# Single-input Multiple-output Signals Third-order Active-R Filter for different Circuit Merit Factor (Q)

***Adnan A. Qasem**** ***Shinde G. Narharraa*****

*School of Physics, Swami Ramanand Teerth Marathwada (SRTM) University, Nanded, Maharashtra, India
**Principal, Indira Gandhi (SR) College, CIDCO, Nanded, Maharashtra, India
***E-mail:** almogammer80@gmail.com

Received 2, May, 2014
Accepted 2, September, 2014



## Abstract:

Single-input Multiple-output Signals Third-order Active-R Filter for different Circuit Merit Factor Q Configuration is proposed. This paper discusses a new configuration to realize third-order low pass, band pass and high pass. The presented circuit uses Single-input Multiple-output signals, OP-AMP and passive components. This filter is useful for high frequency operation, monolithic IC implementation and it is easy to design .This circuit gives three filter functions low-pass, high-pass and band-pass. This filter circuit can be used for different merit factor (Q) with high pass band gain. This gives better stop-band attenuation and sharper cut-off at the edge of the pass-band. Thus the response shows wider pass-band. The Ideal value of this filter circuit which is closed to Ideal value of third-order active-R filter is at $0.8 \leq Q \geq 6$. The advantages of this circuit are reduction in size and weight, increased circuit reliability, more economical and easy for manufacturing.

**Key words:** third-order active-R filter, Single-input Multiple-output signals, circuit merit factor Q.

## Introduction:

The filter is a device designed to separate, pass or suppress a group of signals from a mixture of signals. These are frequency selective networks. The operational amplifier (op. amp.) is now accepted as the basic active component for an inductorless filter. The circuit is realized using single pole (as “integrator”) behavior of an internally compensated operational amplifier [1, 2, 3-5]. The filter without the capacitor is called an active-R filter and has received much attention due to its potential advantages in term of miniaturization, ease of design and high frequency performance [6].It has been also pointed out in the literature that active-R networks offer substantially low sensitivity characteristics as compared to RC active structures (Soderstand & Mitra1971).This paper proposes realization and design method for Single-input Multiple-output Third-order Active-R Filter for different Circuit Merit Factor Q . This filter circuit gives three filter functions low pass, high pass and band pass, with ideal gain roll-off and high pass-band gain. The circuit is designed and studied for different values of circuit merit Factor Q. The filters are extensively used in communication, instrumentation, control systems entertainment electronics, sonar systems etc.

**Proposed Circuit Configuration:**

The Propose Single-input Multiple-output Signals Third-order Active-R Filter for different Circuit Merit Factor Q circuit diagram is shown in figure1. With the advent of the high frequency roll-off in the response of the op-amp, the circuit is constructed with Single-input Multiple-output signals; three op-amp (µA741) and four resistances. The op-amp can be used as an inverting or non-inverting grounded integration depending on connection with identical gain bandwidth product as an active element. This filter gives multiple outputs, which tend three filter functions, low pass, band pass and high pass. The negative feedback is introduced through resistances $R_1$; $R_2$ *and* $R_3$ from the output of three op-amps to inverting input of the first op. amplifiers.

