# ADVANCED LOW VOLTAGE SINGLE CHIP RADIO IC

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## ABSTRACT

We have developed the technology including intermediate frequency (IF) filters in a radio IC by getting IF low. Degrading of image interference characteristic can be avoided by image cancelling circuits by Inphase/Quadrature mixers and Phase Shift Network (P.S.N). We have developed new two ICs for FMstereo/AM and AM only radio using this technology. FM stereo/AM radio IC can work at a supply voltage of 0.95 volt.

## INTRODUCTION

We made a complete single chip radio IC for reducing external parts and adjustment points. But Intermediate Frequency(IF) filter was not included. At conventional radio system, IF filter needs sharp selectivity, we use IFTs or ceramic filters. As IF is high (455kHz or 10.7MHz), so it's very difficult to include filters in IC. Because high frequency filter circuits is too large scale and unstable. But at low IF system, image frequency is very close to desired frequency, so image interference characteristic is degraded.

New IC system includes image cancelling circuits. The circuits have two mixers inquadrature and Phase Shift Network (PSN). So, IF can be very low without image interference characteristic getting worse. Therefore, Selectivity is sufficient in spite of active filter circuits having a 10~20 Q factor which can be fabricated in IC. And we have achieved same performance IC as an usual radio using ceramic filters.

At FMstereo/AM radio IC, FM IF is 150kHz, AM IF is 55kHz. Both frequencies are very close, therefore PSN and mixers as image cancelling circuits are used both for FM and AM. FM IF is very low , so pulse count detector circuits can be realized as FM detector, although supply voltage is 0.95 volt. The adjustment point and external parts of FM detector is eliminated. FM signal to noise ratio is realized on 60dB.

The drawback of low IF system is the beat which occurs by double IF and FM MPX sub carrier. To avoid the beat, linear multiplier is used for FM MPX decoder.

At AM only radio IC, pins of this IC decrease by the technology including IF filter. So 8 pins AM only radio IC can be realized, which has an audio power amplifier. The audio power output is more than 100mW. This IC is suitable for a portable AM radio.

## IMAGE CANCELLING CIRCUITS

At a conventional radio system, IFT or ceramic filter was used for IF filter, Active C R filter which can be fabricated in IC, has low Q factor, about under 20. To achieve sufficient selectivity using such low Q factor filter, IF must be low. At low IF system, image signal can not be decreased by the filters before mixer. Therefore, image cancelling circuit is needed to make IF low.

Fig.1 is a block diagram of image cancelling circuit. Two 90 degrees phase-shifted signals LO1 and LO2 are fed to Mixer Q and Mixer I, respectivery. Received signal ( DSR or IMG ) is converted to IF1 and IF2 by the mixers. And next, phase of IF2 increases 90 degrees by PSN. It is IF2'. After these signals (IF1 and IF2') are added, desired signal appears and image signal is cancelled. These mixers are used both for AM and FM, LO1 and LO2 varied from 500kHz to 60MHz, so we use 1/2counter in order to make two 90 degrees phase-shifted signals LO1 and LO2.

Fig.2 and Fig.3 describe magnitude and phase of these signals. Fig.2 shows desired received signal and Fig.3 shows image signal.

Image signal IMG is higher than LO2, so signal IF2, mixed by LO2 and IMG is 90 degrees lead to signal IF1. IF2' is 90 degrees lead to signal IF2. Therefore, IF1 and IF2' are contrary signals. Therefore, image signal is cancelled.

At real IC system, image rejection ratio is decided by these 3 reasons.

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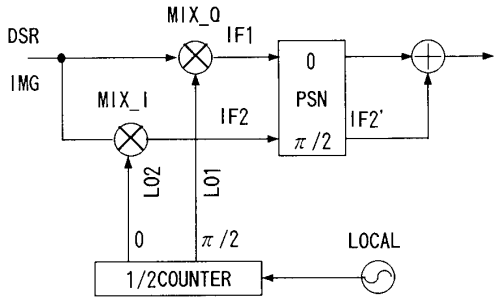


Fig. 1 IMAGE CANCELLING CIRCUIT BLOCK DIAGRAM

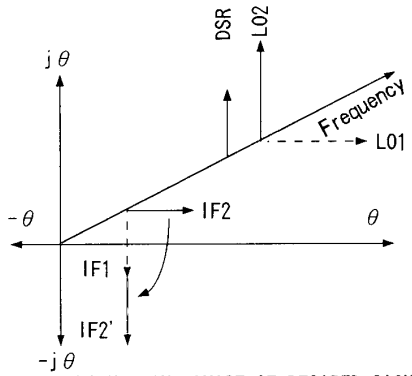


Fig. 2 MAGNITUDE AND PHASE OF DESIRED SIGNALS

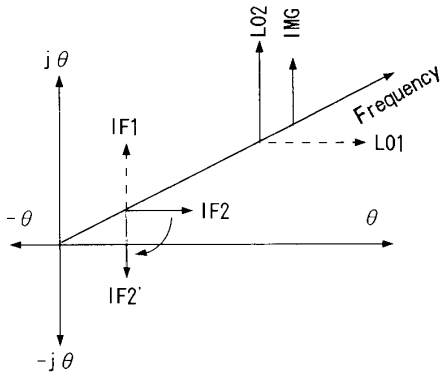


Fig. 3 MAGNITUDE AND PHASE OF IMAGE SIGNAL

1) Gain difference between two mixers
2) Phase error of PSN
3) Phase error of counter

