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Implementation and Performance Analysis of Eigth-Order Active-R Biquadratic Bandpass Filter for Potential Use in UHF RFID Applications

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Abstract
In this paper, a functioning bandpass filter designed, simulated and implemented for potential use in the front-end framework of the Ultra-High Frequency (UHF) Radio Frequency Identification (RFID) receiver is presented. The RFID communications in the UHF domain operate in the frequency range from 860 to 960 MHz as such many other communication systems that utilize frequencies within this range may interfere in the RFID communication. To avoid this interference and eliminate any noise beside the operating bandwidth a Bandpass filter is inserted in the first block of the RFID receiver. The architecture that was used to implement the Eighth-order Active-R Band pass filter is the Biquadratic topology. The filter was first designed using the Second-order active- R Band pass filter (stage 1), with centre frequencies of f0=40 kHz, 107 kHz, 160 kHz, 256 kHz, 320 kHz, 465 kHz, and 640 kHz and variable quality factors of Q=25 and 30. Choosing η=0.1, R1a=1.0x106Ω, R2=40x103Ω, the values of other Resistors were calculated. To realize an Eighth-order configuration, the second-order filter already designed was cascaded in four stages and implemented using Multisim electronic workbench version 11.0 software. The results obtained and presented shows that the Active-R bandpass filter using biquadratic topology at Q = 30 worked well and better as specified in the filter theory and EPC Global Class 1 Generation 2 protocol. This filter is characterized by low gain, bandwidth is in good agreement with filter theory and the roll-off rate is very good, which gave an eighth-order active filter.

Keywords: performance analysis, implementation, eighth-order, active-r filter, bandpass application

Introduction

The Radio Frequency Identification (RFID) is an automatic identification system. RFID uses Radio Frequency (RF) to identify "tagged" items. This data is then collected and transmitted to a host system using an RF Reader. The RFID technology is already of high commercial relevance, which breaks into new application areas, and new markets are emerging. Today's RFID system architecture is carried over from the architecture used in other auto-id systems, chiefly optical barcode systems. As RFID introduces new functionalities and privacy risks, this classic architecture is no longer appropriate [1]. The great appeal of RFID technology allows storing and reading the data without requiring either contact or a line of sight between the tag and reader. RFID consists of three basic component such as transponder (tag), interrogator (reader) and antenna as illustrated in Figure 1.

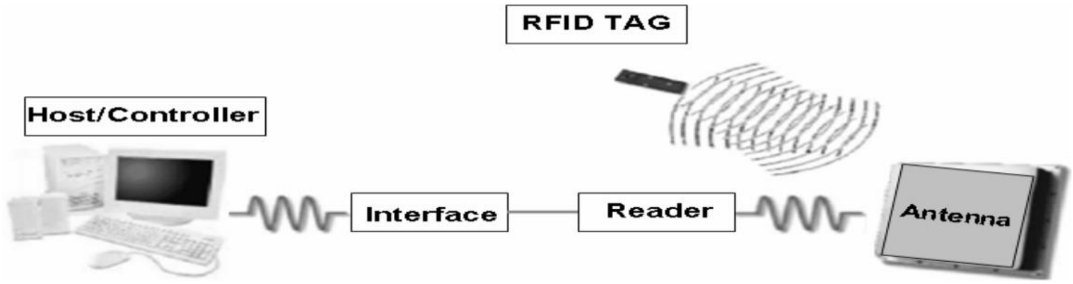

Figure 1: Configuration of RFID system [2]

In a typical communication sequence, RFID system performs a number of functionalities between reader and tag. RFID reader emits a continuous RF carrier sine wave. When a tag enters the RF field of the reader, the tag receives energy from the field. Further, receiving sufficient energy, it begins to modulate the carrier signal to the data storage on the tag. The modulating carrier signal is resonated from the tag to the reader. The reader detects the modulating signal from the tag, and decodes signal in order to retrieve the data from the tag. However, the information relays to the host computer where more manipulation data will be stored and finally will be displayed to the user. RFID is basically based on wireless communication making use of radio waves, which is a part of the electromagnetic spectrum [28]. Moreover, RFID follows the standard frequency ranges, which are low frequency (120-135 KHz), high frequency (10-15 MHz), ultra high frequency (UHF) (850-950 MHz), and microwave frequency (2.45 GHz).