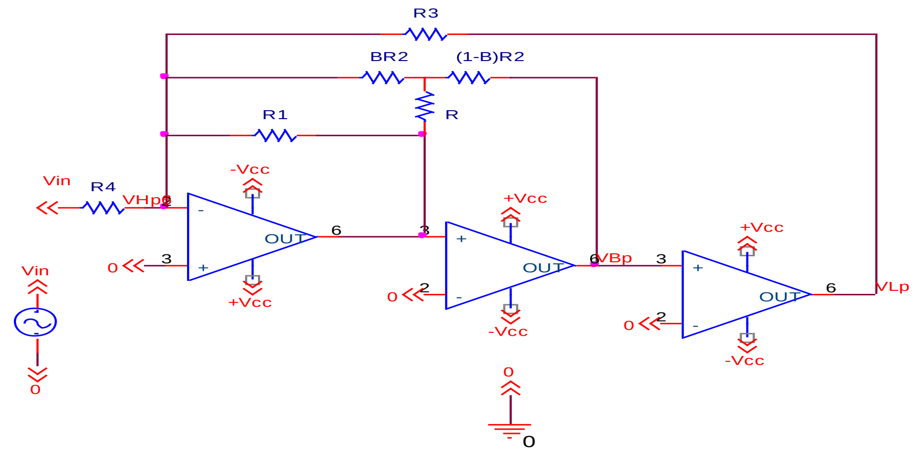


**Fig. 1: Proposed Circuit diagram for Single-input Multiple-output Signals third-order active-R filter.**

The resistance $R_2$ is tapped at different points for variation in feedback. The op-amps are coupled such that output of first op- amplifier is connected to non-inverting input of second op-amp and output of second op-amplifier is connected to non-inverting input of third op-amp. Non-inverting terminal of first op-amp, inverting terminal of second and third op-amps are grounded. The input is applied to inverting input of first op-amp through resistance $R_4$.

**Circuit Analysis and Design Equations:**

The single-pole model of an op-amp leads to complex gain and the transfer function is given by [7].

$$A(s) = A_0\omega_0 / (S + \omega_0) \quad (1)$$

Where,

$A_0$ = open loop d.c. gain, $\omega_0$ = open loop (3dB) bandwidth, $GB = A_0\,\omega_0$ = gain bandwidth product of op-amplifier.

$$A(s) = A_0\omega_0 / S = GB / S, \quad (2)$$

Where, $S >> \omega_0$

This shows that the op-amp is an “integrator”, Thus Single-input Multiple-output Signals Third-order Active-R Filter transfer function at three different terminals are given below. The voltage transfer function for low pass filter.

$$T_{LP}(S) = \frac{-(1/R_4)GB_1GB_2GB_3}{X_1S^3 + X_2S^2 + X_3S + X_4} \quad (3)$$

The voltage transfer function for band pass filter

$$T_{BP}(S)=\frac{-(1/R_4)GB_1GB_2S}{X_1S^3+X_2S^2+X_3S+X_4}$$ (4)

The voltage transfer function for high pass filter

$$T_{HP}(S)=\frac{(1/R_4)S^3}{X_1S^3+X_2S^2+X_3S+X_4}$$ (5)

Where,

$X_1=\left\{\frac{1}{R_1}+\frac{1}{BR_2}+\frac{1}{R_3}+\frac{1}{R_4}-\frac{(1-B)RM}{B}\right\}$

$X_2=GB_1\left\{\frac{1}{R_1}+(1-B)R_2M\right\}$

$X_3=GB_1GB_2RM$

$X_4=\left\{\frac{GB_1\,GB_2GB_3}{R3}\right\}$

$M=1/(RR_2+B(1-B)R_2^2)$

The circuit was designed using coefficient matching technique with general third-order filter transfer function [4, 5]

$$T(S)=\frac{H_3S^3+H_2S^2+HS+H_0}{S^3+S^2\omega_0\left[(1/Q)+1\right]+S\omega_0^2\left[(1/Q)+1\right]\omega_0^3}$$ (6)

By comparing (3), (4), and (5) with (6), we get the design equation as

$\left\{\frac{1}{R_1}+\frac{1}{BR_2}+\frac{1}{R_3}+\frac{1}{R_4}-\frac{(1-B)RM}{B}\right\}=1$ (7)

$GB_1\left\{\frac{1}{R_1}+(1-B)R_2M\right\}=W_0\{1+1/Q\}$ (8)

$GB_1GB_2RM=W_0^2\{1+1/Q\}$ (9)

$\left\{\frac{GB_1\,GB_2GB_3}{R3}\right\}=W_0^3$ (10)

So that Values of $R_1$, $R_2$, $R_3$ and $R_4$ can be calculated using these equations for different values of Q, $f_0$=15 KHz, B=0.5 and R=400 Ω (table1).

**Sensitivity:**

The sensitivities of $\omega_0$ and Q in this Wider Pass-band Third-order Active-R Filter are as follows.

