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Multifunction AM/FM Noise Reduction System

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Automotive radio receivers are increasingly beset with reception difficulties due to increased sources of interference and noise, and with the trend toward luxury vehicles, it only makes good sense that the quality of the receiver should match that of the car. To this end, Fujitsu Ten has expended much effort in combatting receiver noise to provide more stable and higher quality sound.
Fujitsu Ten recently succeeded in producing a highly advanced system which eliminates both AM/FM impulse noise and noise due to multipath. This was achieved with a single-chip AM and FM noise reduction circuit.
This paper covers the basic principles and evaluation of the new system, with emphasis on the AM noise reduction circuit.

1. Introduction

Reception problems posed by atmospheric and topological conditions and noise are exacerbated when the tuner is mobile. In particular, the reception environment has deteriorated with the increase of noise sources. For example, Japan's bullet trains and power lines generate impulse noise which affects AM radio reception. FM radio reception is affected by noise due to multipath (hereafter called multipath noise) resulting from the reflection of radio waves from tall buildings and natural obstacles. Ignition interference from cars and motorcycles affects both AM and FM radio reception and is worse in the newer engines.

Fujitsu Ten has developed a range of noise reduction systems aimed at handling FM impulse noise and multipath noise. Development of systems designed to deal with noise affecting AM radio reception is generally lagging, notwithstanding efforts by Fujitsu Ten. However, recent experience has shown that reduced AM-related noise is essential.

To meet this challenge, Fujitsu Ten has developed an AM impulse noise reduction system. Further, by improving the existing FM pulse noise and multipath noise reduction system and enabling the circuit to function also as an AM noise reduction circuit, Fujitsu Ten has succeeded in developing a single-chip multifunction noise reduction device that effectively reduces AM and FM impulse noise and multipath noise. This paper describes the operation and evaluation of the noise reduction circuit, particularly with regard to AM radio reception.

2. AM noise reduction circuit

2.1 AM pulse noise

As mentioned above, the most typical noise affecting AM reception is impulse noise. This phenomenon is observable as unpleasant crackling when the vehicle is receiving a broadcast from a weak or distant station or is travelling alongside power lines, beside a motorcycle, or through a tunnel.

Figure 1 shows such noise represented by a pulse about 0.2 ms wide in the output of the detector (DET).

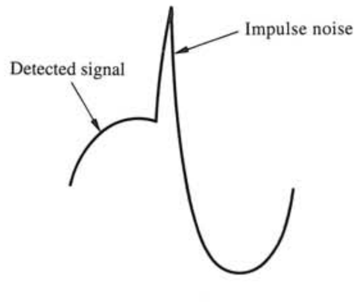

Figure 1. AM impulse noise

2.2 Problems with existing noise reduction systems

Several systems aimed at reducing impulse noise have been proposed. The following gives a brief description of the most representative.

Figure 2 schematically illustrates the concept of a conventional impulse noise reduction circuit, and Figure 3 shows the waveform at a number of points in this circuit. This circuit uses three sections to reduce noise: a noise detection block, a noise reduction and prehold block, and a waveform compensation block.

The noise detection block comprises an amplifier, detector (DET), HPF and level detector. The output from the detector is filtered by a high-pass filter (HPF) and, if impulse noise is a component of the signal, only the noise pulse and its harmonic components are extracted. The level detector then shapes the signal into a gate signal as shown in Figure 3(a).

The noise reduction and prehold block comprises a gate and a capacitor. The noise detector reduces impulse noise by issuing gate signals to open the gate(switch). The capacitor maintains the pre-reduction detection level. When impulse noise is no longer detected, the noise detector stops issuing gate signals, the gate (switch) closes, and output of normal signals resumes. Figure 3(b) illustrates the signal formed by this process.

The harmonic components in the pointed portion of the waveform indicated by are unpleasant to the ear. The waveform compensation circuit removes these harmonic components. Figure 3(c) illustrates the final form of the signal.

This system, however, has the following three disadvantages:

① Noise detection block - Since the signal at the 450-kHz intermediate frequency is amplified and detected, a 900-kHz harmonic component arising from detection leads to beating.