An RFID reader is a device that is used to interrogate an RFID tag. The reader has an antenna that emits radio waves; the tag responds by sending back its data. A number of factors can affect the distance at which a tag can be read (the read range). The frequency used for identification, the antenna gain, the orientation and polarization of the reader antenna and the transponder antenna, as well as the placement of the tag on the object to be identified will all have an impact on the RFID system's read range. The RFID reader provides the connectivity between individual tags and the tracking/management system. Depending on the application and operating conditions, there may be a multiplicity of readers to fully service a specific area. Overall, the reader provides three main functions

• Bidirectional communication with the tags.

• Initial processing of received information.

• Connection to the server that links the information into the enterprise. [1].

The RFID communications in the UHF domain operate in the frequency range from 860 MHz to 960 MHz. There are many other communication systems that utilize frequencies within this range and may interfere in the RFID communication. To avoid this interference and eliminate any noise beside the operating bandwidth, the first block in the RFID receiver is called Bandpass filter as shown in Figure 2.

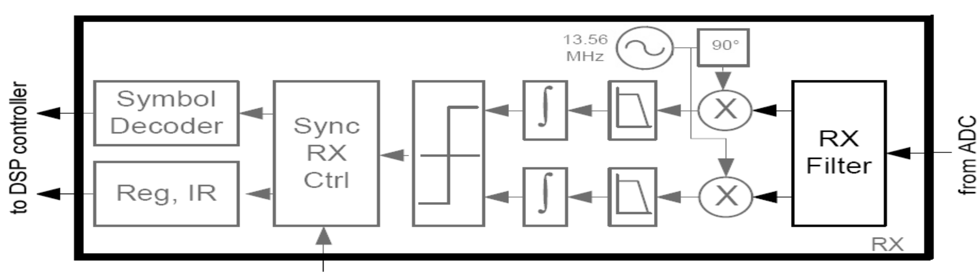

Figure 2: Receiver Block Diagram of Entrance Filter [3]

The tag to reader transmission is performed in a frequency band, commonly used in many other applications, which might interfere in the RFID communication. Therefore, taking into account the wide range of link frequencies that the UHF EPC standard for UHF RFID allows for use, it is necessary to develop a filter with a bandwidth as tight as possible to the spectral width of the receiver RFID signal. The EPC standard for UHF RFID permits the communication from the RFID tag to the RFID reader in a modulation frequency that ranges from 40 kHz to 640 kHz. Therefore, a unique filter would not suit a selective filtering in a single way for all possible transmission link frequencies. The required filtering flexibility is achieved by using a filter bank with bandwidths adequately distributed along the operating range.

In addition, the EPC standard for UHF permits a frequency tolerance that depends on the link frequency requested by transmitter. These values are listed in the EPC standard for UHF. The table shows that the allowed tolerance is assigned by frequency intervals, especially for back link frequencies for 640 kHz and 320 kHz, for which the link frequency deviation tolerance allowed, is more restricted. It is meaningful that the filter bank is equipped with filter bandwidths matching the interval borders. These link frequencies are 40 kHz, 107 kHz, 160 kHz, 256 kHz, 320 kHz, 465 kHz, and 640 kHz, which are spread in quite regular forms along the permitted link frequency range. These are the frequencies finally selected to implement the set of filters. In the design, it is considered that in future an RFID receiver in the UHF domain will operate simultaneously with the one already implemented in the HF domain. The frequencies permitted in the HF domain are 424 kHz and 847 kHz. This former is within the range of frequencies permitted in the UHF domain. The latter frequency is slightly higher than the UHF domain.

In the reader, the front-end system needs RC filter and Active Band pass filter and an Active low-pass filter to reject the undesired signal [4]. Filters are essential components in the many electrical systems. Also in the state-of-the-art RF receivers, high performance filters are required to remove undesired signals at different stages of the receiving process, such as noise from incoming signals the antenna receives undesired signals at the image frequency, and harmonics after the mixing operation [4].

In the UHF RFID system, Active filters are used because of the following advantages [5, 6]. The transfer function with inductive characteristics can be achieved by particular circuit design, resistors can be used instead of inductors. The high input impendence and low output impendence of the operational amplifier means that the filter circuit is excellent in isolation characteristics and suitable for cascade. Active components provide amplification, therefore active filters have high gains. The active filter without the capacitor is called and Active-R filter and has received much attention due to its potential advantages in terms of miniaturization, ease of design and high frequency performance [7, 8]. Also, Active-R filter offer substantially low sensitivity characteristics as compared to R-C structure [9]. Active-R filters give greater stop band attenuation and sharper roll-off at the edge of the pass band. Also, in terms of functionality the Active-R filter is better than the Active-RC [10].