1) Gain difference between two mixers

Gain difference between two mixers are decided by relative error of resistors or transistors in the IC. At FMstereo/AM radio IC, mixer gain is controlled by external terminal. At AM only radio IC, there's no such terminal to decrease a pin. 30dB image rejection ratio is realized by image cancelling circuits in spite of no gain adjustment, in addition to about 20dB by MW ferrite bar antenna. So sufficient rejection over 50dB is accomplished at AM only radio IC.

2) Phase error of PSN

At FMstereo/AM radio IC, PSN is used for both AM and FM, so wide band PSN is needed. PSN circuits is 4th order PSN which consists of two 2nd order all pass network shown at Fig. 4. The characteristic is shown at Fig. 5. If phase of EA is same as phase of EB, the phase difference is 90 degrees with 1 degree phase error from 45kHz to 300kHz. The error corresponds to 40 dB image rejection ratio. At AM only radio IC, PSN is 3rd order all pass network from 45kHz to 65kHz.

3) Phase error of counter

Two 90 degrees-phase-shifted signals are obtained by 1/2counter. So the counter is triggered by both rising up and falling down of oscillator signal. The duty factor of the oscillator signal is important to get two 90 degrees-phase-shifted signals. To get constant duty factor, oscillator signal level is controlled to oscillate as constant level .