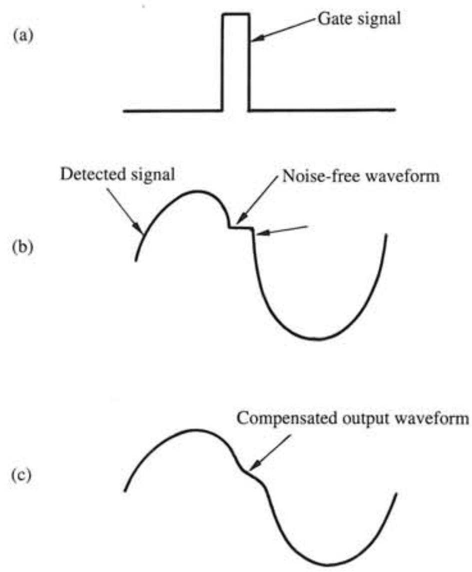

Figure 3. Waveform on AM noise reduction circuit

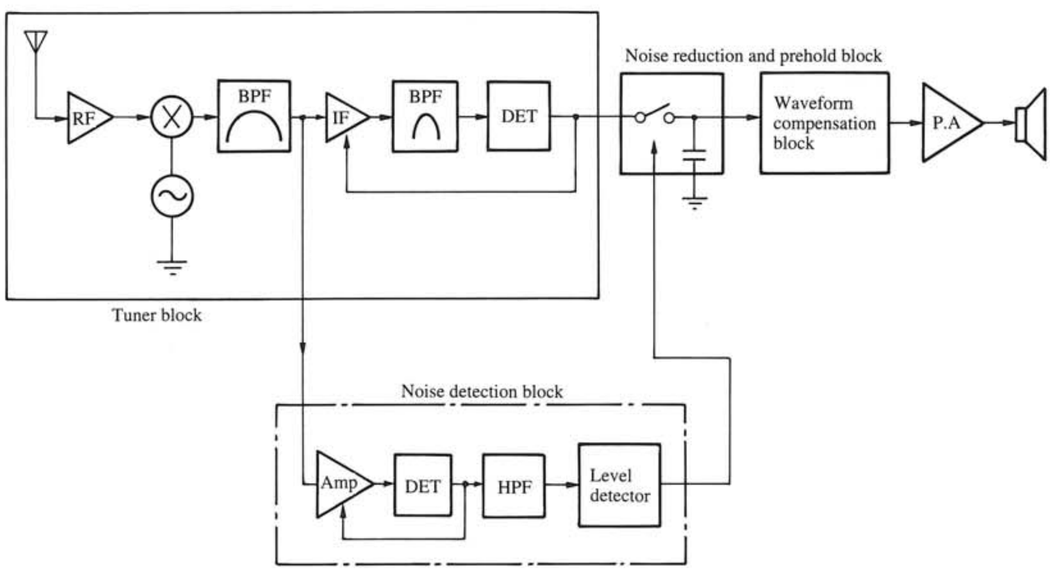

Figure 2. Conventional AM noise reduction circuit

② Noise reduction and prehold block - Since the gate width is fixed, the block cannot respond to changes in the pulse width and leads to excessive waveform distortion.

③ Waveform compensation block - Since the compensation signal is fixed, any increase in the signal frequency causes a corresponding increase in distortion of the compensation signal.

2.3 New AM noise reduction circuit

2.3.1 Overview

After considering the problems inherent in the conventional system, we used the structure explained below for the new AM noise reduction circuit.

① Noise detection block - The detector is designed to detect impulse noise from the output as supplied from the detector. This prevents beating which would arise from intermediate-frequency harmonics.

② Noise reduction and prehold block - This block varies the gate width in response to the noise pulse width to prevent excessive waveform distortion.

③ Waveform compensation block - A variable low-pass filter (LPF) provides appropriate compensation according to the frequency components of the signal and suppresses distortion of the compensation signal. A variable phase shifter having the same phase characteristics as the variable LPF eliminates distortion involved in starting and stopping noise reduction.

Detailed descriptions of each block are given in the next section.

2.3.2 Principle of noise detection and detection circuit

To solve the problems associated with intermediate frequencies in existing noise reduction systems, we adopted a system which detects pulse noise in the output of the tuner's envelope detector. By its nature, pulse noise is distributed over a wide band, but most of it is removed by a bandpass filter (BPF). Therefore, only the components that pass the BPF require processing. This section explains how the new system detects these components.

Figure 4 shows the spectrum of a modulated signal when it contains pulse noise. As shown in the diagram, the upper sideband and lower sideband are symmetrical with respect to the carrier. Impulse noise, except in very rare instances, is asymmetrical with respect to the carrier.

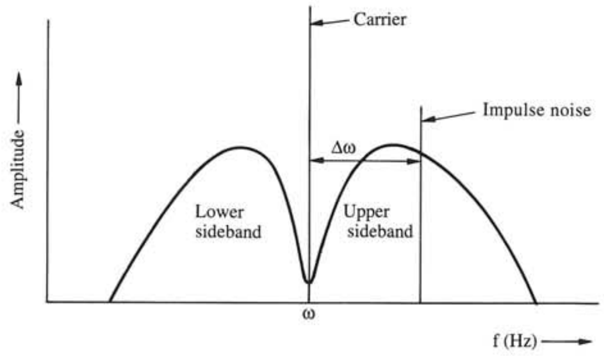

Figure 4. Spectrum of modulated signal and impulse noise

If impulse noise $V_E(t)$ is determined by the equation

$$V_E(t) = A_E \cos\{(\omega+\Delta\omega)t+\phi_o\} \quad (1),$$

the amplitude modulated wave $V_{AME}(t)$ can be found from the following equation:

$$V_{AME}(t) = V_{AM}(t)+V_E(t)$$
$$=(A-A_E)\cos(\omega t+\phi_o) \quad \cdots\text{Carrier}$$
$$+—A\,\Sigma\, A_n\cos\{(\omega+np)t+\phi_o+\phi_n\} \quad \cdots\text{Upper sideband}$$
$$+—A\,\Sigma\, A_n\cos\{(\omega-np)t+\phi_o-\phi_n\} \quad \cdots\text{Lower sideband}$$
$$+A_E[\cos(\omega t+\phi_o)+\cos\{(\omega+\Delta\omega)t+\phi_o\}] \quad \cdots\text{Pulse noise} \quad (2)$$

Where the impulse noise modulated wave $\Delta V_E(t)$ can be found by:

$$\Delta V_E(t) = A_E[\cos\{(\omega t+\phi_o)$$
$$+\cos\{(\omega+\Delta\omega)t+\phi_o\}]$$
$$=2\,AE\cos\{(2\,\omega+\Delta\omega)t+2\,\phi_o\}\times\cos(\Delta\omega t) \quad (3),$$

Where:

A: Amplitude of the carrier

A_n: Amplitude of the modulating signal

p: Angular frequency of the modulating signal

ω: Angular frequency of the carrier

ϕ_n: Initial phase of the modulating signal

ϕ_o: Initial phase of the carrier

Figure 5 shows the modulated signal and demodulated signal which remain unaffected by the impulse noise expressed by Formula (2). The top diagram illustrates modulation of the carrier, upper sideband, and lower sideband as given by Formula (2). The lower diagram shows the signal demodulated by an envelope detector.

