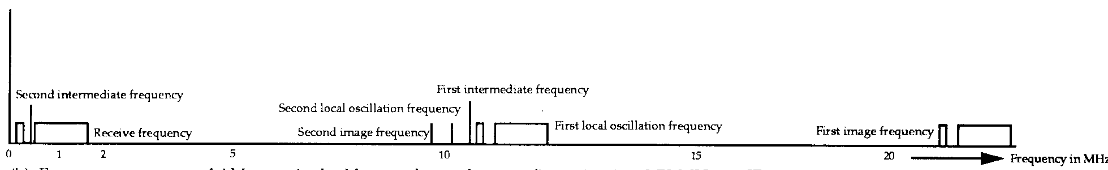
(1) Single-superheterodyne system (IF = 450 kHz) ; Figure 1-(b),

(2) Double superheterodyne system (1st IF = 10.7 MHz, 2nd IF = 450 kHz); Figure 1-(c)

These existing ICs have the receive frequency spectrum characteristics shown in Figure 2. For AM tuners of the single-superheterodyne system, the difference between the receive frequency and local oscillation frequency is relatively small (450 kHz). This small difference allows the electronic tuning system to use the same type of varactor diode as used in the local oscillation circuit even when using the RF amplifier as the tuning circuit load. In this advantage, the RF amplifier section can be provided with the selectivity characteristic, which is very effective in improving the cross-modulation



(a) Frequency spectrum of AM tuner in single superheterodyne configuration (at 450 kHz IF)

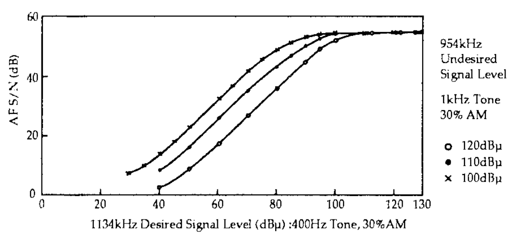


(b) Frequency spectrum of AM tuner in double superheterodyne configuration (at 10.70 MHz 1st IF and 450 kHz 2nd IF)

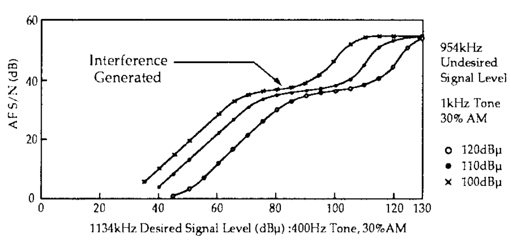
Figure 2 Frequency Spectrum Characteristic

characteristic.

For AM tuners of the double-superheterodyne system, the difference between the receive frequency and local oscillation frequency is 10.7 MHz. Due to this high difference, the same type of varactor diode as used in the local oscillation circuit cannot be used

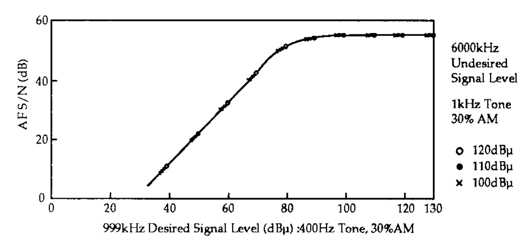


(1) Conventional AM Signal Conversion Tuner

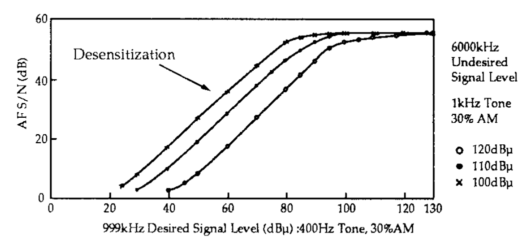


(2) Conventional AM Up-conversion Tuner

Figure 3-1 Cross-modulation Characteristics (Nearby Frequency Disturbance)



(1) Conventional AM Signal Conversion Tuner



(2) Conventional AM Up-conversion Tuner

Figure 3-2 Cross-modulation Characteristics (Short Wave Disturbance)

in the RF-tuned circuit. Should different types of varactor diodes be used in both circuits, and both circuits would have different modulation characteristics, which would make frequency tracking much more difficult. In terms of the electronic tuning-type AM tuner, the difference between the single-superheterodyne system and double-superheterodyne system is determined by whether the RF amplifier can be used as the tuning circuit load.

