Dielectric Receiving Filter with Sharp Stopband Using an Active Feedback Resonator Method for Cellular Base Stations

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Abstract —An 800 MHz band dielectric receiving filter with a sharp stopband has been developed. This filter is composed of a conventional dielectric antenna filter and three active band-stop filters, each sharply eliminating one band in the passband. In the active band-strop filters, small dielectric resonators in which the unloaded Q is raised to about 50000 by means of an active feedback resonator method are used. The active band-stop filter is designed to obtain optimum stability and an optimum noise figure. One of these active band-stop filters has a center frequency of 845.75 MHz, a stopband width of 1.0 MHz, and an attenuation of 30 dB. Deviation of the resonant frequency is held within ± 30 kHz and the noise figure at passband is adequately small. The size of the dielectric receiving filter is $480 \times 250 \times 44$ mm^3, and the volume is less than 1/20 that of a conventional filter using cavity resonators.

I. Introduction

CELLULAR mobile communication systems have been increasing worldwide, and the number of base stations for these systems has been increasing rapidly. One of the most important components in the base station is the antenna filter. Dielectric filters used for this purpose have been developed which are small and inexpensive [1]–[8].

Recently the frequency band used for mobile and other wireless communications has been using up the available operating frequencies. Because of this, an extension of the frequency band and more complex frequency allocation are needed. The FCC has released new frequency allocations, and these are shown in Fig. 1.. In order to avoid interference between service providers, band-stop filters are needed which can provide high rejection in the receive band of other providers and low insertion loss in their own receive band. For such filters, the unloaded Q of the resonator must be quite high. Conventional high-Q resonators are large and expensive and unsuitable for use as resonators in filters which have high rejection and many sections. One solution of this problem is the use of an active feedback resonator constructed from a feedback amplifier circuit and a resonator [9], [10]. Resonators of this type generally have unstable electrical characteristics and an inadequate noise figure.

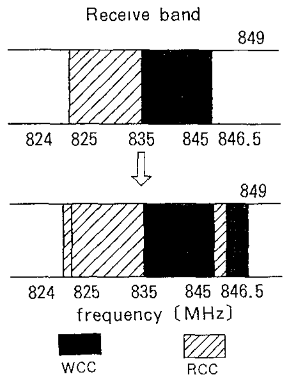

Fig. 1. Frequency allocation

By introducing practical equations concerning the stability and noise figure of the resonator, we have developed a small and electrically stable dielectric active feedback resonators (AFR's). Using the AFR, we manufactured a new active band-stop filter with sharp stopband. The center frequency is 845.75 MHz and the bandwidth is 1.0 MHz. We use a coaxial TEM-mode dielectric resonator as a basic resonator, of which the unloaded Q is 1500. The unloaded Q of the AFR is raised to about 50000. It is easy to make two more active band-stop filters of different center frequencies in the 800 MHz band. By combining these filters with a conventional receiving antenna filter, we obtained a bandpass filter with sharp stopband in the passband.

This paper describes the underlying principles and the construction of the AFR, the construction and design of the active band-stop filter using AFR, and the performance of the receiving filter using active band-stop filters.

II. Principle and Construction of Active Feedback Resonator

A. Principle

The equivalent circuit of an AFR is shown in Fig. 2. The AFR is constructed of a basic resonator and a feedback amplifier circuit. The feedback amplifier circuit is coupled

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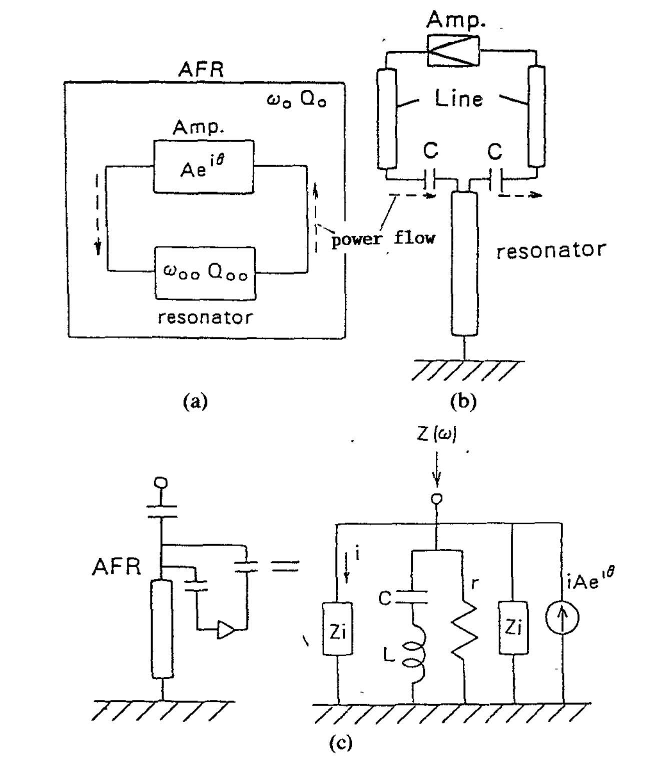