Figure 6 illustrates a demodulated signal (ΔV_E) which has been affected by the pulse noise expressed by formula (2).

A comparison of the signals demodulated by an envelope detector Figs. 5 (b) and 6 (b) shows that the first waveform changes continuously while the changes from fall to rise in Figure 6 are discontinuous. This difference stems from the fact that the modulated signal in Figure 5 produces a double sideband which is symmetrical with respect to the carrier frequency, while the impulse noise produced in Fig. 6 is asymmetrical with respect to the carrier frequency.

Since a noisy envelope-detected signal contains harmonic components corresponding to the impulse noise at the points of discontinuity, the spectrum of the demodulated signal containing impulse noise is as shown in Fig. 7. Therefore, impulse noise can be detected through detection of the harmonic components.

An HPF is used to detect the higher harmonic components and should be able to detect the weakest pulse noise. In addition, the filter should detect neither signal components nor signals from adjacent stations.

The frequency interval is 9 kHz in Japan and 10 kHz in the United States. Therefore, the above criteria can be met by using an HPF which detects components above these frequencies.

This noise detection system is capable of detecting impulse noise without the beating that arises in conventional systems due to intermediate-frequency harmonics.

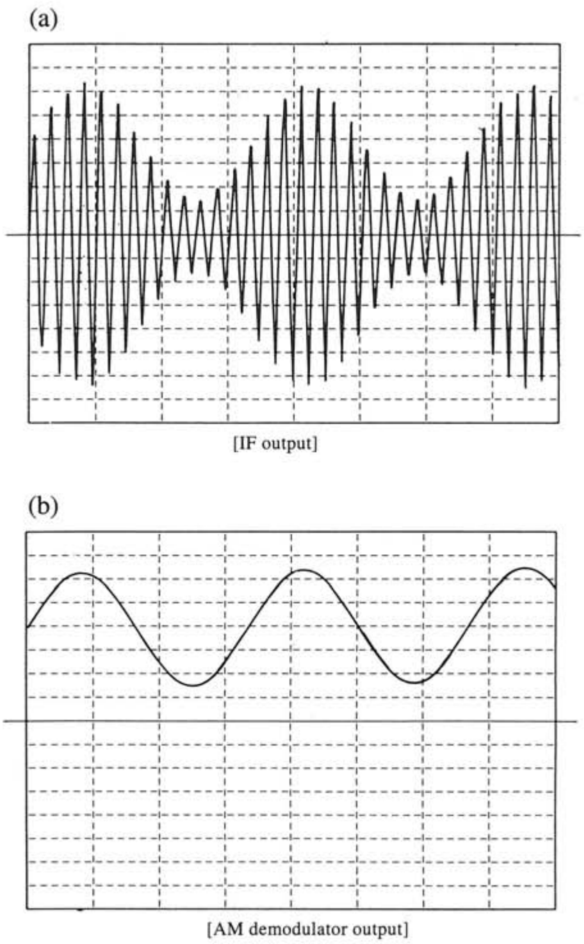

Figure 5. Output on AM detector

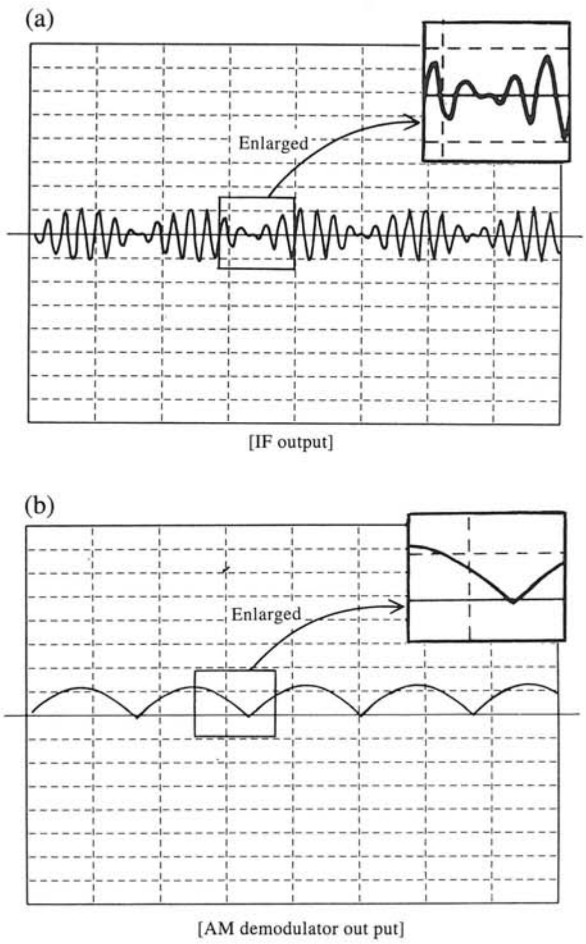

Figure 6. Output on pulse noise

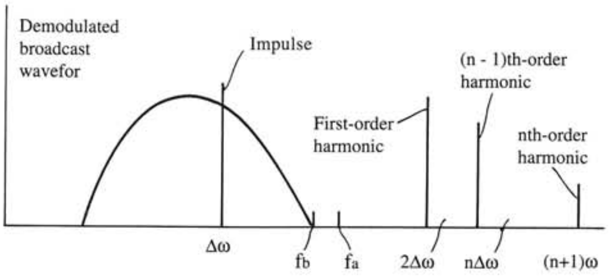

Figure 7. Spectrum of demodulated signal with impulse noise

2.3.3 Time-variable noise detector circuit

Impulse noise in a signal produces the detected output waveform shown in Figure 1. The width of the noise is determined by the characteristics of the BPF and by the input level of the impulse noise and signal. Since the input level of the impulse noise and signal is variable, the pulse width is also variable. Using a fixed gate width despite the variable pulse width leads to the following problems.