Figures 3.1 and 3.2 respectively show the cross-modulation characteristic caused by the nearest wave disturbance and that caused by the most distant. The figures indicate a superior cross-modulation characteristic using a single-superheterodyne AM tuner that can incorporate the RF-tuned amplifier circuit. This is why most car AM tuners on the market today employ the single-superheterodyne system.

Conversely, AM tuners of the single-superheterodyne system offer a lower image rejection ratio and whistle interference than AM tuners of the double-superheterodyne system. This is due to the small difference between the receive frequency and local oscillation frequency. Single-superheterodyne-type AM tuners also exhibit characteristic deviation caused by frequency tracking error according to the receive frequency. Figure 4 compares the characteristics of AM AGC-FOM deviation (according to the receive frequency) and Seek-Stop sensitivity deviation.

As shown in Figure 4, the AM tuner of the double-superheterodyne system is superior in terms of

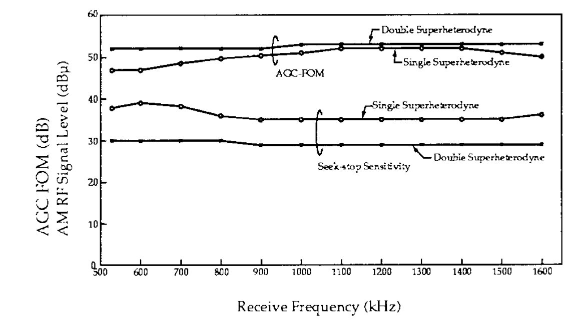


Figure 4 Seek-stop Sensitivity and AGC FOM Frequency Response

flatness in the receive frequency characteristic.

3. Improved AM Up-conversion Tuner System

Although use of the double-superheterodyne system in AM tuners increases set productivity, it adversely affects cross modulation. This is why conventional AM Up-conversion tuners using the double-superheterodyne system cannot satisfy automaker specifications regarding cross modulation, a most important tuner characteristic. We found that using the RF amplifier as the tuning circuit load is most effective in improving the cross modulation characteristic of AM tuners.

One objective in our developing the computer-controlled IC was to design an AM tuner that eliminates the disadvantages of the electronic tuning-type AM tuners shown in (b) and (c) in Figure 1. By adding the RF amplifier circuit to the AM Up-

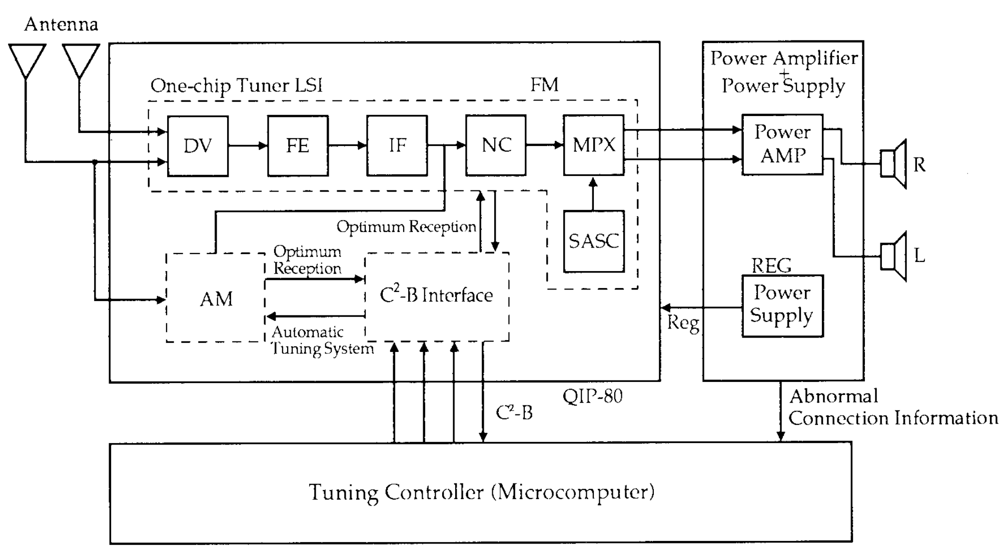


Figure 5 Car Tuner System Configuration

conversion tuner for use as the tuning circuit load, we were able to improve the cross-modulation characteristic. We also minimized the frequency tracking error common in single-superheterodyne tuners by using microcomputer control to set the tuning circuit to automatic tuning. Thus, we were able to improve both the characteristics and productivity of AM tuners.