Fig. 2. (a) Concept of AFR. (b) Equivalent circuit of AFR. (c) Equivalent circuit of trap filter using AFR.

to the basic resonator (related to Q_{ei}) and compensates power loss in this resonator. Consequently, the AFR operates as a very high Q resonator; the unloaded Q of the AFR (Q_0) can be much more than that of Q_{00}. For the basic resonator, various resonators can be used, such as cavity resonators, dielectric TE-mode or TEM-mode resonators, and microstrip resonators. With respect to size and natural unloaded Q (Q_{00}), dielectric resonators are chosen. The value of Q_0 is calculated by the following equations:

$$Z(\omega) = jX(\omega) + R(\omega) \qquad X(\omega_0) = 0 \tag{1}$$

$$Q_0 = \frac{\omega_0}{2}\frac{\delta X}{\delta\omega}\bigg|_{\omega=\omega_0}\frac{1}{R(\omega_0)} \qquad (\omega=\omega_0)$$

$$= \frac{Q_{00}}{\{1+2(Q_{00}/Q_{ei})\}\{1-A(Q_{00}/Q_{ei})\cos\theta\}} \tag{2}$$

where Q_{00} is the unloaded Q of the basic resonator ($Q_{00} = r/\omega L$); Q_{ei} is the external Q to the feedback amplifier circuit ($Q_{ei} = z_i/\omega L$); A is the gain of the feedback amplifier circuit; and θ is the phase delay of the feedback amplifier circuit.

By using (2), a relation between the gain of the feedback amplifier circuit, A, and Q_0/Q_{00} is shown in Fig. 3. As the amplifier gain and Q_{00}/Q_{ei} become greater, Q_0/Q_{00} becomes greater. When the phase delay of the feedback amplifier circuit, θ, is $2n\pi$, Q_0/Q_{00} is raised to infinity at the lowest gain value. In practice this condition is very unstable. For stable operation Q_0/Q_{00} is usually chosen to be about 100 or less. When the gain exceeds this value, Q_0/Q_{00} is negative and the AFR often oscillates.

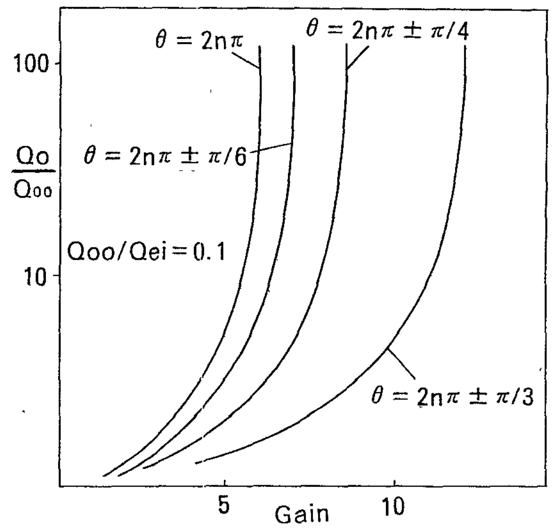

Fig. 3. Unloaded Q of AFR.