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In this paper, active-R band-pass biquadratic filter is designed and simulated. An active-R band-pass filter is used for the RFID system to reject all signals outside the (40-640) kHz signals and to amplify the low antenna signal.The most common filter responses are the butterworth, chebysshew and Basel types. Among these responses, butterworth type is used to get a maximally-flat response. Also, it exhibits a nearly flat pass-band with no ripple. The roll-off is smooth and monotonic with a low-pass or high-pass roll-off of 20dB/dec for every pole [4]. Thus an Eight-order Butterworth band pass filter would have an attenuation rate of -160dB/dec and 160dB/dec.

literature reviewed showed that, the works of [11, 12, 4, 13, 3, 14, 15] were on the active-RC filter design. While the works of [16, 17] presents a new technology of active inductors which was utilized in the RFID reader. The active inductor technology is inferior to the active-R filter because of their small dynamic ranges, poor noise performance, high power consumption and a high sensitivity to supply voltage rises and falls as well as process variation. This research is the only work so far on the implementation of the Eighth (8^{th})-Order Active-R filter for the ultra-high frequency Radio Frequency Identification System. Because of the numerous advantages of the Active-R filter over the other filter types which are enumerated in the previous research [18, 19, 20, 21, 22, 23, 24]), this informed the choice of the Active-R filter. The choice of Eighth-Order filter was as a result of the recommendations from the work of [3, 21, 25]. For better selectivity, greater stop band attenuation and steeper cut-off at the edge of the band with increasing order of the filter. The choice of butterworth topology is based on the submission of [4, 26] which is a maximally-flat response. It also exhibits a nearly flat pass band with no ripple and has a roll-off of 20dB/decade for every pole.

Materials and Methods

Design specification

The architecture that was used to implement the Eighth-order Active-R Band pass filter is the Biquadratic topology. This topology was realized by cascading Second-order bandpass filter of figure 3 (stage I with two Operational Amplifiers) which is from the work of [25].

The Eighth-order Bandpass Biquadratic filter topology was used because of its advantages in terms of mid-frequency stability, high-Q factor, independent gain and Q values, and high-roll-off

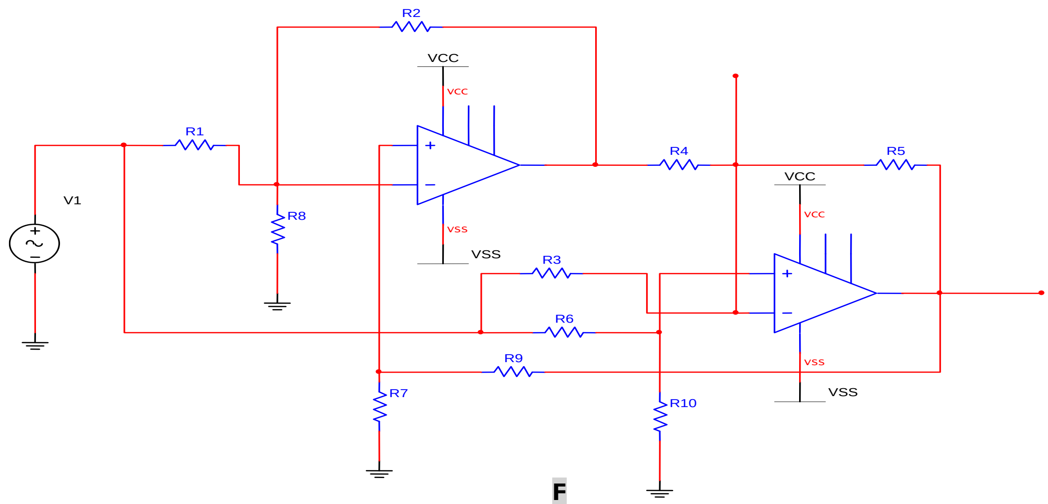


Figure 3. Second-order Active Biquadratic Filter

Design of eighth-order active-R filter using biquadratic topology

The eighth-order active-R bandpass filter using biquadratic topology was also realized through the cascading of four second-order stages to form an eighth-order circuit presented in Figure 4.