Figure 5 shows the car tuner system using our one-chip IC. Except for the PLL control circuit, all commands issued from the tuning controller are executed and processed using only four C^2-B interface lines, which greatly simplifies the interconnections needed between the analog circuit and digital circuit. Our improved AM Up-conversion tuner operates in this system.

Figure 6 shows the main circuit which includes the AM tuner of the system shown in Figure 5. The RF amplifier circuit contains two systems of tuning circuit load and detuning circuit load. In Seek mode, the tuner operates as a conventional Up-conversion tuner. After selecting the desired station, the tuner is set to Reception mode through the RF-tuned amplifier circuit. The tuning voltage for the RF-tuned circuit is supplied by the DAC output voltage. The voltage is output after software correction of frequency tracking error.

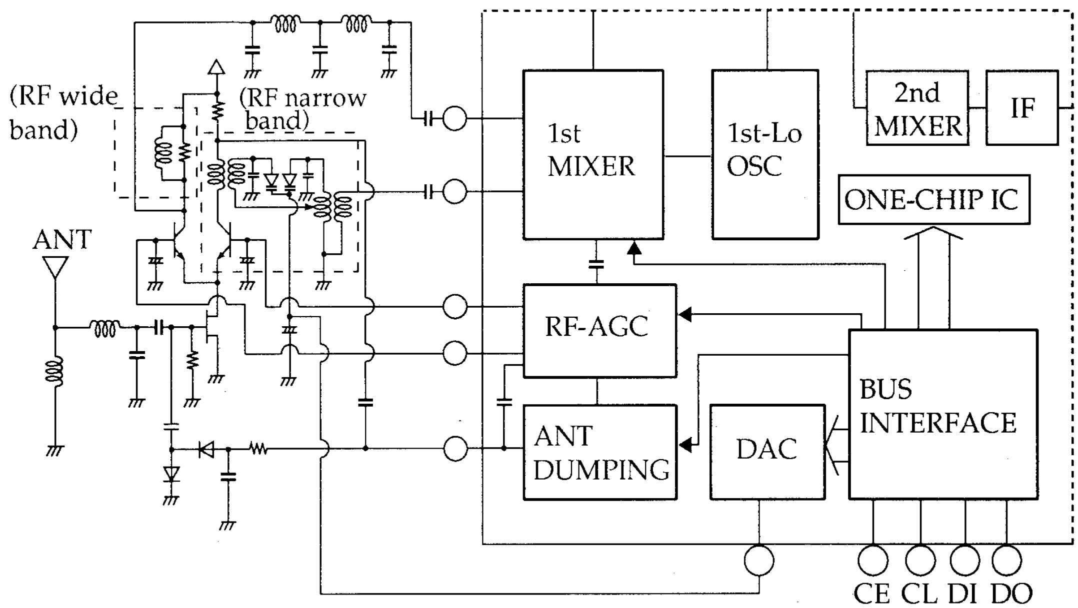


Figure 6 Improved AM Up-conversion Tuner

4. C^2B (Computer Control Bus)

Our new one-chip IC is designed for controlled communication using the C^2Bus, as described in Chapter 3. The C^2Bus refers to the bus format of a multi-LSI system used to establish reliable and economical inter-LSI communication. The C^2Bus is designed for use between LSIs in the same unit, but not for communication between two remote units over a long line. The C^2Bus is capable of eliminating complex arbitration processing because of the single-master system. This advantage greatly reduces the hardware workload and facilitates the construction of a very economical system. The C^2Bus can easily interface with different types of controllers through software or serial I/O without special hardware. Figure 7 shows the conceptual diagram of the C^2Bus system.