① When the gate width is too small to accommodate a wide noise pulse, noise reduction processing is abandoned.

② A large gate width leads to excessive distortion of the waveform.

Since conventional systems have used a fixed gate width, a larger gate width was employed to obviate, to a great extent, the first problem. Figure 8 illustrates the waveforms obtained at various points in the conventional system. Figure 8(a) shows the waveforms output from the detector (DET), (b) shows the waveforms output from the HPF, and (c) shows the waveforms inside the level detector, which outputs a short rectangular pulse when the HPF output level exceeds +Vr. Figure 8(d) shows the output waveform of the level detector. As can be seen in the diagram, the waveform involves excessive distortion corresponding to $\tau_B = \tau_1 + \alpha$.

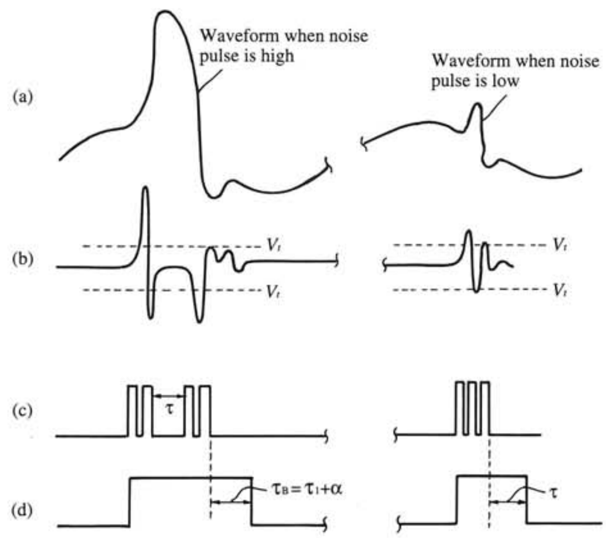

Figure 8. Waveform of conventional noise detector circuit

We made the gate width variable by structuring the level detector so that it operates as follows:

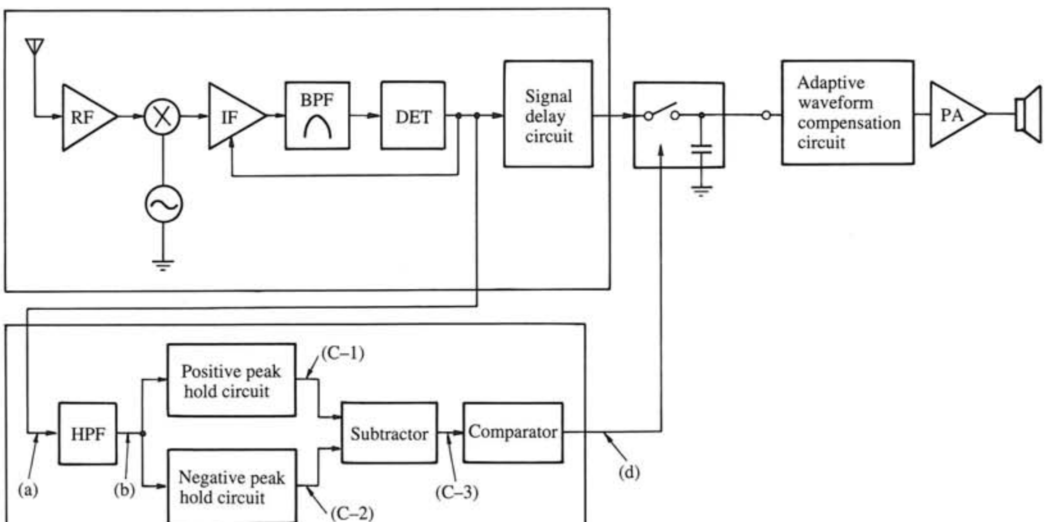

Figure 9. New noise detector circuit

① The output from the HPF is split into positive and negative signals which maintain their peak levels.
② The difference between the positive and negative signals produced in step 1 is shaped to a single pulse.
③ The gate signal is output while the signal produced in step 2 is above a reference value.

Figure 9 shows the new AM noise detector circuit, and Figure 10 the waveforms output at various points in the new AM noise detection block. The signals in Fig. 10(a) are output from the detector, those in (b) from the HPF, those in (c-1) and (c-2) from the hold and attenuator circuit, those in (c-3) from the subtractor, and those in (d) from the comparator.

The new system eliminates the need to include τ_B in the gate time, and since the gate signal width can be varied according to the amplitude of the impulse noise, it sup presses impulse noise without causing excessive distortion of the waveform as in current systems.