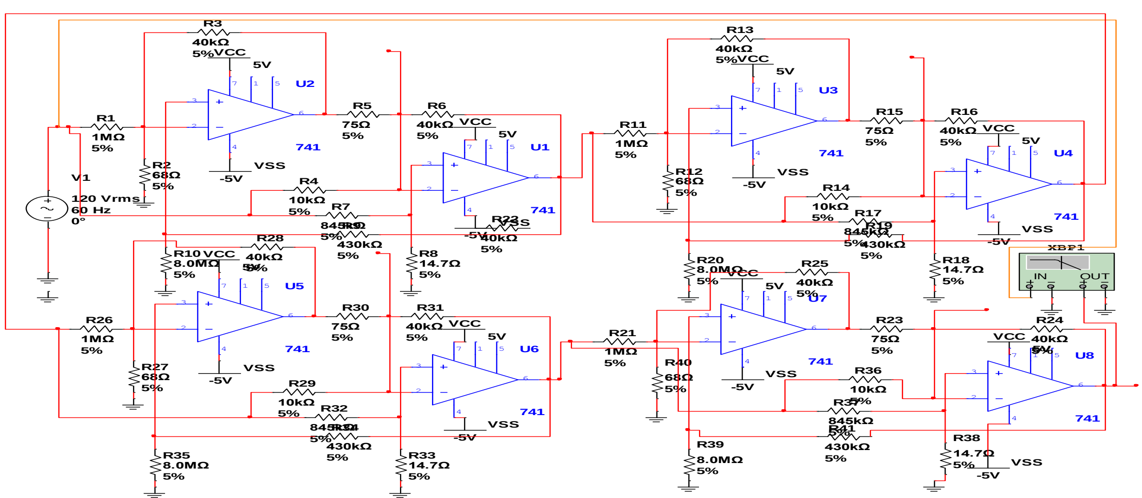


Figure 4: Eighth-Order Active-R Biquadratic Filter.

The eighth-order active-R band pass filter shown in Figure 4 has a gain given as

$$\frac{V_0}{V_i} = \frac{(\alpha-\beta)^4 s^4}{\begin{array}{l} s^8+2(\omega_1+\omega_2)s^7+4(1+k)1+k\omega_1\omega_2 s^6+2(\omega_1+\omega_2)^2 s^6+4(1+k)(\omega_1+\omega_2)\omega_1\omega_2 s^5 \\ +4(1+k)(\omega_1+\omega_2)s^5+2(\omega_1+\omega_2)^3 s^5+6(1+k)^2\omega_1^2\omega_2^2 s^4+4(1+k)(\omega_1+\omega_2)^2 s^4 \\ +4(1+k)(\omega_1+\omega_2)\omega_1\omega_2 s^4+(\omega_1+\omega_2)^4 s^4+8(1+k)^2(\omega_1+\omega_2)\omega_1^2\omega_2^2 s^3+4(1+k) \\ (\omega_1+\omega_2)^3 s^3+4(1+k)^3+\omega_1^3\omega_2^3 s^2+6(1+k)^2(\omega_1+\omega_2)^2\omega_1^2\omega_2^2 s^2+4(1+k)^3 \\ (\omega_1+\omega_2)\omega_1\omega_2 s+(1+k)^4\omega_1^4\omega_2^4 \end{array}} \quad (1)$$

The values of the different resistances are given from the rearrangement of the equations given below

$$\frac{R_2}{R_{1a}//R_{1b}} = \frac{2\ Q_p}{\omega_p} \times\ GB_1 - 1$$

$$\Rightarrow \frac{R_2(R_{1a}R_{1b})}{R_{1a}+R_{1b}} = 2\ \frac{Q_p}{\omega_p}\ GB_1 - 1 \qquad 2$$

$$\frac{R_5}{R_3} = \eta\ \times 2\ \times \frac{Q_p}{\omega_p} \times GB_2 \qquad 3$$

$$\frac{R_5}{R_4} = (1-\eta)\ \times\ 2\ \times \frac{Q_p}{\omega_p} \times GB_2 \qquad 4$$

Where η is the damping factor whose value is chosen by the designer? The remaining resistor values are determined using the following equations

$$\frac{R_{6a}}{R_{6b}} = \frac{1+\frac{R_5}{R_4}\left(1+\frac{R_2}{R_{1a}}\right)}{\frac{R_5}{R_3}-\frac{R_5}{R_4} X \frac{R_2}{R_{1a}}} \qquad 5$$

$$\frac{R_{7b}}{R_{7a}+R_{7b}} \frac{2\ \frac{Q_p}{\omega_p} GB_1\left(1-\frac{1}{4\ X\ Q_p^2}\right)}{(1-\eta)\ 2\ \frac{Q_p}{\omega_p} GB_2 - 1} \Rightarrow \frac{R_{7a}}{R_{7b}} = \left[\frac{(1-\eta)\ 2\ \frac{Q_p}{\omega_p} GB_2 - 1}{2\ \frac{Q_p}{\omega_p} GB_1\left(1-\frac{1}{4\ X\ Q_p^2}\right)}\right] - 1 \qquad 6$$

Implementation of the eighth-order active-r bandpass filter using biquadratic topology