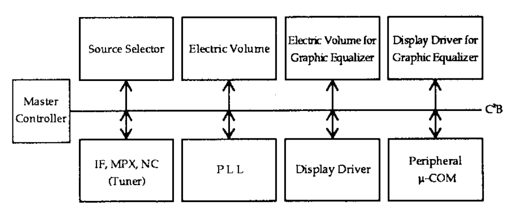


Figure 7 Conceptual Diagram of C^2B System

Our one-chip IC contains C^2-Bus-1 consisting of four lines (CE, DI, DO, and CL), each assigned an 8-bit address.

Figure 8 shows the data transfer format.

The C^2Bus interface circuit of the one-chip IC is designed using I^2L (Integrated-Injection Logic) and has achieved the following processing speed: $t_{cs} = t_{ds} = t_{dh} \geq 1.50$ μsec
Figure 9 shows the actual serial control data of the one-chip IC.
Figure 10 shows the items for C^2Bus control of the one-chip IC.
The serial control data contains 48 bits (including the address bits), and can be used to adjust and vary the automatic tuning of the RF-tuned circuit in the AM Up-conversion tuner, as well as sensitivity and the time constant of each function block. In contrast, conventional technology requires that the external constant of the IC be varied by destination. For our one-chip IC, the required adjustment is made by changing the microcomputer software.