$S_R^{w0}=\frac{1}{3}\{\left(\frac{1-B}{B}\right)(1-RR_2M)\}$

$S_{R1}^{w0}=\frac{1}{3}\{\frac{1}{R_1}\}$

$S_{R2}^{w0}=\frac{1}{3}\{\frac{1}{BR_2}-RR_2M^2\left(\frac{1-B}{B}\right)(R_2+2B(1-B)R_2)\}$

$S_{R3}^{w0}=-\frac{1}{3}\{1+\frac{1}{R_3}\}$

$S_{R4}^{w0}=\frac{1}{3}\{\frac{1}{R_4}\}$

$S_{GB1}^{w0}=S_{GB2}^{w0}=S_{GB3}^{w0}=\frac{1}{3}$

$S_R^Q=-(1+Q)\{R(1-RR_2M)(\frac{1}{R}+\frac{1}{3}M(\frac{1-B}{B}))\}$

$S_{R1}^Q=-\frac{1}{3}(1+Q)\{\frac{1}{R_1}\}$

$S_{R2}^Q=-R_2(1+Q)\{\frac{1}{3}(\frac{1}{BR_2^2}-RM\left(\frac{1-B}{B}\right)(R_2+2B(1-B)R_2))-R_2M(1+2B(1-B))\}$

$S_{R3}^Q=-\frac{1}{3}(1+Q)\{1+\frac{1}{R_3}\}$

$S_{R4}^Q=-\frac{1}{3}(1+Q)\{\frac{1}{R_4}\}$

$S_{GB1}^Q=S_{GB2}^Q=-\frac{1}{3}(1+Q)$

$S_{GB3}^Q=-\frac{2}{3}(1+Q)$

Thus, passive and active sensitivities are all less than unity. So for all practical purposes this circuit is stable as these sensitivities are very low.

**Table1: Resistance values for some values of Q.**

| Q | $R_1$ (Ω) | $R_2$ (Ω) | $R_3$ (Ω) | $R_4$ (Ω) |
|---|---|---|---|---|
| 0·1 | 3.4 | 118 | 52k | 1.4 |
| 0·4 | 10.8 | 330 | 52k | 1.1 |
| 0.8 | 16.9 | 477 | 52k | 1.06 |
| 1 | 19 | 524.8 | 52k | 1.05 |
| 6 | 32.9 | 797 | 52k | 1.03 |
| 10 | 34.9 | 833 | 52k | 1.03 |

## Material and Methods:

The circuit performance was studied with different values of Q (*0.1, 0.4, 0.8, 1, 6 and 10*) with constant values of $f_0$=15 KHz, B=0.5 and R=400 Ω for GB=$2\pi\times5.6\times10^5\,rad/sec$. The table 1 shows resistance values of resistors for different Q values. Same circuit was also studied for different values of center frequency $f_0$. The observed frequency response shows good agreement with theoretical results. The general range of this frequency response for this active-R filter is from 10 Hz to 1MHz as operating range of this op-amp is 10 Hz to 1.2MHz. Following observations are noticed from experimental study at three different terminals low pass, band pass and high pass filter function for different values of Q.

