# An RF Amplitude Equalizer ; Improved Passband Flatness of a Bandpass Filter

Hee-Yong Hwang[1] · Jung-Seong Jung[2] · Sang-won Yun[3]

## Abstract

Many communication systems require bandpass filters with sharp skirt frequency characteristics in order to avoid the interference, which results in more order in the filter design. However, because of the limited Q values bandpass filters made of small sized ceramic resonators suffer from relatively large ripples at the band edges as the order of the filter increases. In order to compensate the large ripples while maintaining the sharp skirt frequency we propose a new RF amplitude equalizer. The equalizer made of two pole bandpass filter and an amplifier whose amplitude characteristics are the reverse of those of the bandapss filter. At the cellular band 9-pole bandpass filter with 10 MHz bandwidth exhibits 3 dB ripple when 8mm*8mm ceramic coaxial resonators are used. We added the RF equalizer to this filter and the flatness is improved as less than 1 dB.

***Key words*** : RF equalizer, amplitude equalizer, bandpass filter, quality factor, concave shape

## I. INTRODUCTION

Recently, various communication systems such as AMPS, GSM, PCS, GPS, IMT-2000, WILL, B-WLL, LMDS, etc, are fully developed or widely used. The improving the system performance with small size and low cost components is driven by the expansion of the market and the development of new technologies for these systems.

Bandpass filters are one of the critical components in most of communication systems to isolate a channel from adjacent ones, maintaining a compact size. In the design of bandpass filters, one of the main issues is how to realize a high performance filter, closer to an ideal bandpass filter with limited size and cost. As the size of the filter is reduced, the quality factor of the resonators of the filter is decreased and then the flatness in the passband of the filter also degraded due to the Q factors of the resonators.

The degradation of the filter performance is more serious as the number of poles is increased when the bandwidth is small and a very tight skirt frequency specification is imposed. This problem can be solved by adding an amplitude equalizer to the bandpass filter or by inserting it into proper position of the system. The equalizer is also a filter that compensates passband shape of the normal bandpass filter. The shape of the response in the passband is designed as a reverse or concave shape of the normal one, which is degraded as a convex shape. The additional advantage is improvement of skirt response as the number of poles used in the RF amplitude equalizer.

In this paper, the design method and application example of the concave-shaped bandpass filter or amplitude equalizer in cellular band is presented. The designed filter compensated properly and easily the degraded shape of the passband characteristics of the bandpass filter. As the result, a small sized filter can also give the same good frequency response as large bandpass filters made of high Q resonators. This amplitude equalizer can also be applied to the design of various communication systems in which the improved passband flatness is required in order to maintain the uniform characteristics throughout the whole communication channels.

## II. CONCEPT OF RF AMPLITUDE EQUALIZER

The passband frequency response of a conventional bandpass filter that made with resonators of finite quality factor is shown in Fig. 1. As the size is reduced, generally, the quality factor is decreased and then the degree of flatness degradation or the passband ripple, $\Delta S$ is increased. This situation is the same when we design a bandpass filter with smaller fractional bandwidth, $W$ and/or larger number of poles of the filter. Because of this phenomenon, the passband ripple and skirt characteristics of the realizable bandpass filter using resonators of limited size is limited to meet a given specification of bandpass filter. As the number of resonator used in the filter to achieve sharp skirt response is increased, the passband ripple, $\Delta$

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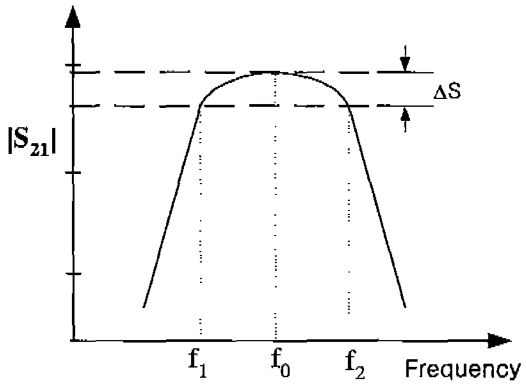


Fig. 1. Typical characteristics of a BPF or system.