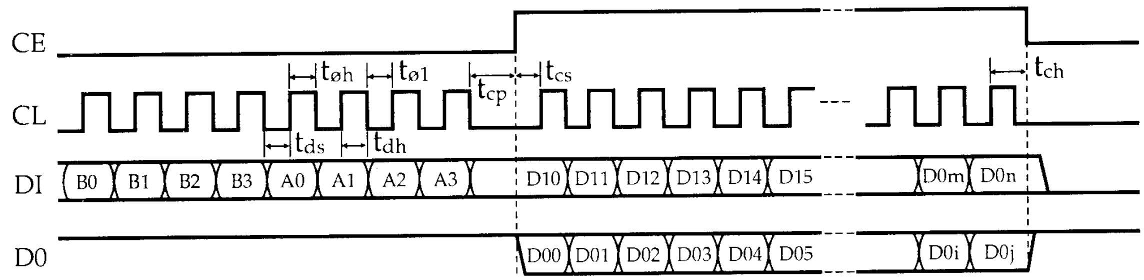


Figure 8 Basic C^2Bus-1 Format

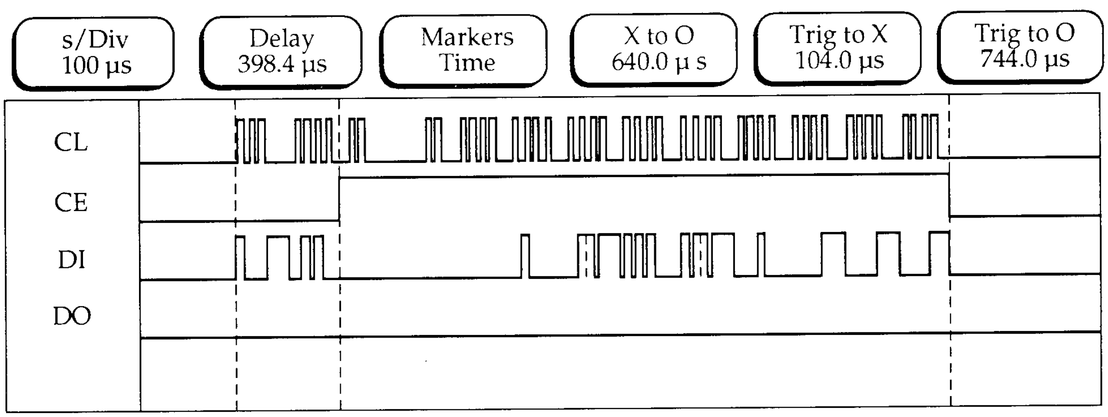


Figure 9 Data Transfer in One-chip IC

5. Automatic AM Tracking System

The automatic AM tracking system has two modes of operation: Auto Seek mode to seek the desired station, and Automatic tracking mode to search for the right tuning point in the AM RF-tuned circuit after tuning to the desired station. In Auto Seek mode, the RF amplifier section is detuned to increase the flatness of seek-stop sensitivity deviation within the receive band. After tuning to the desired station, the RF amplifier section is substituted for the tuning circuit load to achieve steady-state reception with an improved cross-modulation characteristic.
Figure 11 shows the AM automatic tracking system illustrated by each mode.
At this point, AM automatic tracking is activated after tuning to the desired station. This operation depends on the AM S-meter output voltage that will vary linearly on the tuned frequency points in the RF-tuned circuit. In the AM tuner, changes in the received signal strength due to multipath fading are lower than in the FM tuner. For the AM tuner, therefore, the right RF-tuning voltage can be determined by quickly scanning the tuning voltage range of the tuning circuit in a relatively narrow band and calculating the S-meter peak voltage during that period through software.
Figure 12 shows the cyclic routine used to scan the RF peak tuning voltage. When the DAC voltage corresponding to the tuning voltage is varied sequentially by this loop at 32 steps within the specified band, the DAC voltage corresponding to the highest point of the S-meter output voltage in this