## Result and Discussion:

### *A. Low pass response:*

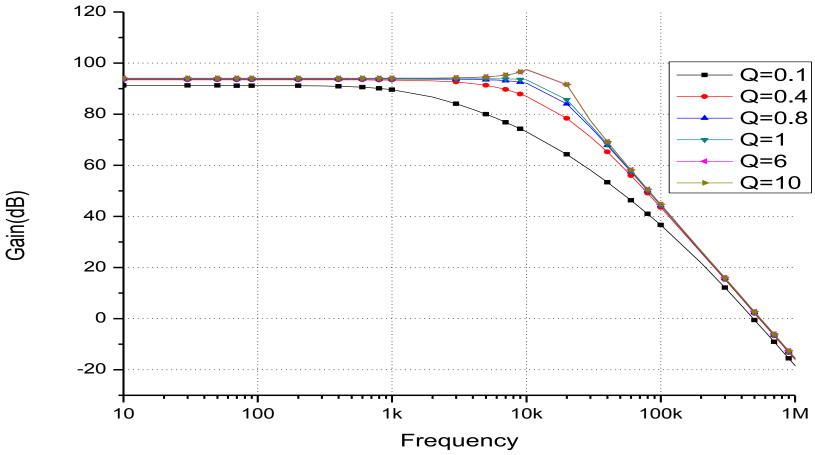


**Fig. 2: Low pass (LP) responses for different values of Q**

**Table: 2. Analysis of Low Pass Response for Graph (Fig 2)**

| Q | Max .Pass-band Gain(dB) | $f_{0L}$ (kHz) | $f_0 \sim f_{0L}$ (Hz) | % change in $f_{0L}$ | Gain Roll-off in stop band | | Overshoot in the pass band | |
|---|---|---|---|---|---|---|---|---|
| | | | | | dB/Octave (kHz) | Octave starting at (kHz) | (dB) | $f_{0SL}$ (kHz) |
| 0·1 | 91.2 | 20 | 5 | 25 | 17.8 | 197 | 0 | 0 |
| 0·4 | 93.5 | 38 | 23 | 60 | 18 | 50 | 0 | 0 |
| 0.8 | 93.8 | 43 | 28 | 65 | 18 | 40 | 0 | 0 |
| 1 | 94 | 43 | 28 | 65 | 18 | 40 | 0 | 0 |
| 6 | 94 | 44 | 29 | 66 | 18 | 40 | 0 | 0 |
| 10 | 94 | 44 | 29 | 66 | 18 | 40 | 3.3 | 10 |

The maximum pass-band gain varies between 91.2dB to 94dB .Also, the gain roll-off per octave varies between 17.8 to 18dB/octave. The maximum pass-band gain increase with increase in values of circuit merit factor Q but after Q≥1 this value gets stabilized at the maximum pass-band gain 94dB. The Gain roll-off values are closed to ideal value of 18dB/octave for third order active-R filter. Overshoot is observed at Q≥10.But in previous reported configuration Overshoot is observed and increases for Q ≥ 1.2 [8].

***B. Band-pass response:***

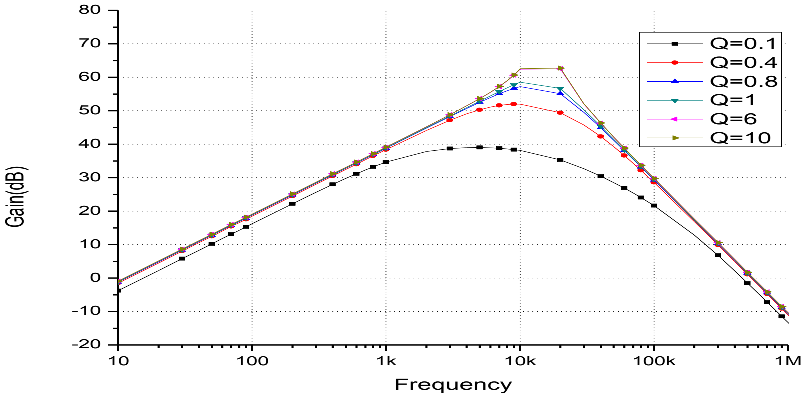


**Fig.3: The band pass (BP) response for different Q,**

**Table: 3. Analysis of Band Pass Response for Graph (Fig. 3)**

| Q | Max. Pass-band gain (dB) | $f_1$ (kHz) | $f_2$ (kHz) | BW (kHz) | Gain Roll-off / octave in stop band | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Leading Part | | Trailing Part | |
| | | | | | dB/octave | Octave starting at (kHz) | dB/octave | Octave starting at (kHz) |
| 0·1 | 39 | 0.4 | 56 | 55.6 | 6 | 0.6 | 12 | 198 |
| 0·4 | 52 | 0.8 | 60 | 59.2 | 6 | 2 | 12 | 60 |
| 0.8 | 56.8 | 1.1 | 54 | 52.9 | 6 | 3 | 12 | 60 |
| 1 | 58 | 1.3 | 50 | 48.2 | 6 | 3 | 12 | 60 |
| 6 | 62.4 | 1.8 | 45 | 43.2 | 6 | 3 | 12 | 60 |
| 10 | 62.4 | 1.8 | 45 | 43.2 | 6 | 3 | 12 | 60 |

The maximum pass-band gain varies between 39dB to 62.4dB. Also, the bandwidth varies between 43.2 KHz to 59.2 KHz. The maximum pass-band gain increases with increase in circuit merit factor Q. The bandwidth decreases with increasing in values of circuit merit factor Q but after Q≥1 the bandwidth gets stabilized at 43.2 KHz. For lower values of circuit merit factor Q, this filter can be used for wide bandwidth and for higher values of circuit merit factor Q it can be used for narrow bandwidth. There is no shift in the central frequency. It is also observed that the pass band distribution of frequency is symmetric for both sides. But in previous reported the pass band distribution of frequency isn't symmetric for both sides [8]. The circuit works better band pass response for Q ≥1.