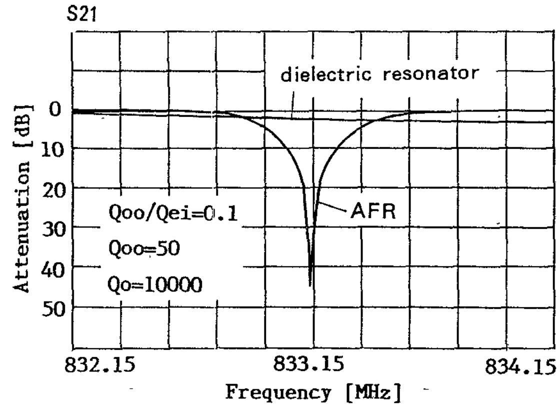

Fig. 4. Performance of AFR and dielectric resonator.

Fig. 4 shows the performance of a trap filter using an AFR when the feedback amplifier circuit operates and when it does not operate. The unloaded Q is raised from about 50 to about 10000 under the operation.

When the feedback amplifier circuit operates, the resonant frequency of the AFR varies from that of the basic resonator. The variation value is calculated by the following equations:

$$\omega_{00} = 1/\sqrt{LC} \tag{3}$$

$$\Delta\omega = \omega_0/\omega_{00} - \omega_{00}/\omega_0 \tag{4}$$

$$\Delta\omega Q_0 = \frac{A(Q_{00}/Q_{ei})\sin\theta}{1-A(Q_{00}/Q_{ei})\cos\theta}. \tag{5}$$

This is shown in Fig. 5. As the phase delay, θ, approaches $n\pi$ and Q_{00}/Q_{ei} becomes smaller, the variation value becomes smaller. Q_{00}/Q_{ei} must be determined considering (2) and (5).

By taking partial derivatives of (2) and (5) with respect to θ and by minimizing the differential constant, a stable condition is induced by the following equation:

$$Q_0 A \sin^2\theta = Q_{ei}\cos\theta. \tag{6}$$

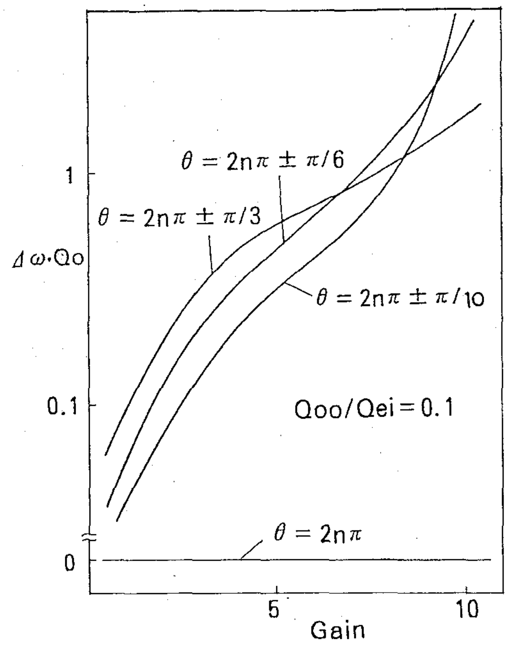

Fig. 5. Variation of center frequency.

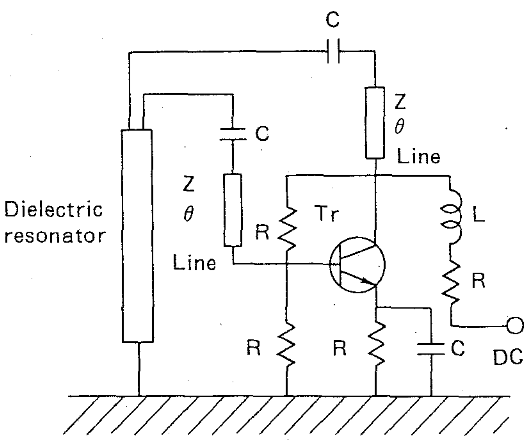

Fig. 6. Basic circuit of AFR.

By using the above equations, a stable AFR can be designed exactly.

The unloaded Q of a coaxial TEM-mode resonator is proportional to the square root of the volume. By using the AFR, a large volume reduction of the high-Q resonator becomes possible. When Q_0/Q_{00} is 10, for example, the rate of volume reduction becomes 100.