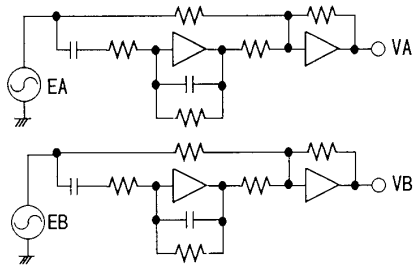


Fig. 4 4TH ORDER PHASE SHIT NETWORK

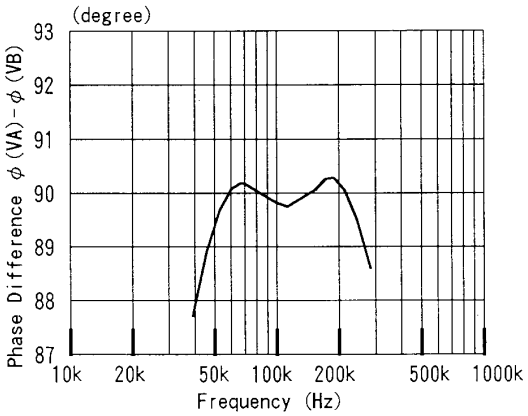


Fig. 5 PHASE SHIFT NETWORK CHARACTERISTIC

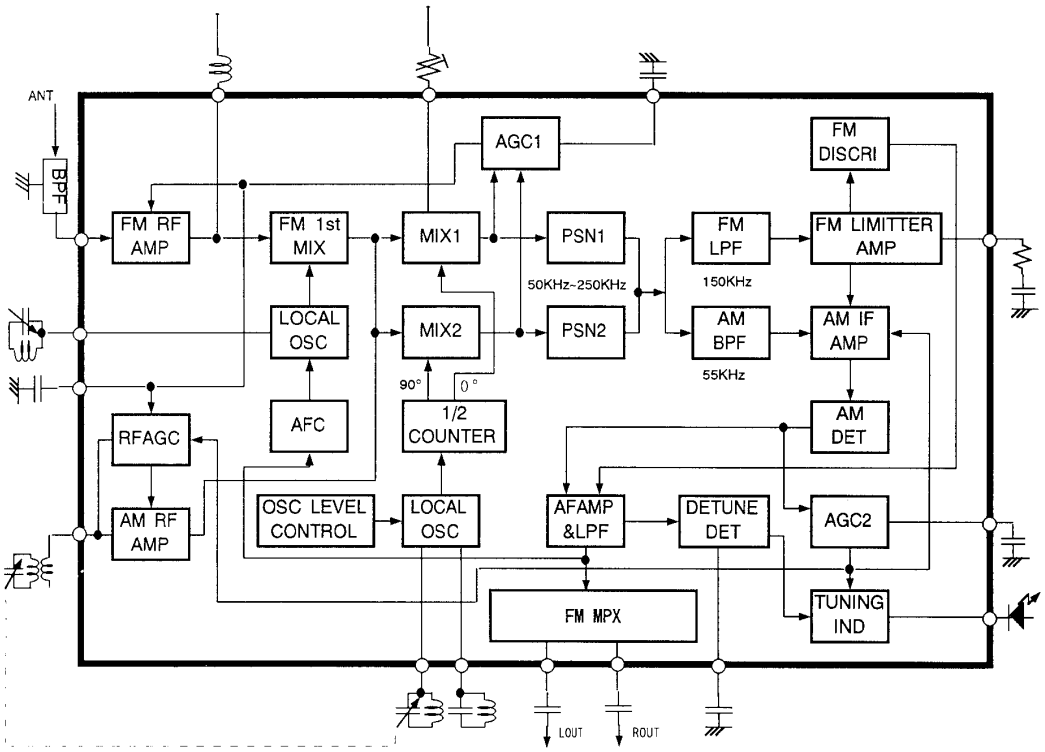


Fig. 6 BLOCK DIAGRAM OF LOW VOLTAGE FMSTEREO/AM RADIO IC

**LOW VOLTAGE FMSTEREO/AM RADIO IC**

At first, I will describe about low voltage FM stereo / AM radio IC.

The IC has all functions for FM and AM radio and FM stereo decoder. It operates only at a supply voltage of 0.95 volt, and intermediate frequency filter is included. Image cancelling circuit consists of in-phase and quadrature mixers .

The figure 6 shows a block diagram of low voltage FM stereo / AM radio IC. FM radio receiver is dual conversion super heterodyne, 1st IF is 30 MHz and 2nd IF is 150 kHz. To make two 90 degrees phase shift signals, local oscillator signal is divided by 1/2 counter.

FM received signal passes through band pass filter to FM RF amplifier. The signal is converted to 1st IF signal about 30 MHz by FM 1st mixer. So image rejection ratio is better than a conventional FM radio in which 1st IF is 10.7 MHz.

1stIF signal is converted to 2nd IF signal 150 kHz by in-phase/quadrature mixer, and 2nd IF signal is selected by FM low pass filter. 2nd IF signal is amplified by FM limitter amplifier, and detected by pulse count circuit. The detected signal is decoded to FM stereo signal by FM MPX decoder.

AM received signal is converted to IF signal 55 kHz by in-phase/quadrature mixers, and selected by band pass filter. AM IF signal is amplified by AMIF, and detected by AMDET. Gain of AMIF and AMRF is controlled by AGC2 to keep audio output signal level constant. Phase shift network and band pass filter are realized by active circuits, so input signal level is limited under dynamic range by AGC1.

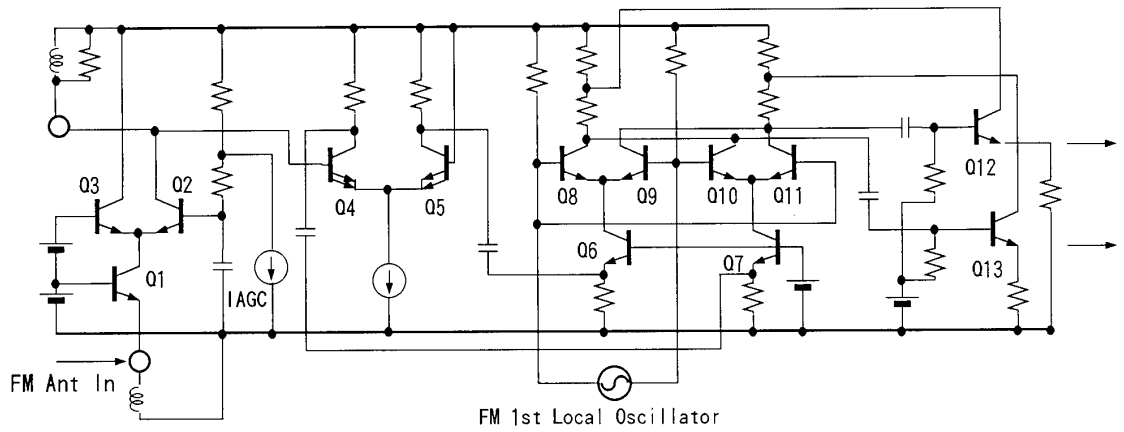


Fig. 7 FM RF AMPLIFIER AND 1ST MIXER

**FM RF AMP**

The FM RF AMP consists of common-base amplifier and cascade configuration by Q1 and Q2. And its gain is 10 dB. The gain of FM RF AMP is controlled by base voltage of Q2 varied with AGC voltage.

The mixer is a double-balanced mixer consisting of Q4~Q11. The collector output of emitter follower Q12 and Q13 are fed back positively to compensate a gain loss of the emitter follower.

At conventional FM radio IC, The output stage of RF AMP is a tunable bandpass filter to get good sensitivity and good interference characteristic. In this IC, by making circuits low noise and improving the circuits linearity, same characteristic as conventional one is achieved in spite of untunable bandpass filter. As for image interference characteristic, sufficient image signal rejection can be realized because FM 1st IF is 30MHz

The local oscillator is a positive feedback type. Its frequency is controlled by AFC (automatic frequency control) circuit to avoid frequency drift.

**I, Q MIXER and PSN**

Two mixers inquadrature are used as FM 2nd mixer and as AM mixer. These mixers are double-balanced type. Fig. 8 shows one mixer circuit. Mixer output flows into buffer amplifier. The gain of mixer is controlled by external variable resistor R1. So image rejection ratio is adjusted by the resistor.