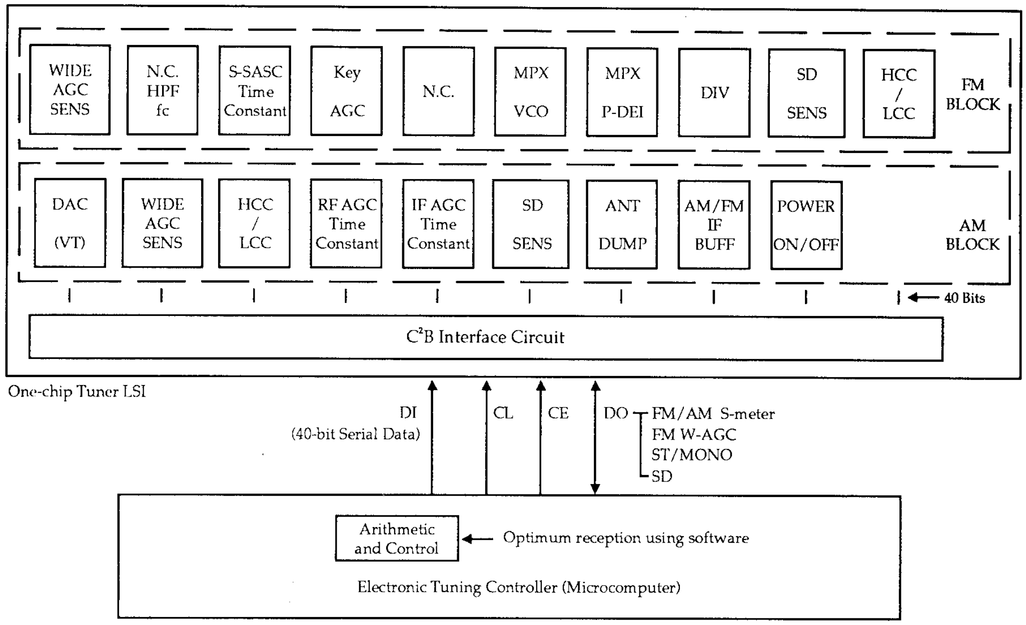


Figure 10 Outline of Computer Control Items

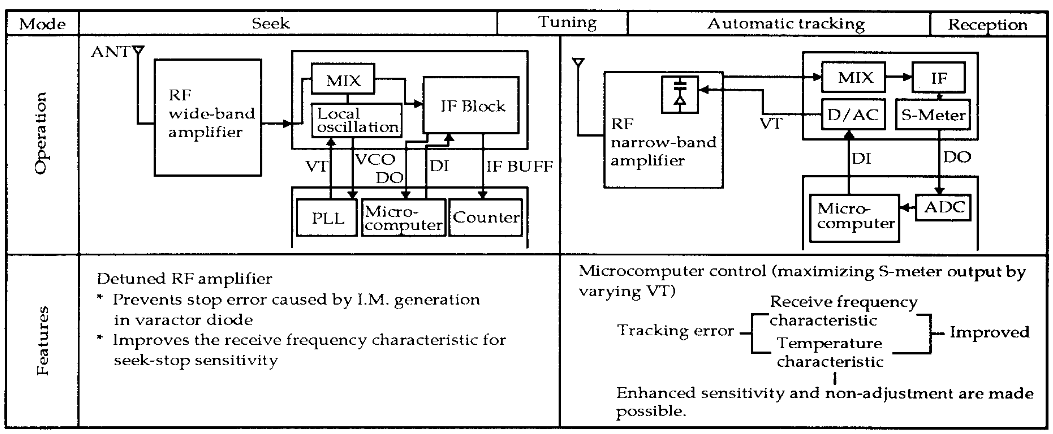


Figure 11 AM Automatic Tracking System

tuning period is the RF peak tuning voltage. But the AM S-meter output voltage contains overlapping noise determined by the band of AM 450 kHz IF filter and the residual AM modulated signal. And these noise level depend on the AM received signal strength. Also the AM RF-tuned circuit, which is the double tuned one, provides three types of frequency characteric which are double humped resonance curve, flat and single-peak. Those frequency characteristics are depending on the coupling state of the primary and secondary coils. Therefore, the right tuning voltage corresponding to the right tuning point of the RF-tuned circuit cannot be simply acheived by seeking the RF tuning voltage in the narrow band and determining the corresponding S-meter voltage peak point. To solve this problem, we improved the accuracy of detecting the peak RF tuning voltage by using the following two methods:

(1) During automatic tuning, this system forcibly operates the ACG circuit in the AM tuner under software control so that the AM S-meter output voltage is not influenced by overlapping noise under AM received signal strength.
Figure 13 shows the actual AM S-meter voltage. At detuned RF reception period, we read the AM S-meter voltage by the microcomputer

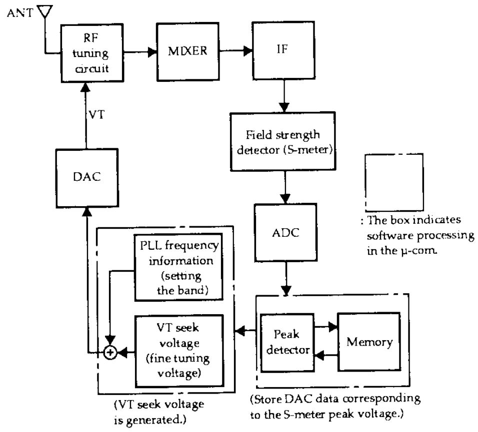


Figure 12 AM Automatic Tuning Procedure

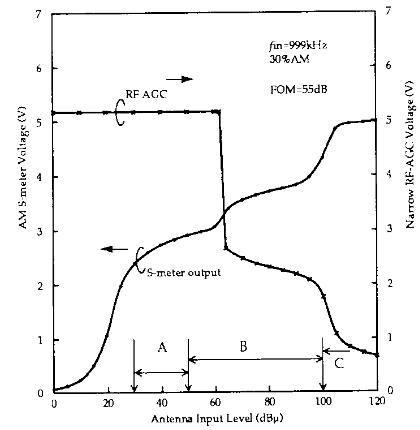


Figure 13 AM Received Signal Strength Indicator Output and AM RF AGC Response

beforehand, we recognize the AM received signal strength division at that automatic tuning period. We set the corresponding forcible AGC operation A, B on C in Figure 13. Forcible AGC operation is set to increase RF signal attenuation in proportion to the received signal strength, in order to detect the correct peak S-meter voltage.