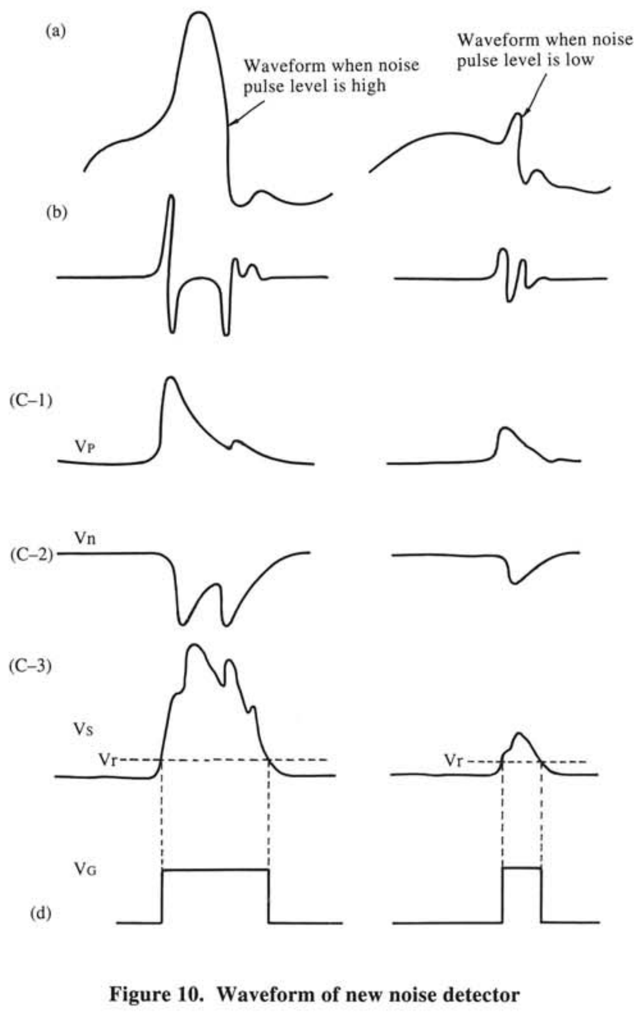

Figure 10. Waveform of new noise detector

2.3.4 Adaptive waveform compensation circuit

Simply suppressing impulse noise by passing the signals through a gate circuit as shown in Figure 3(c) does not eliminate harmonics which are unpleasant to the ear.

As shown in Figure 11, the new system reduces these unpleasant components by suppressing the harmonics by switching a variable LPF and a variable phase shifter (PS), and also reduces loss of signal components to a minimum. This process involves the following operations:

① The output from the variable LPF is used only when impulse noise accompanies the signal.
② In all other cases, signals from the variable PS are used.
③ The cutoff frequency of the variable LPF is promptly varied according to the signal components.
④ The variable LPF and variable PS always keep the same phase characteristics.

An LPF is useful for removing harmonic components from the prehold block (Fig. 2c). However, an LPF also causes loss of components which are higher than the cutoff frequency. To counter this, the LPF processing time must be minimized and the cutoff frequency varied in response to the signal components.

When LPF processing is performed while impulse noise is present in the signal, switching to the original signal produces waveform distortion due to delay by the LPF. To avoid this, the system switches first to a phase sifter (PS) having the same phase characteristics as the LPF, and then gradually switches to the original signal.

Figure 12 shows the waveforms at various points in the waveform compensation circuit. The waveform in (a) is output from the gate circuit and that in (b) from the variable LPF. The variable LPF suppresses high-frequency components from the prehold block shown in (a), but causes a time lag Δt. The waveform in (c) is the output of the variable PS. This signal lags the gate output in (a) by Δt, which corresponds to the setting of the variable LPF. The frequency characteristics in Figure 13 cause the waveform to drop from the preheld flat portion as shown in Figure 12(a). The declining part of the prehold output rises sharply due to a great degree of phase inversion in the higher frequency components. The waveform in (d) represents the signal produced as a result of switching between the variable LPF and variable

PS using the gate signal from the pulse noise detection circuit as shown in (e). As can be seen from the waveforms, pointed portions are removed from the compensation signal to obtain a waveform which is similar to the original.

The following explains the method of varying the cutoff frequency of an LPF. As shown in Figure 13, the variable PS allows signals over the entire band to pass without attenuation and keeps the amplitude constant when the phase varies. However, the variable LPF causes the amplitude to vary in response to changes in the cutoff frequency. A feedback loop controls the cutoff frequency of the variable LPF so that the outputs of the variable LPF and variable PS agree in amplitude and within tolerance. The tolerance is determined on overall consideration of the properties of the music, voice, impulse