PSN is 4th order PSN as described before.

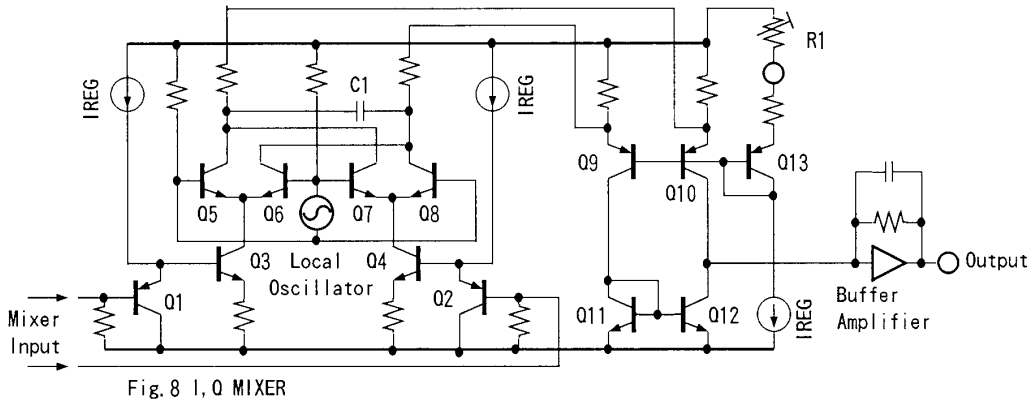


Fig. 8 I, Q MIXER

**FM LPF**

IF filters consists of active filters with capacitors and resistors.

FM LPF is 9th order low pass filter with 300kHz cutoff frequency shown in Fig. 9. The filters characteristic is shown at Fig. 10.

As a result, this FM effective selectivity shown in Fig. 11 is realized. Adjacent channel suppression is over than 40dB, corresponds to using 3 elements ceramic filter shown as an interrupted line in Fig. 11. Image signal -300kHz away from center frequency is 40 dB attenuated.

**AM BPF**

Fig. 13 illustrates AM band pass filter characteristic. The filter consists of three 2nd order biquad 55kHz band pass filters shown at Fig. 12, and adjacent channel suppression 10kHz away from center frequency is 35 dB.