*C. High pass response:*

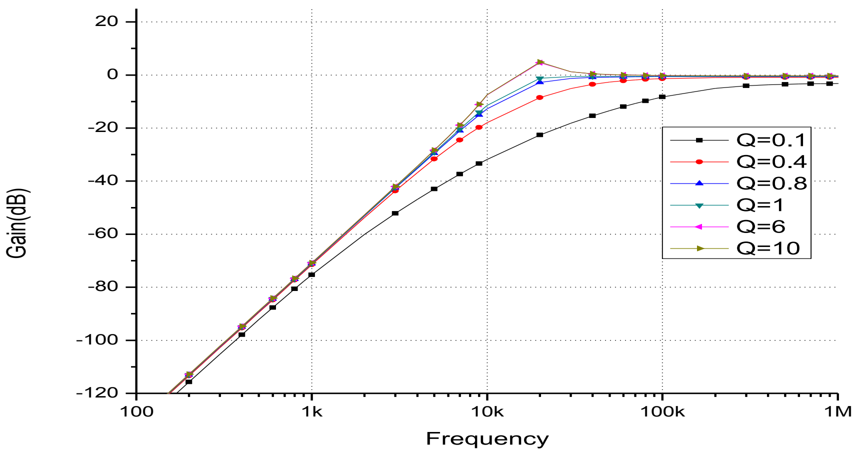


**Fig. 4: High pass (HP) responses for different values of Q**

**Table: 4. Analysis of High Pass Response for Graph (Fig.4)**

| Q | $f_{0H}$(kHz) | $f_0 \sim f_{0H}$ (kHz) | % change in $f_{0H}$ | Gain Roll-off in stop band | | Gain Stabilization | | Peak Gain of overshoot (dB) |
|---|---|---|---|---|---|---|---|---|
| | | | | dB/Octave | Octave starting at (kHz ) | (dB) | $f_S$ ( kHz ) | |
| 0.1 | 155 | 140 | 90 | 17.6 | 20 | -3.6 | 603 | 0 |
| 0.4 | 47 | 32 | 68 | 18 | 5 | -0.9 | 137 | 0 |
| 0.8 | 20 | 5 | 25 | 18 | 5 | 0 | 55 | 0 |
| 1 | 18 | 3 | 17 | 18 | 5 | 0 | 55 | 0 |
| 6 | 13 | 2 | 15 | 18 | 5 | 0 | 55 | 4.5 |
| 10 | 13 | 2 | 15 | 18 | 5 | 0 | 55 | 4.6 |

The Gain roll-off in stop-band varies between 17.6 to 18dB/octave which is close to the ideal value of 18 dB /octave for third order active-R filter .Also, the gain gets stabilized almost at 0 dB for all values of Q ≥ 0.8.Also, the response shows overshoot for all the values of Q ≥ 6. But in previous reported configuration the gain stabilized for Q ≥ 5.Also, overshoot is observed for all the values of Q [8-15]. The analysis for the responses are summarizes in the table 3.

## Conclusion:

A realization of voltage-mode transfer function for Single-input Multiple-output Signals Third-order Active-R Filter for different Circuit Merit Factor Q has been presented. The filter circuit is composed only of three op. amplifiers and four resistances. Also this single filter circuit gives Multiple-output functions low pass, band pass and high pass filters. It is suitable for high frequency operation and monolithic IC implementation. The low pass and band pass performance of the circuit gives high pass band gain and excellent for lower value of $f_0$. For high pass filter, circuit shows gain stabilization at 0 dB for Q≥0.8. The Ideal value of this filter circuit which is closed to Ideal value of third-order active-R filter is at 0.8≤ Q ≥6.Also, filter circuit can be used for both narrow as well as for wide bandwidth.

## References:


[1] Huelsman, L. P. Equal-valued capacitor active-RC network realisation of a 3rd order low pass Butterworth characteristics. Electron. Lett. 1971, 7: 291–293.

[2] Mohan, N. Patil, R. L. Ripple pass function and their active-R realization. Indian J. Pure Appl. Phys., 1989, 30: 749–750.

[3] Shinde, G. N.; Patil, P. B. Study of active-R second-order filter using feedback at non-inverting terminals. Bull. Pure Appl. Sci. 2002,D21: 23–31.

[4] Senani, R.; Gupta, S. S. 2006. Low universal filter using only Current followers as active elements, International Journal of electronics and Communication, 60:251-256.