In the implementation of this filter, first we considered the design of Second-order Band pass R filter (stage 1), from the first op.amp. with centre frequency of 40 kHz, Q=25 and GB1=10MHz. Choosing η=0.1, R1a=1.0x106Ω, R2=40x103Ω, the value of R1b was calculated from equation 2. R5 was also calculated using equation 3, R4 from equation 4 and R6 was calculated using equation 5, R7 was calculated from equation 6. Similarly, calculations were carried out for the component values using equations 2 to 6 for higher values of centre frequencies f0= 107 kHz, 160 kHz, 256 kHz, 320 kHz, 465 kHz, 640 kHz, and 847 kHz with constant Q of 25, η=0.1 and GB1 = GB2=10MHz. All calculated component values are presented in Tables 1 and 2. To realize an Eighth-order configuration, the second-order filter was cascaded as shown in Figure 4 and implemented using MULTISIM electronic workbench version 11.0 software. The same calculations were repeated for the implementation of the eighth-order Active filter at Q=30.

Table 1: Resistor Values for Eighth-Order Active- R Bandpass BIQUAD Filter Network at Q=25

			Calculated Resistor Values										Experimental Resistor Values									
S/N	FLF (MHz)	BLF (KHz)	R_{1a}(MΩ)	R_{1b}(Ω)	R_2(kΩ)	R_3(Ω)	R_4(Ω)	R_5(kΩ)	R_{6a}(kΩ)	R_{6b}(Ω)	R_{7a}(Ω)	R_{7b}(Ω)	R_{1a}(MΩ)	R_{1b}(Ω)	R_2(kΩ)	R_3(kΩ)	R_4(Ω)	R_5(kΩ)	R_{6a}(kΩ)	R_{6b}(Ω)	R_{7a}(kΩ)	R_{7b}(Ω)
1	860	40	1.00	3.20	40	32.00	3.56	40	40	1.50	11.25M	200.00	1.00	3.20	40	10	3.56	40	40	1.5	40	69.80k
2	880	107	1.00	8.56	40	85.60	9.51	40	107	14.62	4.23M	535.00	1.00	8.50	40	10	9.53	40	107	14.70	107	2.00k
3	900	160	1.00	12.80	40	128.00	14.23	40	160	14.62	2.81M	799.68	1.00	12.80	40	10	14.23	40	160	14.70	160	4.30k
4	910	256	1.00	20.48	40	204.80	22.77	40	256	14.62	1.76M	1.28k	1.00	20.48	40	10	22.77	40	256	14.70	256	19.10k
5	920	320	1.00	25.60	40	256.00	28.46	40	320	14.62	1.40M	3.20k	1.00	25.50	40	10	28.00	40	324	14.70	324	38.30k
6	930	465	1.00	37.21	40	371.99	41.38	40	465	14.62	989k	2.32k	1.00	37.40	40	10	41.20	40	464	14.70	464	147k
7	940	640	1.00	51.20	40	512.00	56.97	40	640	14.62	700k	3.20k	1.00	51.10	40	10	57.60	40	649	14.70	649	29.40k