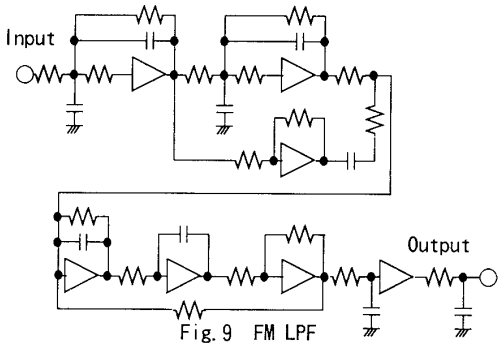


Fig. 9 FM LPF

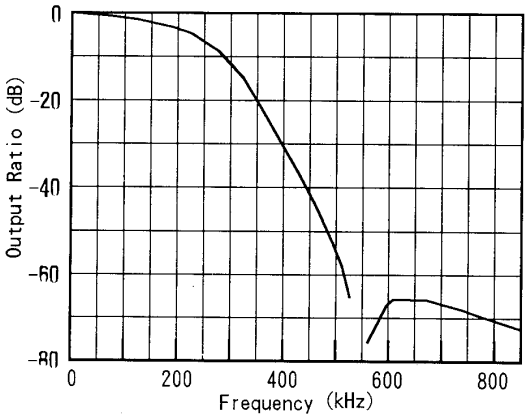


Fig. 10 FM LPF CHARACTERISTIC

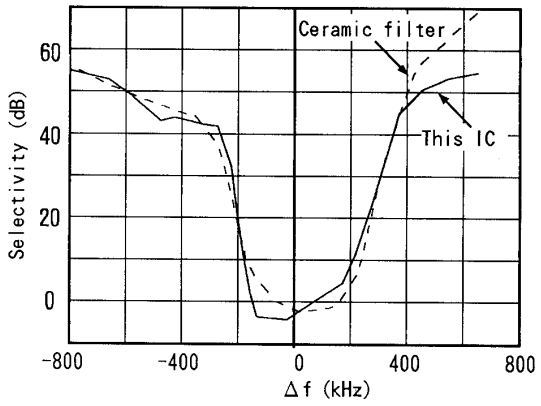


Fig. 11 FM EFFECTIVE SELECTIVITY

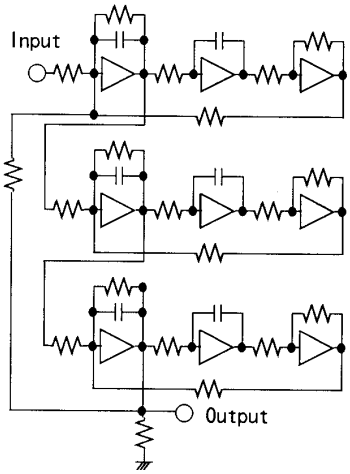


Fig. 12 AM BPF

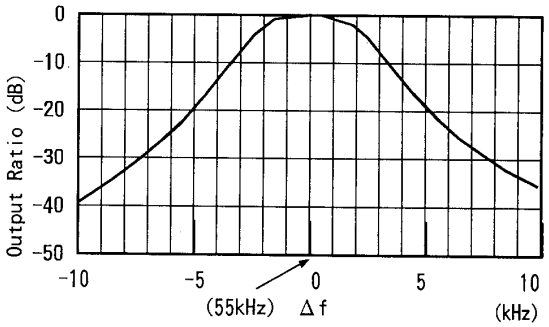


FIG. 13 AM BPF CHARACTERISTIC

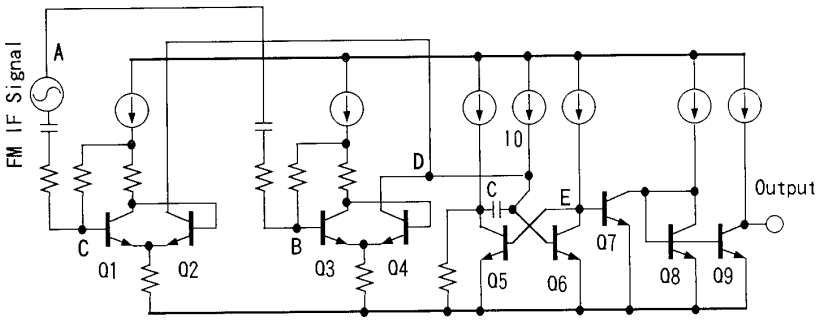


Fig. 14 FM PULSE COUNT CIRCUIT

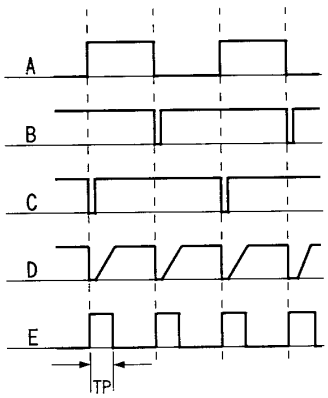


Fig. 15 SIGNALS AT PULSE COUNT CIRCUIT

**Pulse Count Circuit**

The fig. 14 is a pulse count circuit of this IC. The differential outputs of FM IF amplifier are added to two trigger circuits consisting of Q1~Q4 respectively, so mono-stable multivibrator consisting of Q5 and Q6 is triggered by both rising up and falling down of the FM IF signal.

Therefore, sampling frequency is the double of IF , and Nyquist frequency is IF. So sufficient band width for FMstereo MPX signal is achieved. Pulse width TP decided by I0 and C is 875 nano second, so peak separation is 500 kHz.

Fig. 15 shows signals of each stages.

**FM MPX Decoder**

At FM stereo decoder, mixed by double intermediate frequency about 300 kHz and harmonics of FM MPX sub carrier 38 kHz, the beat will occur. To prevent the beat, in this IC 4th order low pass filter is included at detector output and FM detected signal is decoded to left and right output by 38 kHz sin wave.

Figure 16 is FM MPX decoder circuit. Input signal Vin is converted to Iin by negative feedback circuit consisting of Q1~Q3. And Iin is decoded to left signal and right signal by stereo MPX decoder consisting of Q4~Q9. Sub carrier signal which inputs to base of stereo MPX decoder is logarithmically transferred signal. So collector current of stereo MPX decoder is proportional to the stereo sub carrier Isub. Therefore the decoder is linear multiplier.

Logarithmic amplifier consists of Q10~Q13. By feedback circuit (Q10~Q12) current Isub flows into transistor Q10, so output signal is logarithmically transferred.