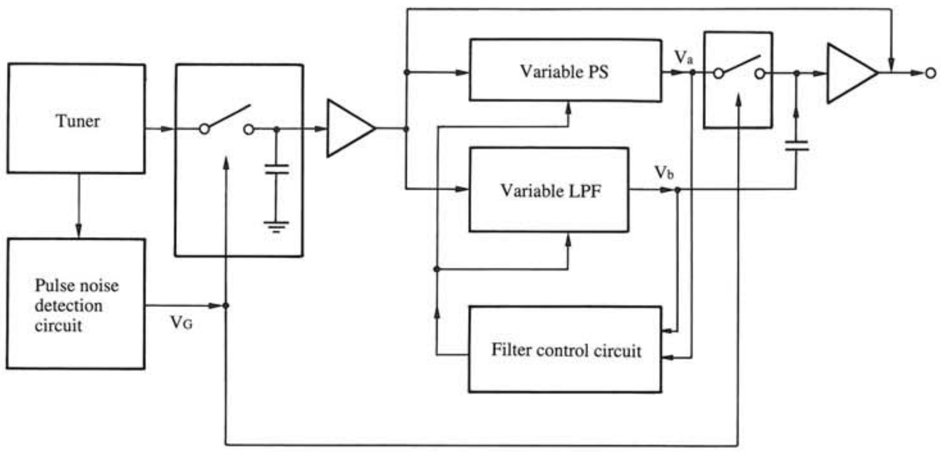

Figure 11. Adaptive waveform compensation circuit

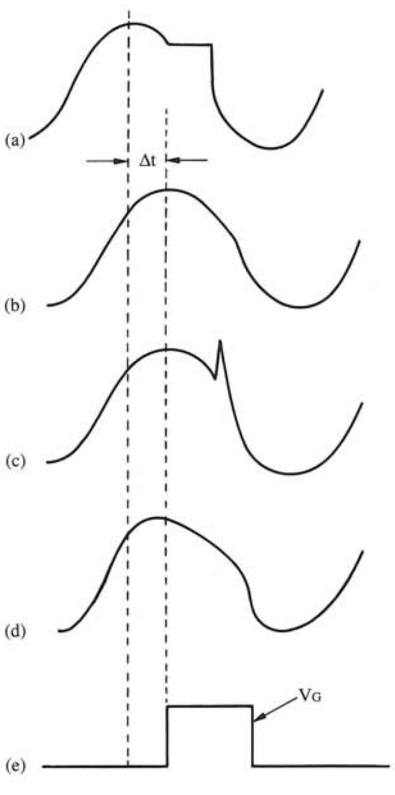

Figure 12. Waveform of adaptive waveform compensation circuit

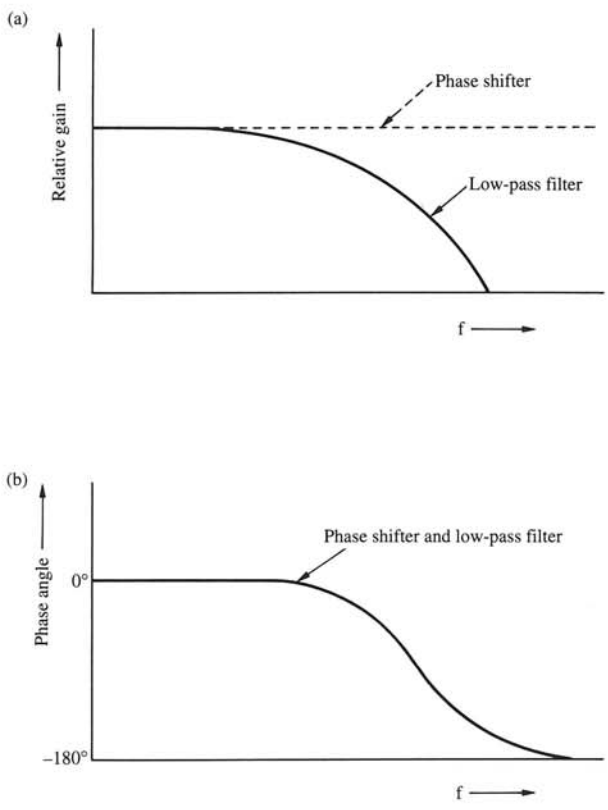

Figure 13. Frequency response of LPF and PS

noise, and audio characteristics. Given that the frequency components of the signals change very little within a very short time interval, the cutoff frequency of the LPF can be calculated from the signal components present immediately before the pulse noise mixes with the signal.

Fujitsu Ten developed this waveform compensation method by modifying and improving the principles of the circuit used previously to counter FM multipath interference for application to AM radio reception.

As explained above, Fujitsu Ten has succeeded in developing an extremely effective AM noise rejection circuit by using new methods for the noise detection circuit, the noise reduction and prehold circuit, and the waveform compensation circuit.

3. FM noise reduction circuit

3.1 FM noise

The most common forms of FM noise are impulse noise and multipath noise. As with AM reception,impulse noise is introduced in the signal when a vehicle is travelling alongside a motorcycle or through a tunnel, and is experienced by the listener as an unpleasant crackling noise. However, since the width of the noise output from the detector is extremely short (several microseconds) in comparison with that of AM noise due to a difference in the characteristics of the IF filter, the frequency of FM noise is high. Multipath noise is the unpleasant static in the signal and is caused by phase and amplitude distortion due to interference between the direct waves and the indirect waves reflected from tall buildings, topological features, and other vehicles.

3.2 New FM Noise Reduction Circuit

3.2.1 Impulse noise reduction circuit

As with the existing impulse noise rejection (PNL) circuit, the new circuit detects impulse noise and suppresses it by closing a gate circuit.

Whereas existing systems use a single gate circuit to suppress noise by using a composite signal derived from the left and right channels, the new system uses a separate gate circuit for each channel. The new system is therefore more effective in suppressing noise for stereo sound sources.

3.2.2 Multipath noise reduction circuit

By incorporating the new pulse suppression circuit that suppresses the pulse components in multipath noise into the existing adaptive waveform compensation system, Fujitsu Ten made the noise reduction function more effective.