B. Basic Construction of the AFR

The basic circuit of the AFR we used is shown in Fig. 6. We chose a TEM-mode quarter-wavelength coaxial dielectric resonator as the basic resonator because it is small and has high temperature stability and a high unloaded Q relative to physical size. The dielectric material is shown in Table I. The conductor of the electrode is fired silver. The feedback amplifier circuit pattern, which is the microstrip line circuit, is constructed on the dielectric substrate by using a photoetching technique. The transistor is Si bipolar; the other passive components are of the chip type and these are mounted directly on the substrate surface. This circuit is coupled to the inner conductor on the open side of the basic resonator.

TABLE I
DIELECTRIC MATERIAL

Material system	$MgTiO_3$ − $CaTiO_3$
Dielectric permittivity	21
Dissipation factor	5.0×10^{-5} (800MHz)
Temperature coefficient	+3 ppm/°C

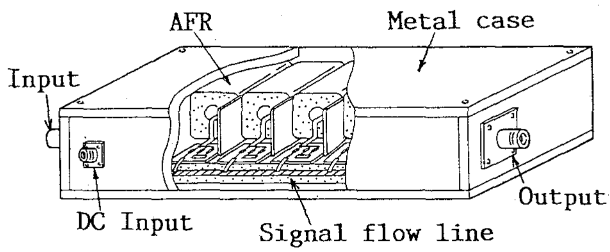

Fig. 7. Basic construction of active band-stop filter.

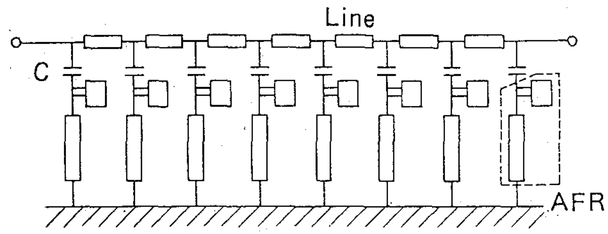

Fig. 8. Equivalent circuit of active band-stop filter.

III. Active Band-Stop Filter

A. Construction

The construction of an active band-stop filter using an AFR is shown in Fig. 7. The casing is made of brass. The input and output terminals are N-type connectors and the dc input terminal is an SMA-type connector; these are fixed on the casing. The input and output terminals are isolated from each other by more than 80 dB. The AFR's are arrayed side by side and isolated individually by using shielding metal plates. The signal flow line is a 50 Ω dielectric coaxial line, to which AFR's are connected at intervals of a quarter of the wavelength as high-Q trap resonators. The dc line is wired under the feedback amplifier circuits, to which each bias input of the feedback amplifier circuit is connected in parallel.

B. Filter Design

The equivalent circuit of the active band-stop filter is shown in Fig. 8. The filter type is a distributed band-stop filter, and the values of the design parameters are calculated by the usual Chebyshev characterization design method. Resonant frequencies of the basic resonators of AFR's are determined considering the deviation of resonant frequencies shown by (5). Usually the phase delay of the feedback amplifier circuit, θ, is chosen to be within

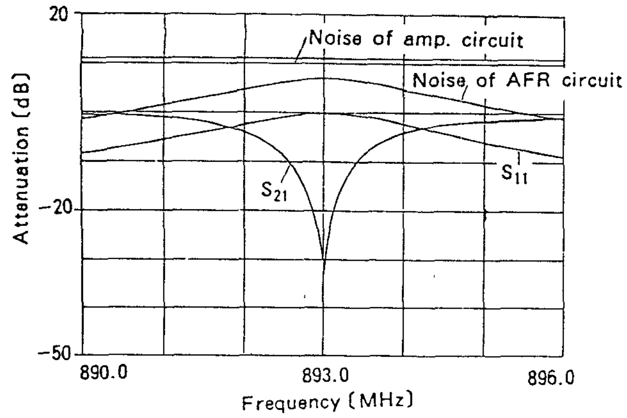

Fig. 9. Noise power of active trap filter.