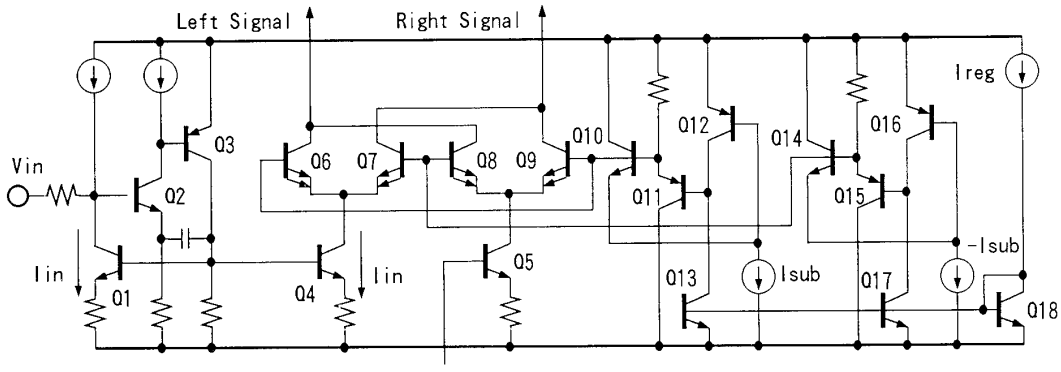


Fig. 16 FM MPX DECODER CIRCUIT

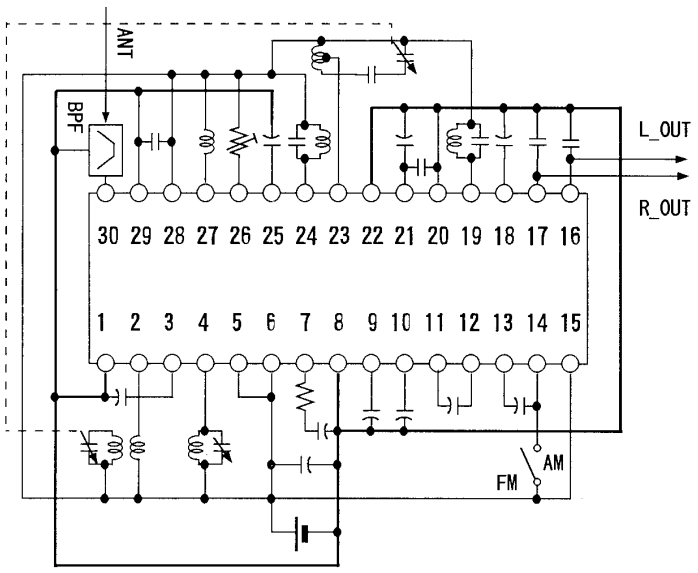


Fig. 17 PERIPHERAL COMPONENTS OF LOW VOLTAGE FMSTEREO/AM RADIO IC

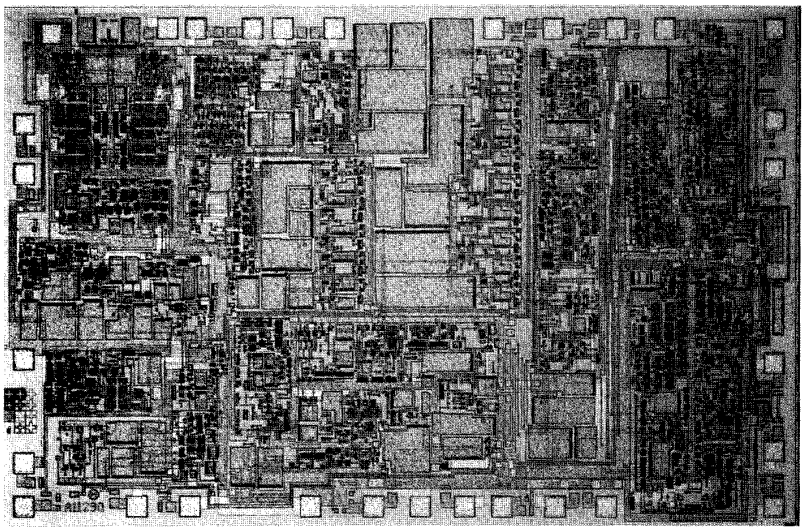

Fig. 18 MICROPHOTOGRAPH OF LOW VOLTAGE FMSTEREO/AM RADIO IC

VCC=1.5V
Frf=1000kHz
Fmod=400Hz 30%

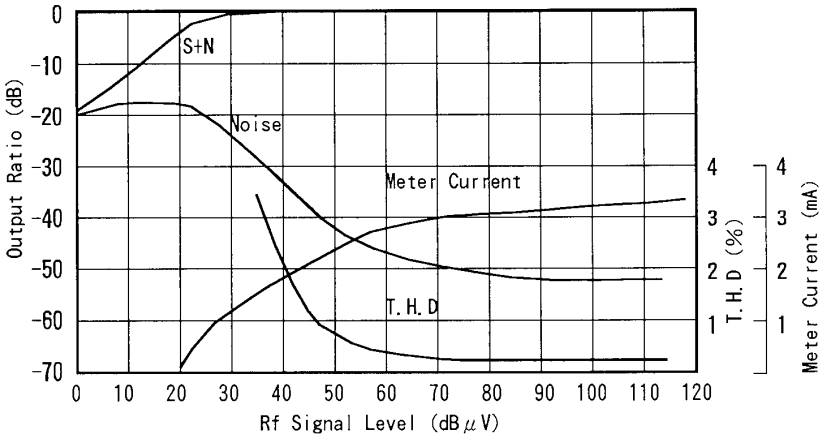


Fig. 19 AM S/N PERFORMANCE

VCC=1.5V
Frf=100MHz
Fmod=400Hz 22.5kHz dev

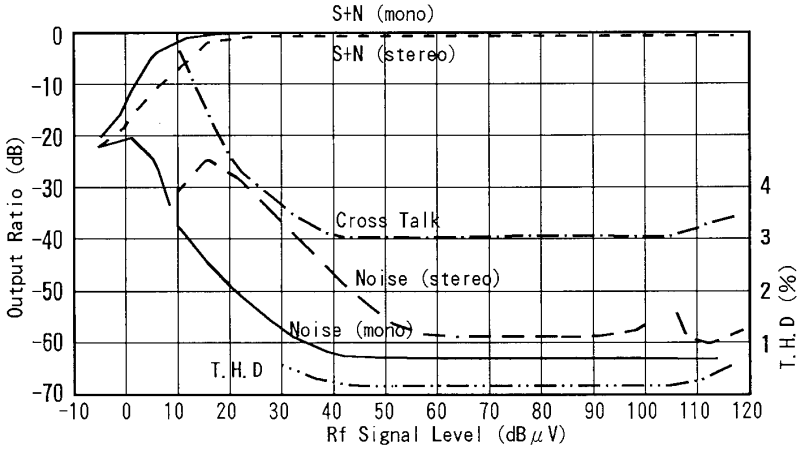


Fig. 20 FM S/N PERFORMANCE

Table. 1 Static Characteristic

| | |
|---|---|
| Operating Voltage | 0.9v~4.5v |
| Current Consumption (FM) | 16mA |
| Current Consumption (AM) | 14mA |

Table. 2 FM and AM Characteristic

| | |
|---|---|
| FM Selectivity(Δf=400kHz) | 40dB |
| FM Image Rejection | 39dB |
| AM Selectivity(Δf=10kHz) | 35dB |
| AM Image Rejection | 41dB |

**Overall Characteristic**

Fig. 17 shows peripheral components of low voltage FMstereo/AM radio IC. The IC is 30 pins small outline package.

Fig. 18 shows a microphotograph of the IC. The chip size is 4.37mm×2.84mm, and the number of devices is 1360. There are some rectangles on the chip. These are MIS capacitors. Capacitors in the PSN and BPF as AM IF filter are from 50 pF to 100 pF. So capacitors occupy such large space.

Fig. 19 shows AM S/N performance of the IC. S/N6dB sense is 10dBμV, S/N is 50dB, T.H.D is 0.3%.