While the existing adaptive waveform compensation system used a single circuit to process both left and right channel signals, the new system processes the left and right channels separately. This means that stereo sound (separation) is unaffected by the noise reduction process.

Figure 14 is a conceptual diagram of the new FM noise reduction circuit. Since the gate circuit and adaptive waveform compensation circuit are an improved version of those used in the existing system, they are not covered in this paper. However, an explanation of the pulse suppression circuit is provided.

Figure 15 is a conceptual diagram of the pulse suppression circuit. As shown in the diagram, the pulse suppression circuit comprises an LPF circuit and a diode-controlled feedback circuit.

The input-output characteristics of this circuit are expressed by the following equation.

$$E_O = E_I \frac{1}{1+j\omega\, CR_2(1+R_1/R_D)} \quad (4)$$

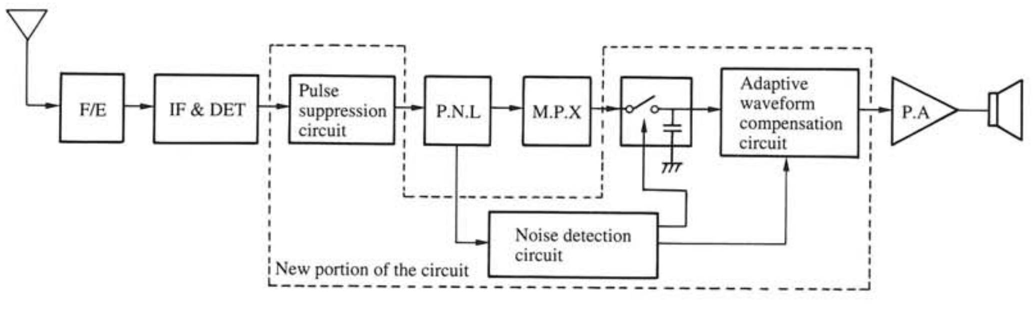

Figure 14. New FM noise reduction circuit

In this equation, the resistance R_D is infinite when the voltage across the diode is less than clamping voltage V_D. When the voltage across the diode is greater than V_D, R_D drops and the ratio R_I/R_D increases. The filter is therefore equivalent to one having a large time constant.

Figure 16 shows the waveforms of outputs of the circuit. The waveform in (a) represents the output when no feedback circuit is used. Incorporating a feedback circuit produces an output represented by the waveform in (b). The solid line represents the waveform of the output, and the dotted line represents the waveform at point a. The level is suppressed when the voltage across the diode exceeds V_D.

The cutoff frequency of the LPF in this circuit determines the impulse noise suppression level and the throughput of the left and right channel signals derived from the high-frequency components of the composite signal. At the same time, it also determines the amount

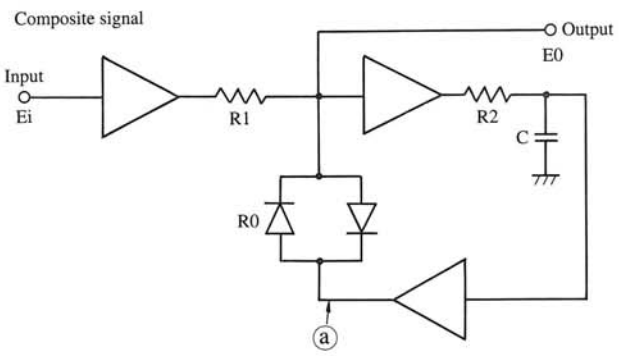

Figure 15. Block diagram of pulse suppression circuit

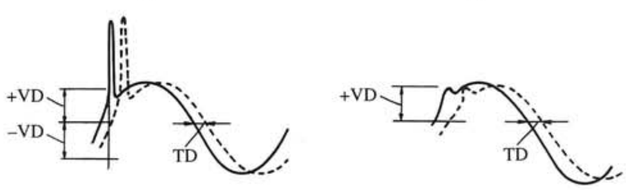

Figure 16. Operation of pulse suppression circuit

of separation. When used to process signals containing multipath noise, this circuit reduces the impulse noise components of the multipath noise. The degree of separation for signals containing multipath noise depends on the characteristics of the LPF.

3.3 IC Implementation

There are already a number of AM and FM noise reduction ICs available. However, none of these are designed for both AM and FM radio reception.

Since Fujitsu Ten's new system performs noise reduction and waveform compensation for audio signals, it uses almost the same circuit to process both AM and FM radio waves. It is therefore called a multifunction (AM/FM) noise reduction circuit.

Figure 17 shows the entire multifunction noise reduction circuit block. The FM and AM circuits are identical except for the pulse suppression circuit used to process FM. However, the operating condition settings of each circuit must be changed according to the particular requirements. For example, the noise rejection and prehold circuit and the waveform compensation circuit are both used for processing AM. In contrast, when processing FM, the waveform compensation circuit is used only when the signals contain multipath noise. Also, since AM and FM stations tend to broadcast quite different programs, variable LPFs with different characteristics are used for AM and FM.

By taking these differences into account, Fujitsu Ten succeeded in producing a system which uses the same circuit for both AM and FM radio reception without loss of noise reduction characteristics. The size of the circuit is also significantly reduced.

3.4 Benefits

Figure 18 shows the S/N characteristics on the multifunction noise reduction circuit when impulse noise is a component of the AM signal. Figure 19 shows the input and output waveforms. Since the peak value of the noise impulse is high, the display range has been changed accordingly. As shown in the diagram, there is almost no impulse noise in the output waveform. The system improves reception quality from the level at which the broadcast signal is almost lost.