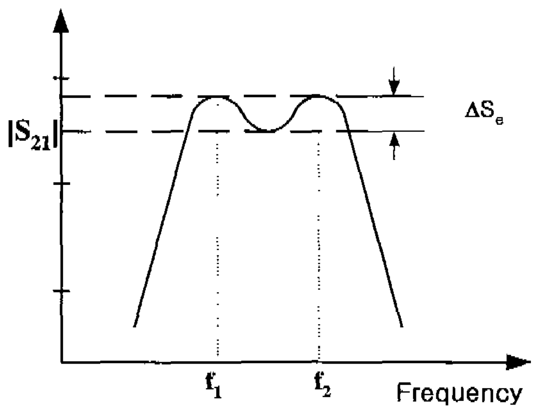


Fig. 2. The characteristics of amplitude equalizer.

$S$ is also increased.

A typical frequency response of a bandpass filter or system to be considered is shown in Fig. 1. This passband ripple shape can be calculated or measured with conventional simulator or measurement tools. Then we can design a two pole bandpass filter has the reversed ripple shape as shown in Fig. 2. After cascading the two filters, we can obtain the more closed to ideal filter that the passband ripple is nearly removed as shown in Fig. 3.

The amplitude equalizer can be designed with normal Chebyshev bandpass filter of any number of poles according to the amplitude shape of the bandpass filter or system we want to compensate. The standard bandpass filter design method[1] in Fig. 4 and design equations of eq. (2)~(4), respectively can be used to realize the proper ripple, $\Delta S$ and fractional bandwidth, $W$, after we comparing each bandwidth of Fig. 1 and Fig. 2. The passband ripple of normal filter, $\Delta S$ and that of the amplitude equalizer should be the same value. The simplest amplitude equalizer is two-pole bandpass filter that has the same ripple with the normal one.

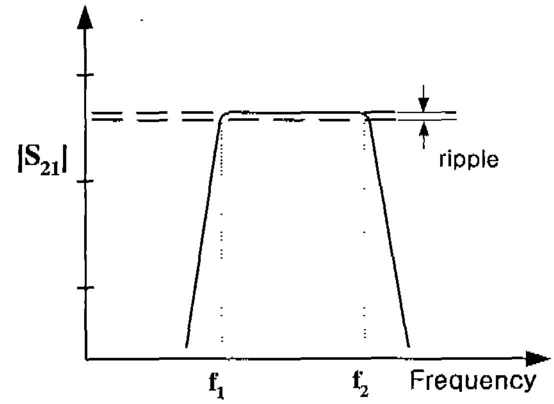


Fig. 3. Compensated response by amplitude equalizer.

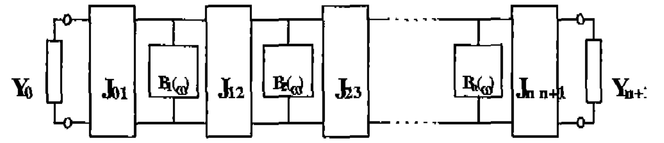


Fig. 4. A BPF with admittance inverters[1].

$$\Delta S = \Delta S_e \tag{1}$$

where $\Delta S$ and $\Delta S_e$ is the ripple of the normal filter and the amplitude equalizer, respectively.

$$J_{0,1} = \sqrt{\frac{Y_0 W b_1}{\omega_i g_0 g_1}} \tag{2}$$

$$J_{j,j+1} = \frac{W}{\omega_i}\sqrt{\frac{b_j b_{j+1}}{g_j g_{j+1}}} \tag{3}$$

$$J_{n,n+1} = \sqrt{\frac{Y_{n+1} W b_n}{\omega_i g_n g_{n+1}}} \tag{4}$$

The entire block diagram of the amplitude equalizer is shown in Fig. 5. Which consist of a shaping filter that has a reversed passband response, and one or two buffer amplifier(s) and/or an attenuator that meets the matching condition of input and output port. The shaping filter can not be normally matched to 50 $\Omega$ system because of the large ripple which means passband mismatching. The buffer amplifier and attenuator are used for solving the matching problem. A 10 dB attenuator gives return loss or $S_{22}$ of 20 dB.

The total noise figure of cascaded blocks is calculated using equation (5)[2]. The noise figure of amplitude equalizer can be minimized by the gain of the buffer amplifier of input stage because the loss term of shaping filter and attenuator is divided by the gain $G$ of the amplifier as the equation (5).