Fig. 20 shows FM S/N performance of the IC. S/N30dB quieting sense is 10dBμV, S/N is 60dB, T.H.D is 0.1%.

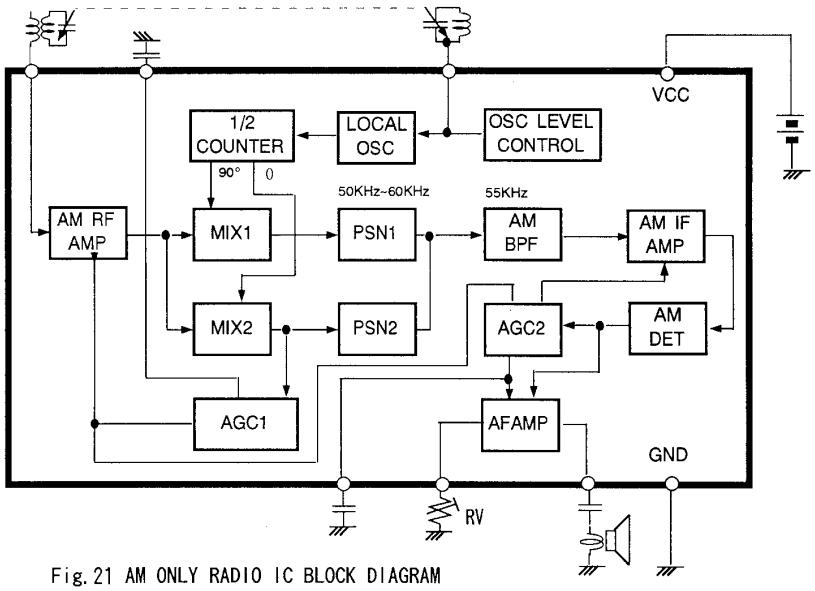


Fig. 21 AM ONLY RADIO IC BLOCK DIAGRAM

**AM ONLY RADIO IC**

This figure 21 shows a block diagram of 8 pins AM only radio IC. IF filter is included in the IC using image cancelling technology. Audio power amplifier is included, which can sound speaker.

AM received signal is amplified by AM RF, and converted to IF signal by Mixer 1 and Mixer 2. 1/2counter is used to make two 90 degrees phase shifted local oscillator signals. In order to receive AM broadcast from 150kHz to 30MHz, the counter operates from 150kHz to 60MHz. Image cancelling circuits consists of Mixer 1, Mixer 2, PSN1 and PSN2. IF signal is selected by AM BPF which is two 2nd order 55kHz biquad BPF. The selected signal is amplified by AM IF and detected by AM DET. The audio signal is amplified by AF AMP which sounds a speaker.

In this IC, we make much effort to decrease pins of an AM radio IC.

At an AM radio IC which has an audio power amplifier, most difficult problem is the feedback of audio signal and its harmonics to RF AMP or MIXER. To solve the problem, usually ripple rejection circuits or regulator are used. At this IC, the amplifiers are balanced type. So the ripple of supply voltage doesn't influence received signal. Therefore, The pins for ripple filter and for regulator are eliminated.