Figure 20 shows the input and output waveforms of the multifunction noise reduction circuit when multipath noise is a component of the FM signal. As shown, multipath noise has been removed and the waveform

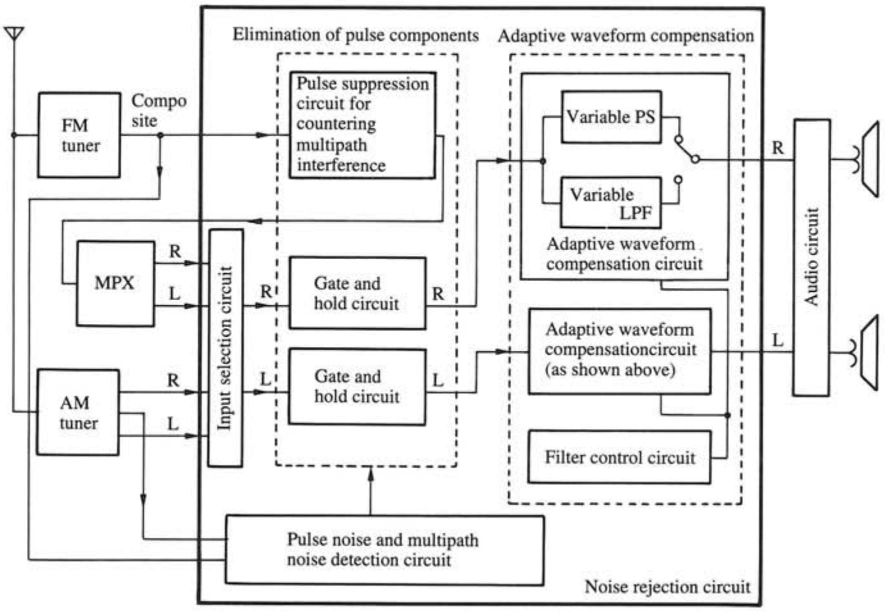

Figure 17. Multifunction noise reduction circuit

compensated so that it resembles the original waveform (sine wave). Even portions of the actual broadcast waveform with multipath noise were improved to the point where they could be heard without a disturbing degree of static.

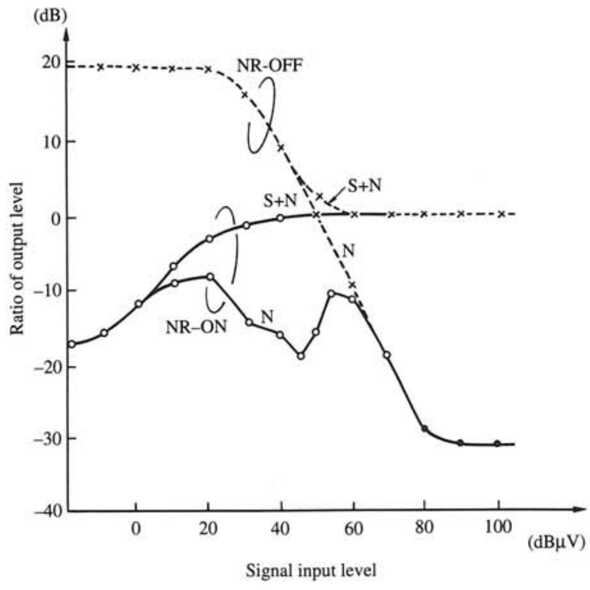

Figure 18. S/N characteristics of AM noise reduction circuit

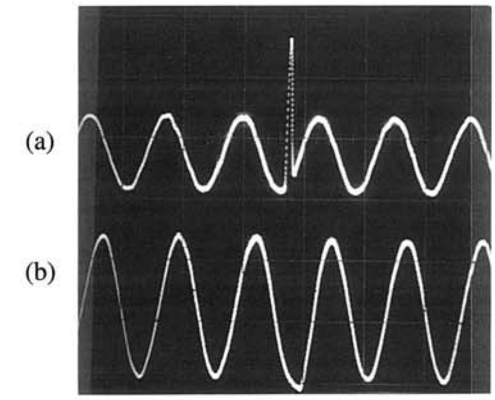

Figure 19. Input and output waveforms of multifunction noise reduction circuit (AM)

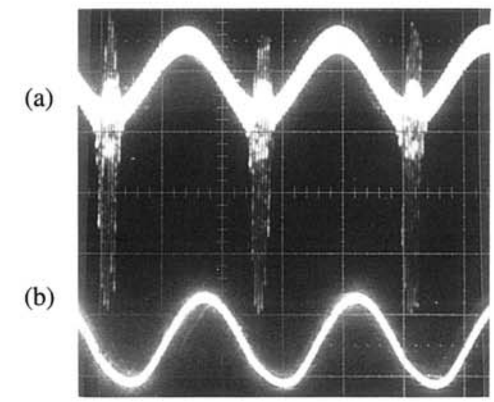

Figure 20. Input and output waveforms of multifunction noise reduction circuit (FM)

4. Conclusion

As described above, Fujitsu Ten has developed an effective system for dealing with AM impulse noise and FM impulse and multipath noise. All required circuits were implemented on a single IC.

There is, however, noise of a nonpulse nature that also affects radio reception. Fujitsu Ten will continue technological development to resolve this and other problems that affect radio reception.

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