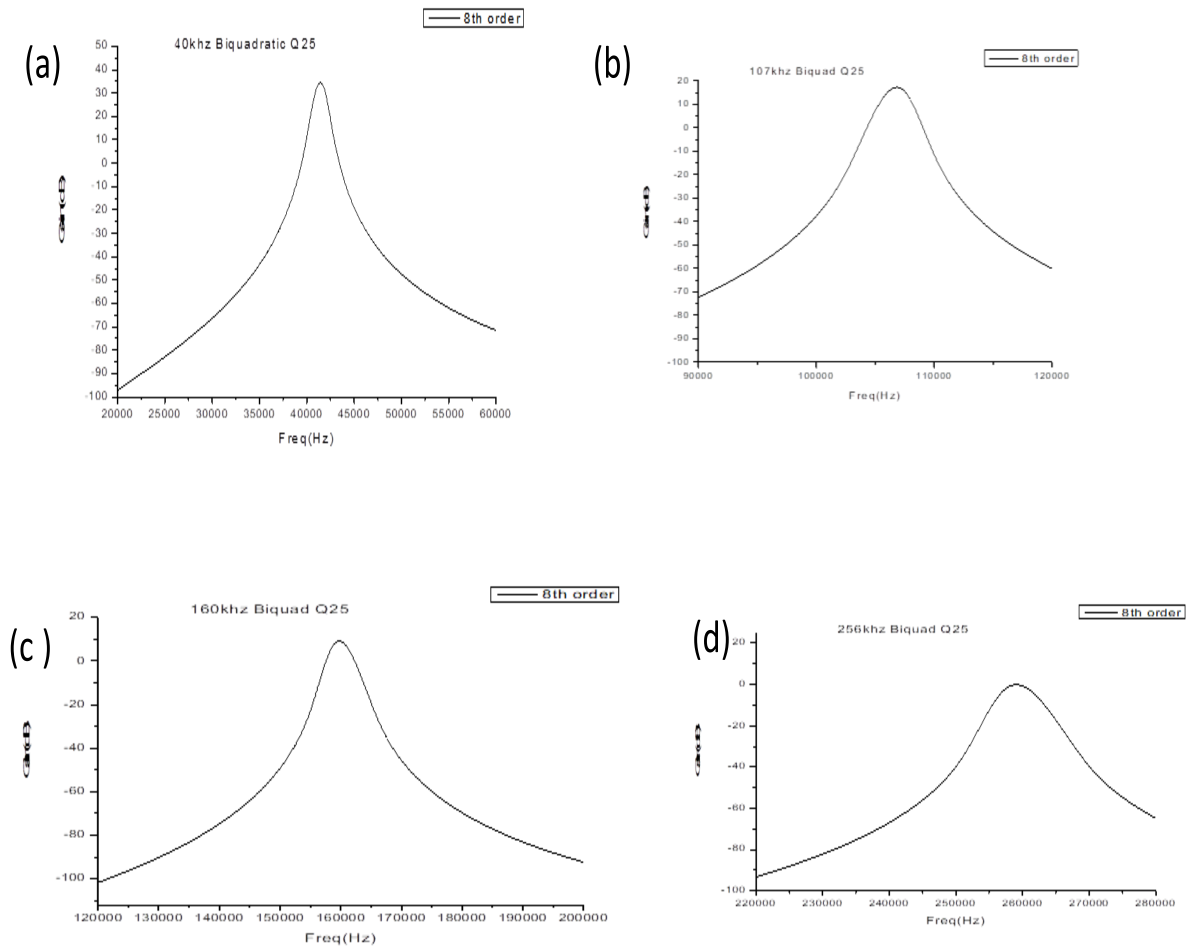
Table 2: Resistor Values for Eighth-order Active- R Bandpass BIQUAD Filter Network at Q=30

			Calculated Resistor Values										Experimental Resistor Values									
SN	FLF (MHz)	BLF (kHz)	$R_{1a}(\Omega)$	$R_{1b}(\Omega)$	$R_2(k\Omega)$	$R_3(\Omega)$	$R_4(\Omega)$	$R_5(k\Omega)$	$R_{6a}(k\Omega)$	$R_{6b}(\Omega)$	$R_{7a}(\Omega)$	$R_{7b}(\Omega)$	$R_{1a}(\Omega)$	$R_{1b}(\Omega)$	$R_2(k\Omega)$	$R_3(k\Omega)$	$R_4(\Omega)$	$R_5(k\Omega)$	$R_{6a}(k\Omega)$	$R_{6b}(\Omega)$	$R_{7a}(k\Omega)$	$R_{7b}(\Omega)$
1	860	40	1.0	2.67	40	26.67	2.96	40	40	14.62	13.50	240.00	1.0	2.67	40	10	2.94	40	40	14.70	13.5	22.10
2	880	107	1.0	7.13	40	71.33	7.93	40	107	14.62	5.03	640.00	1.0	7.15	40	10	8.00	40	107	14.70	13.5	158
3	900	160	1.0	10.67	40	106.67	11.86	40	160	14.62	3.37	959.62	1.0	10.07	40	10	12.00	40	160	14.70	13.5	360
4	910	256	1.0	17.10	40	170.66	18.97	40	256	14.62	2.11	1.54k	1.0	17.40	40	10	19.10	40	256	14.70	13.5	976k
5	920	320	1.0	21.33	40	213.33	23.72	40	320	14.62	1.69	1.92k	1.0	21.50	40	10	23.70	40	324	14.70	13.5	1.60k
6	930	465	1.0	31.00	40	310.10	34.47	40	465	14.62	1.16	2.79k	1.0	30.90	40	10	34.80	40	464	14.70	13.5	3.90k
7	940	640	1.0	42.67	40	426.67	47.46	40	640	14.62	845k	3.84k	1.0	43.00	40	10	47.50	40	649	14.70	13.5	10k

Results and Discussion

Simulated (theoretical) results for eighth-order active-r bandpass filter using biquadratic topology at q = 25 at varying centre frequencies

The results obtained from the simulated (theoretical) resistor values of the eighth – order active-R bandpass filter using biquadratic topology at constant quality factor of Q = 25 and varying centre frequencies in Table 1 is presented in Figure 5.