The input signal level of PSN and BPF is limited by AGC1 to prevent too large signal input. By minimizing the variety of the voltage of AGC1, the voltage is used as reference voltage of amplifiers in the IC. These amplifiers are used in PSN and BPF.

AM detected signal consists of DC voltage (AGC voltage) corresponding to carrier signal and AC voltage (audio signal). To connect AM detector output and audio amplifier input, capacitor is needed. The capacitor is too big (several $\mu$F) to include in IC. At this AM only radio IC, audio amplifier input is differential type. AM detected signal is fed to one side input and AGC voltage is fed to the other side input, so only audio signal is amplified by the audio amplifier. As the result, AM detector output and audio power amplifier input is connected in the IC.

Fig. 22 shows characteristic of band pass filter as AM IF filter. Adjacent channel suppression 10kHz away from center frequency is about 20dB.

Fig. 23 shows input characteristic: S/N6dB sensitivity is 10dB$\mu$V. S/N is 50 dB and total harmonic distortion(T.H.D) is 0.5%.

Fig. 24 shows a photograph of an AM radio using the AM only radio IC. Chip size of the IC is 1.9mm×2.4mm.

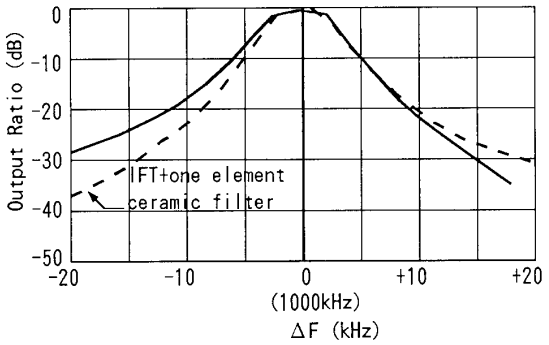


Fig. 22 AM SELECTIVITY

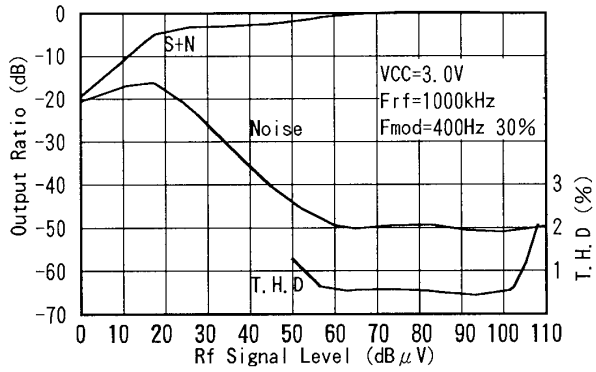


Fig. 23 AM S/N PERFORMANCE

## CONCLUSION

The technology including IF filters in bipolar monolithic IC has been discussed. These filters are fabricated by existing process with diffused resistors and MIS (Metal Insulator Semiconductor) capacitors. So the cost is not so high to make a radio IC.

This technology including IF filters in IC can be used not only for a radio, but also for communication receiver.

## ACKNOWLEDGEMENTS

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We also wish to express our thanks to engineers who were engaged in the development of radio for their co-operations.

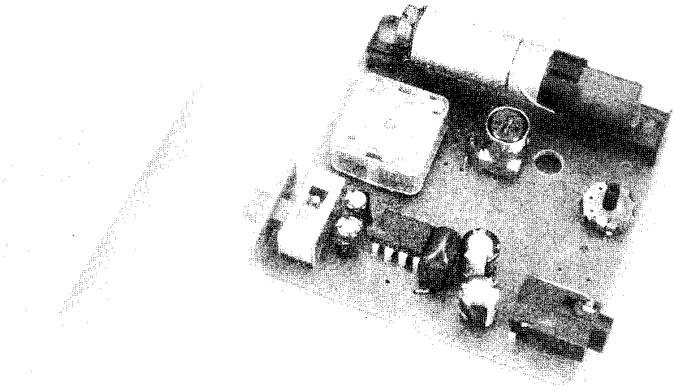

Fig. 24 Photograph of AM radio using the AM only radio IC

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## BIOGRAPHIES

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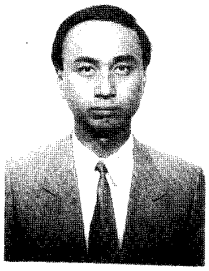
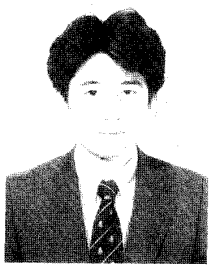


**Hitoshi Tomiyama**, Assistant manager of Personal Telecommunications Group, received his B. S. in Electronic Engineering from Keio University, Tokyo, in 1983. In 1983, he joined Sony Corporation and Participated in the development of Radio and LSI for Radio.



**Hiroshi Arimoto** received his B. S. in Electrical Engineering from Sophia University, Tokyo, in 1987. In 1987, he joined Sony Corporation, where he has been engaged in the Bipolar Div.