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_2 - 1}{G_1 G_2} \tag{5}$$

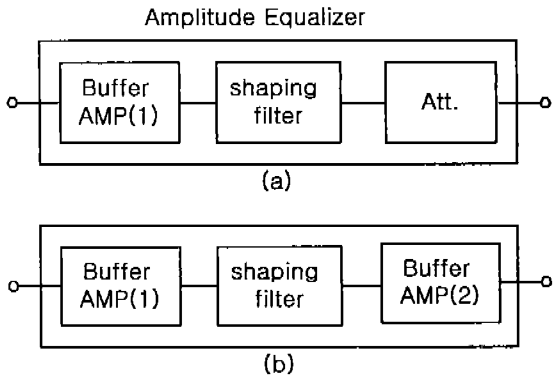


Fig. 5. The structure of amplitude equalizer.

The amplitude equalizer is cascaded before or after the bandpass filter or system to be compensated according to the filter or system requirements such as noise figure, gain and matching conditions.

## III. EXAMPLE OF AMPLIUDE EQUALIZER

We designed and tested a nine-pole comb-line bandpass filter with coaxial type ceramic resonators whose sizes are 8×8 mm and unloaded Q values are about 750. The center frequency of the bandpass filter is 847.14 MHz, insertion loss of 18.02 dB at the center frequency, and bandwidth of 3.7 MHz at the cellular band as shown in Fig. 6. We also prepared 10 MHz bandpass filter of center frequency of 840 MHz and loss of 6.8 dB other features are the same or similar to those of the 3.7 MHz bandpass filter as shown in Fig 9. We used the configuration of Fig. 5 (a), for the amplitude equalization. The size of the RF amplitude equalizer is 26.5*23*9mm consisting of two 8*8 resonators and MMIC amplifier of 14 dB gain and noise figure of 2.5 dB.

Because the filter size is small and number of resonator is large(nine-poles) for reducing the bandpass filter size and sharp skirt response, the passband ripple is about 3.5 dB in 3.7 MHz bandwidth. After connecting of the amplitude equalizer of Fig. 7, the resultant passband ripple is reduced within 2.0 dB as shown in Fig. 8. For the 10 MHz bandpass filter, the passband ripple is improved from 3.8 dB to within 1 dB as in Fig. 10. Additional improvement of the skirt response can be also read, when we compare the Fig. 6 and Fig. 8 or Fig. 9 and Fig. 10, respectively. This is the same effect of adding two resonators to the filter of Fig. 6 or Fig. 9, because two-pole filter was used in shaping filter of the amplitude equalizer. The overall size of the filter including the RF equalizer is 100*23.9 mm, regardless of the value of bandwidth or center frequency.

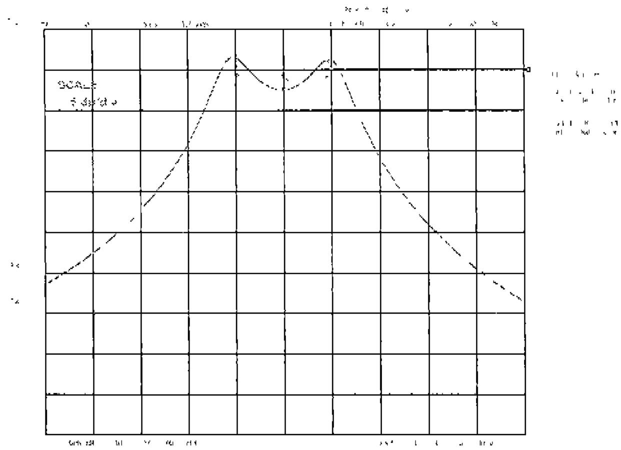

Fig. 7. Measured response of the amplitude equalizer.

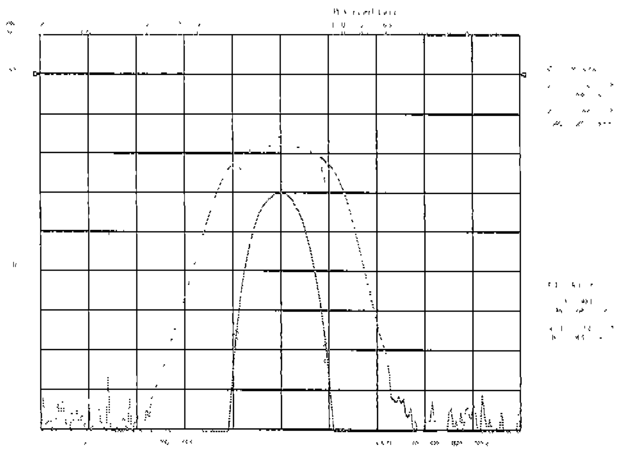

Fig. 6. Measured response of a 3.7 MHz bandpass filter in cellular band.