TABLE II
PERFORMANCE OF ACTIVE BAND-STOP FILTER

	Required	Measured
Number of section	8	8
Center frequency	845.75MHz	845.75MHz
Stopband width	1.0MHz	1.0MHz
Attenuation	30dB	32dB
Insertion loss (fo±0.95MHz)	0.8dB	0.7dB
Return loss (fo±0.95MHz)	15dB	15dB
Input power	0 dBm max	0 dBm max
Physical size	60×200×30mm	55×180×25mm

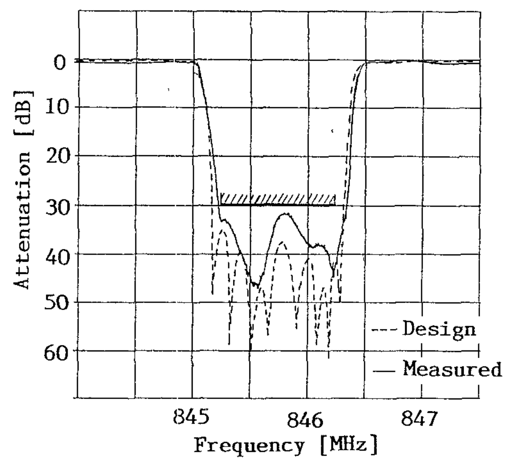

Fig. 10. Attenuation characteristics of active band-stop filter.

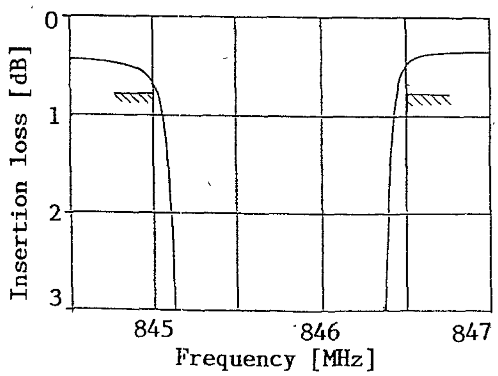

Fig. 11. Insertion loss characteristics of active band-stop filter.

$2n\pi \pm \pi/10$ for the reason that the variation of power and temperature is small. The unloaded Q of the basic resonator is chosen to be about 1/30–1/40 of the unloaded Q of the AFR for the same reason. We use the basic resonator with an unloaded Q of 1500, and the deviation of the resonant frequency is held within ±30 kHz at 0–60°C under 0 dBm.

C. Noise Figure

When an AFR is used as a trap filter coupling to the signal flow line by a capacitor, the noise figure of this filter is calculated by the following equations:

$$\text{N.F.} = \text{N.F.}_{Tr} AB/(1-AB) \tag{7}$$

$$B = \frac{(2/Q_{et})^2}{(2/Q_e + 1/Q_{00} + 2/Q_{et})^2 + (\Delta\omega)^2} \tag{8}$$

where Q_e is the external Q of the filter.

Noise power reaches its maximum value at the resonant frequency. Noise power in the passband is sufficiently small compared with the case of a conventional amplifier circuit using the same transistor. An example of noise power characteristics is shown in Fig. 9. The noise power characteristic curve is similar to the S_{11} characteristics curve. When an AFR is used in a band-stop filter and the noise figure of the transistor is about 1.3 dB, the noise figure of the AFR is less than 1.0 dB and the noise power generated in the AFR is negligible. This is an advantageous point of the active band-stop filter.

D. Performance

We have manufactured an eight-pole active band-stop filter. The required characteristics and performance of this filter are shown in Table II. The center frequency is 845.75 MHz, and the bandwidth is 1.0 MHz. The electrical characteristics are shown in Figs. 10 and 11. The unloaded Q of the AFR is about 50000. A very sharp band-stop characteristics curve was obtained. The physical size is $55 \times 180 \times 25\text{mm}^3$.

IV. DIELECTRIC RECEIVING FILTER USING ACTIVE BAND-STOP FILTERS

Two more active band-stop filters were made in the 800 MHz band. By combining these filters with a conventional dielectric antenna receiving filter, a new type of receiving filter was obtained. A block diagram of this filter is shown in Fig. 12. Each filter is combined in cascade and the electrical lengths of the cables between each filter are adjusted. These filters are put into a single metal casing. The entire physical size is $480 \times 250 \times 44\text{mm}^3$, and the volume is less than 1/20 that of a conventional filter using cavity resonators. The electrical characteristics are shown in Table III and Fig. 13. A bandpass characteristic curve having three sharp stopbands was obtained. Attenuation in