(2) This system searchs for the S-meter peak voltage corresponding to the tuning peak point of the RF-tuned circuit through a rising sweep and falling sweep of the V tuning voltage (= DAC output voltage).
One purpose of this method is to reduce the effects of noise on detecting the S-meter peak

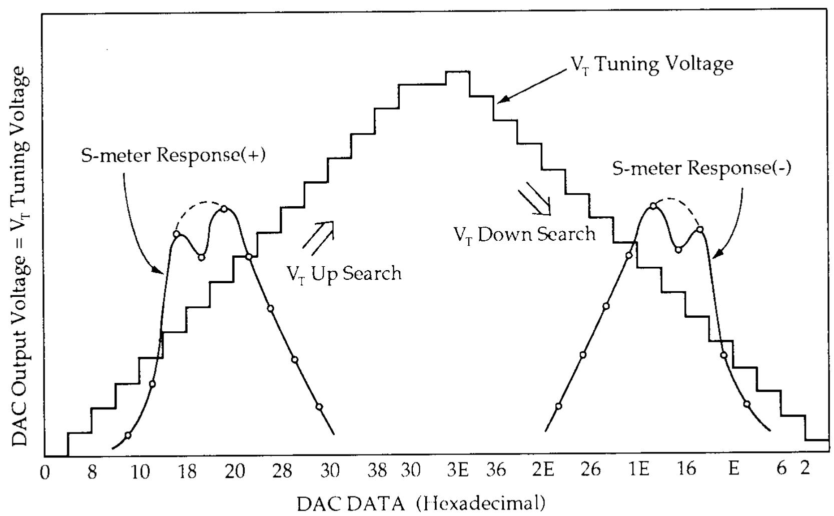


Figure 14 V_TPeak Voltage Search Procedure

voltage by time integration. We also used this method to discriminate between different frequency characteristic deviations depending on the coupling state of the RF-tuned circuit, and calculate the $V_T$tuning peak voltage. Figure 14 expresses schematically the S-meter output voltage response depending on the RF-tuned circuit frequency characteristic when processing $V_T$tuning through a rising sweep and falling sweep.

Figure 15 shows the actual time response characteristic of AM automatic tuning achieved by applying the above series of operating procedures. This result indicates that accurate frequency tracking

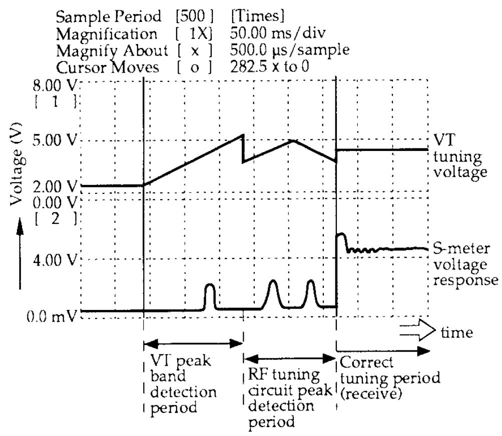
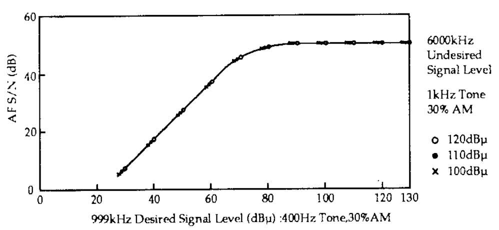
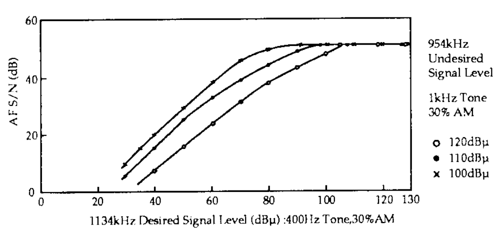


Figure 15 S-meter Voltage Response during Automatic Tuning Period

can be achieved by the AM Up-conversion tuner with different tuning characteristics for the RF-tuned amplifier circuit and RF local oscillation circuit. Figure 16 shows the cross-modulation characteristic of the AM Up-conversion tuner obtained during actual operation of the one-chip IC. The AM Up-conversion tuner using the one-chip IC is free from interference and sensitivity suppression, unlike the conventional AM Up-conversion tuner shown in Figures 3.1 and 3.2.