[5] Sun, Zhi-Xiao, Active-R filter: a new biquadratic with four terminals. Int. J. Electron. 1983, 54, 523–530.

[6] Hioashimura, M. Active -R realization of current mode high pass filter. Int. J. Electron. 1992, 73: 1279–1283.

[7] Srinivasan, S. Synthesis of transfer function using the peration amplifier pole. Int. J. Electron. 1992 73: 1279–1283.

[8] U.N. Chavan and G. N. Shinde, 2013. Synthesis of third order active-R multifunction filter using feed forward input signal, IJMER, 3(6).

[9] Shinde, G. N. Mirkuteand P. R.; Achole, P. D. A third order active R Filter with feedforward input signal for different center frequency f0, 2002. Bulletinofpure & AppliedSciences, 21D (2): 77-83.

[10] Shinde, G. N.; Mirkute, P. R. Achole, P. D. 2003. Second order active-R filter with multiple feedback for different Q. Indian J. Phys., B77.

[11] Soderstand, M. A. 1976. Design of active-R Filter using only Resistance and Operational Amplifier, Int. J. Of Electronics, 40 (5):417-432.

[12] Shinde, G. N. and Achole, P. D. A third order active R Filter with multiple feedback, feedforward input signal and varying positive feedback resistor R. Bulletin of pure & Applied Sciences, 2005,24D(2): 83-89.

[13] Jinguang Jiang and Yaonan Wang, 2006. Design of atunable frequency CMOS fully differential fourth order Chebyshev filter, Microelectronics Journal, 37:84-90.

[14] Soderstand M A, Mitra S K, Sensitivity analysis of third- order filter. Int. Journal of Electronics 1971, 30: 265–273.

[15] Shinde, G. N.; and Achole, P. D. 2003. Second order active R Filter with multiple feedback for different Q, Indian Journal of physics, 77B, and (2):237-239.

# مرشح المقاومات الفعال ذات الإشارة أحادية الدخول و متعددة الخروج من الدرجه الثالثة لعديد من عوامل الجودةالمختلفة(Q)

عدنان عبدالله قاسم * شيندي غانيش شاندرا نار هارو**

*كلية الفيزياء-جامعة سوامي رامانااندا تيرث ماراثوادا- نانديد ماهاراشترا- الهند
**الرئيسي، كلية انديرا غاندي- نانديد ماهاراشترا الهند

**الخلاصة:**

لقد تم في هذه الورقة العلمية تصميم دائرة إلكترونية ذات الإشارة أحادية الدخول و متعددة الخروج بحيث تعطينا ثلاث و ظائف في نفس الوقت وهي مرشح تمرير منخفض(عمل هذا المرشح هو تمرير الترددات المنخفضة وحجب الترددات العالية)، مرشح تمرير عالي(عمل هذا المرشح هو تمرير الترددات العالية وحجب الترددات المنخفضة) ومرشح تمرير حزمة من الترددات(عمل هذا المرشح هو تمرير الترددات التي تقع بين الترددين $f_1,f_2$ وحجب الترددات التي تكون أعلى من $f_2$ و أقل من $f_1$ ).حيث تتكون هذه الدائرة من اربع مقاومات ($R_1,R_2,R_3$ and $R_4$) وكذلك من ثلاثة مكبرات .حيث سميت هذه الدائرة بدائرة المرشح المقاومة و بسبب استخدام مقاومات فقط في تصميم هذه الدائرة. ان هذا المرشح مفيد بالنسبة للترددات العالية وكذلك في تصميم الدوائر المتكاملة. ومن مزايا هذه الدائرة هي تخفيض في حجم ووزن الدائرة الإلكترونية وأكثر اقتصادية وسهلة التصنيع . لقد تم دراسة هذه الدائرة بأستخدام عامل الجودة (Q) . وهذه الدائرة مفيده جدا في مجال تمرير حزمة الترددات الواسعة حيث وجد ان القيم المعطاه من هذه الدائرة تكاد تكون قريبة جدا الى القيمة المثالية لدائرة المرشح من الدرجة الثالثة عندما تكون قيمة عامل الجودة (Q) بين $0.8 \leq Q \geq 6$.

**الكلمات المفتاحية:** مرشح المقاومات الفعال من الدرجة الثالثة, الإشارة أحادية الدخول و متعددة الخروج,عامل الجودة Q