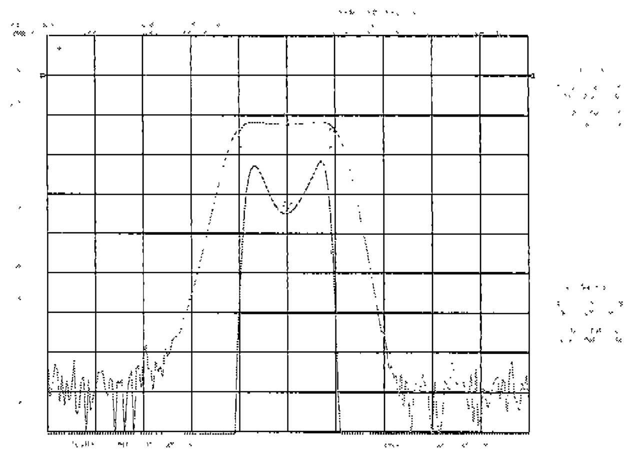

Fig. 8. Compensated response of the bandpass filter in Fig. 7 by amplitude equalizer (measured).

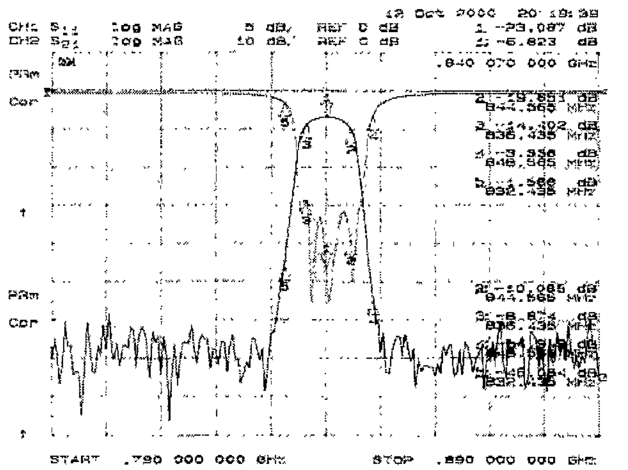


Fig. 9. Measured response of a 10 MHz bandpass filter in cellular band.

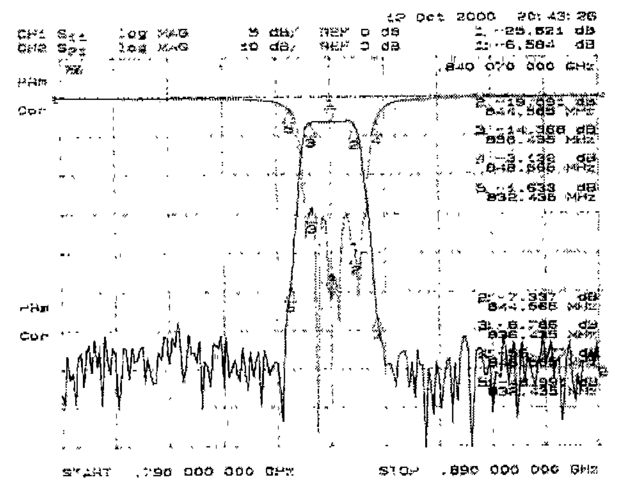


Fig. 10. Compensated response of the filter in Fig. 9 by amplitude equalizer.

## Ⅳ. CONCLUSIONS

An RF amplitude equalizer is presented for improving the ideality of a bandpass filter frequency response in cellular band. Generally, it is very difficult to meet all the requirements such as small size, sharp skirt response and passband flatness of a bandpass filter simultaneously. The proposed amplitude equalizer, which consists of a shaping filter, gain block and in/out -matching blocks, is one of the possible solutions for this problem.

By using the amplitude equalizer, about 3.5 dB of the passband ripple, 9-pole bandpass in cellular band is improved to within 1dB ripple and the skirt response is also improved by the 2-pole bandpass filter. Therefore, a small sized filter with an amplitude equalizer can also gives good skirt frequency response as that of a large cavity type filter. This amplitude equalizer is not only applicable to improve the flatness of bandpass filters but also applicable to many communication systems that are required to improve flatness of overall RF frequency response.

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