(a) Short Wave Disturbance



(b) Nearby Frequency Disturbance

Figure 16 Cross-Modulation Characteristics of the Improved AM Up-conversion Tuner

6. Total Performance

Figure 17 is a photo of the one-chip IC chip. The chip size has been reduced to 5.72 x 3.93 mm^2 for mounting in a 80-pin QFP package. The maximum power consumption is 1.2W and the operating ambient temperature range is -40°C to +85°C. Table 1 lists the electical characteristics of the AM section. The results of field testing the one-chip IC have thus confirmed that our improved type of AM Up-conversion tuner and single-IF diversity FM stereo tuner satisfy automaker specifications for the car tuner.

Table 1 Electrical Characteristics of the Improved AM Up-conversion Tuner

fr=1MHz, fosc=11.71MHz, fm=1kHz ANT input

Item	Symbol	Condition	typ	unit
Quiescent current	I_{CCO}- AM	No signal input	103	mA
Current consumption	I_{CC} - AM	130dBμ	113	mA
Demodulation output	V_O	74dBμ 30%mod	150	mVrms
Total harmonic distortion rate	THD - AM	130dBμ 80%mod	0.5	%
AGC FOM	AGC - FOM	The widest possible range of antenna input level required to make the AF output level drop by 10 dB from at 74 dBμ.	57	dB
Usable sensitivity	QS - AM	S/N=20dB input level	26	dBμ
Signal-to-noise ratio	S/N - AM	74dBμ 30%mod	52	dB
Signal meter output	V_{SM-0}	No signal input	0	V
	V_{SM-130}	130dBμ	4.5	V
SD sensitivity	V_{SDAM}		30	dBμ
Local oscillation BUFF output	$V_{OSCBUFFAM}$	No signal input	350	mVrms
IF BUFF output	$V_{IFBUFFAM}$	74dBμ 30%mod	300	mVrms

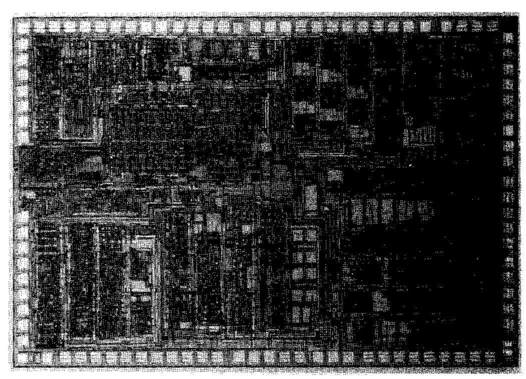


Figure 17 Chip Photograph

7. Conclusion

We incorporated the C^2B interface circuit and DAC circuit into a one-chip IC to enable BUS control using a microcomputer. With this technology, the tuning

circuit load can be provided for the RF amplifier circuit of the AM Up-conversion tuner.
Consequently, we could build an AM tuner system with enhanced image-rejection and a whistle interference, as well as an improved cross-modulation characteristic. This AM tuner system is the first of its kind to be efficiently constructed and operated in the computer-controlled, one-chip IC system. Unlike the conventional one-chip IC whose characteristics are determined by hardware factors, our new one-chip IC has elements capable of searching for optimum reception based on advanced software design. This paper described our AM automatic tracking system and gave some advanced examples of using the system.
This one-chip IC relies on advanced software design to satisfy the car tuner requirements of automakers, which is not possible using external circuit constants, and represents a significant breakthrough for car tuners of tomorrow.

Acknowledgements
The authors wish to thank those members of Nissan Motor Co., Ltd., Clarion Co., Ltd., Tottori Sanyo Electric Co., Ltd., and Xanavi Informatic Co., Ltd. that provided assistance and advice in the long-term field testing following the development of our one-chip IC.

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(1) Teruyuki Takahashi; "Minimum frequency tracking error design for AM Electric tuner," Sanyo Semiconductor Technical Document No.81
(2) Sakae Sugayama; "Monolithic IC for AM Tuner with Improved Cross-modulation Characteristics," Sanyo technical review, Vol. 17, No. 1

Biography

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Mr. Ishii received his BEE degree from Gunma University in March 1977.
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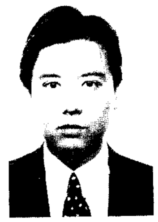

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