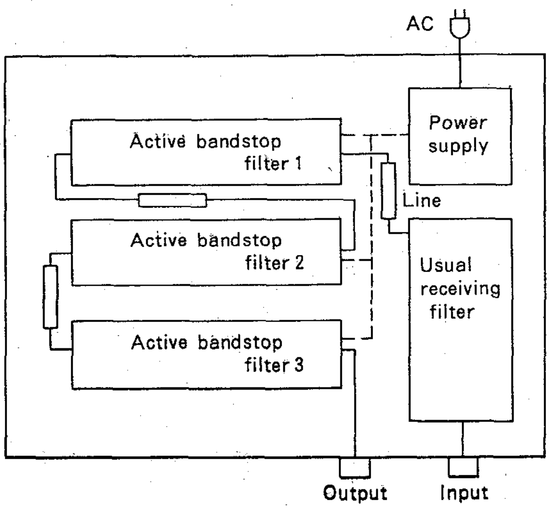

Fig. 12. Block diagram of new receiving filter.

TABLE III
PERFORMANCE OF NEW RECEIVING FILTER

	Required	Measured
Passband width	835.2−844.8MHz 846.7−848.8MHz	
Stopband width	824.0−834.7MHz 845.3−846.2MHz 849.3−851.0MHz	
Insertion loss	2.0dB	1.7dB
Attenuation	30dB	30dB
Return loss	12dB	12dB
Input power	0 dBm max	0 dBm max
Physical size	480×350×44mm	480×250×44mm

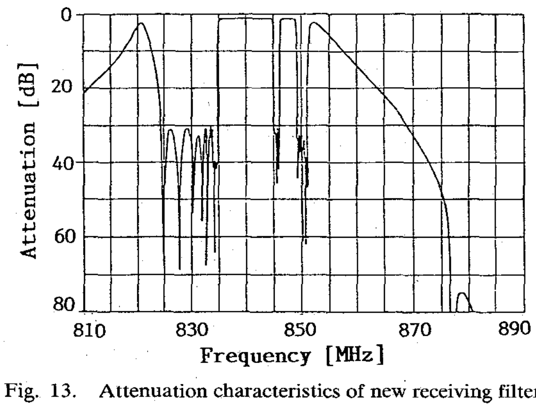

Fig. 13. Attenuation characteristics of new receiving filter.

the stopband is 30 dB. By using this filter as the receiving filter for extended cellular systems, unwanted signals can be effectively rejected.

V. CONCLUSION

We have developed an 800 MHz band dielectric receiving filter with sharp stopband by using the active feedback resonator (AFR) method. We considered the principle of the AFR and introduced certain effective equations. We used a coaxial TEM-mode dielectric resonator as the basic resonator of the AFR, and the unloaded Q of the AFR was raised to about 50000. Noise power generated in the AFR in the passband is sufficiently small. We manufactured an active band-stop filter using AFR's in the 800 MHz band which is small and has sharp rejection characteristics. In addition we manufactured a new dielectric receiving filter by combining the active band-stop filters and a conventional receiving filter having sharp stopbands. Attenuation in the stopband was 30 dB. The entire physical size is $480 \times 250 \times 44 mm^3$. This filter is useful as the receiving filter of cellular base stations.

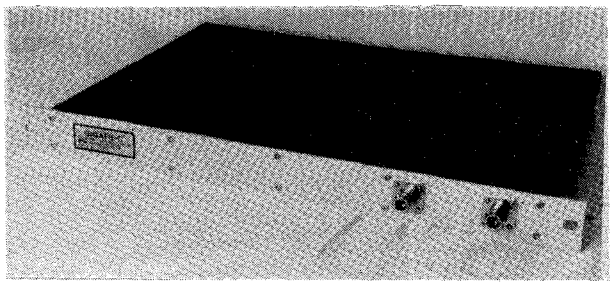

Fig. 14. External view of new receiving filter.

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Dr. Wakino received the Award of Invention from the Japan Institute of Invention and Innovation in 1971, the Award of Engineering from the Japanese Ceramic Society in 1978, and the Award of Engineering Progress from the Japan Society of Powder and Powder Metallurgy in 1984. The holder of ten U.S. patents, he has written over 86 technical papers. Dr. Wakino is a fellow of the American Ceramic Society Society and a member of the Institute of Electronics, Information and Communication Engineers and the Institute of Electrical Engineers of Japan.