(a)
40khz Biquadratic Q25
8th order
Freq(Hz)
(b)
107khz Biquad Q25
8th order
Freq(Hz)
(c)
160khz Biquad Q25
8th order
Freq(Hz)
(d)
256khz Biquad Q25
8th order
Freq(Hz)

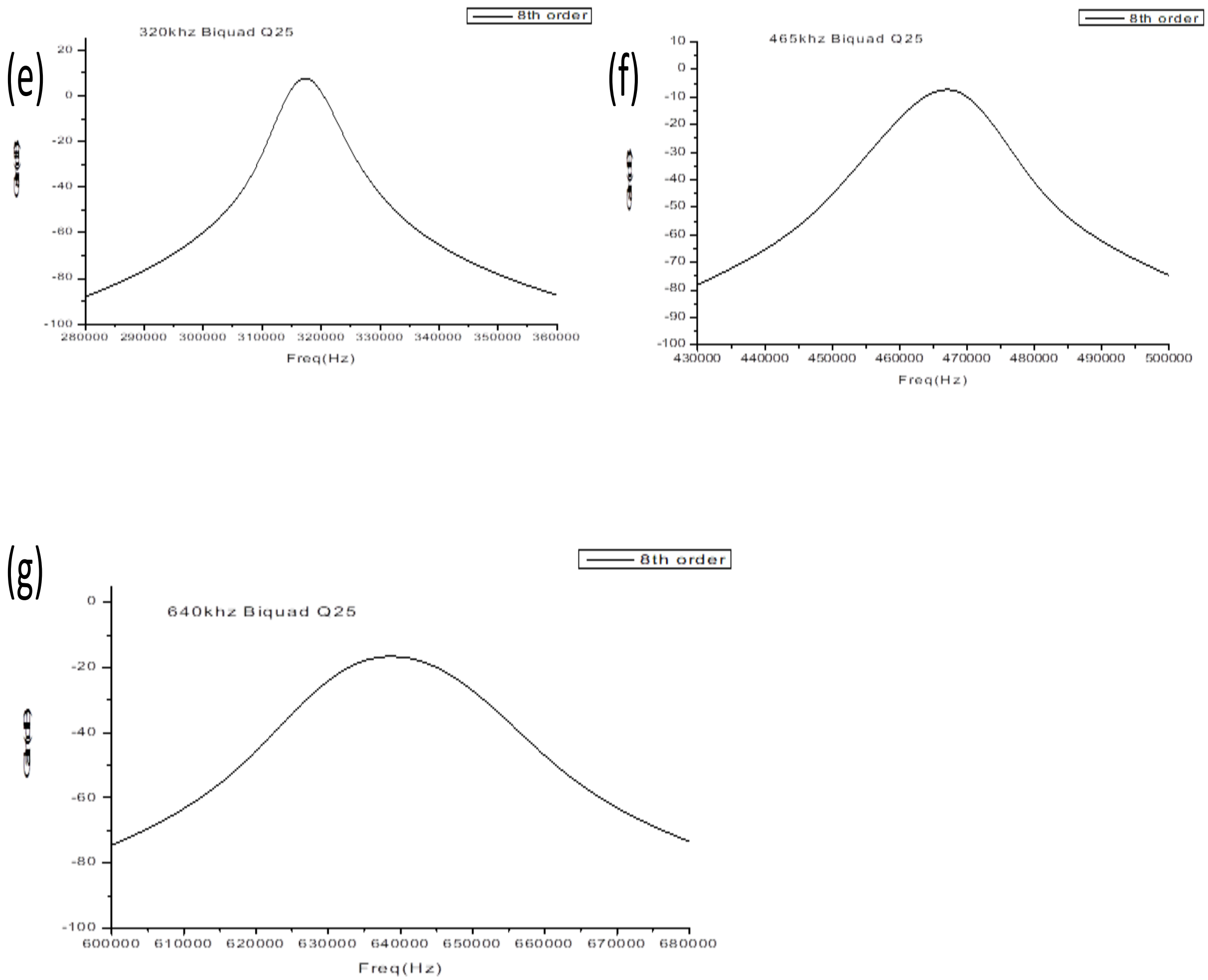
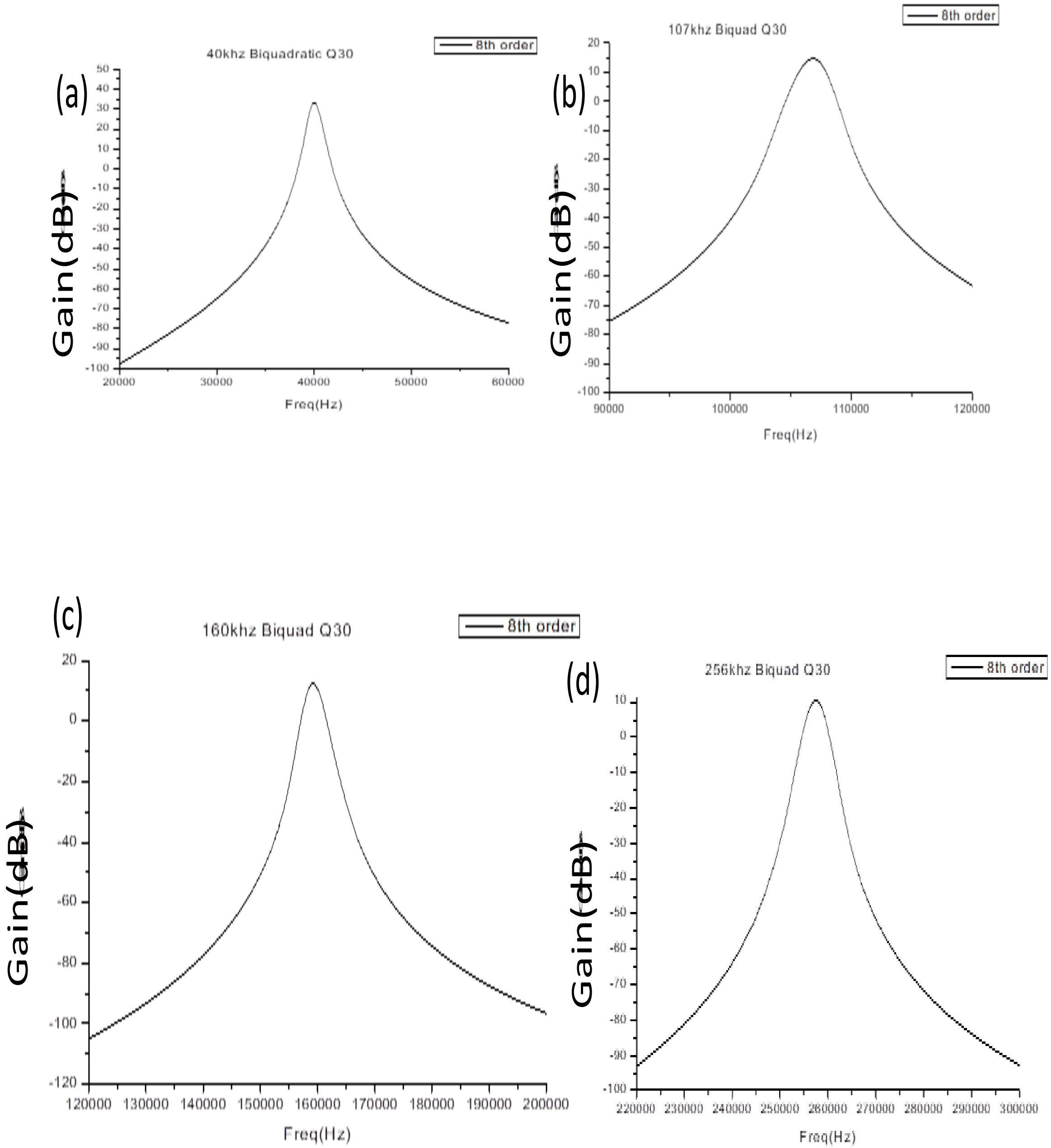
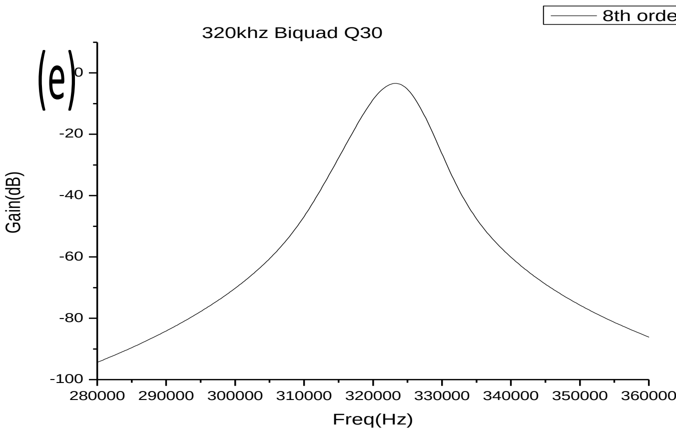


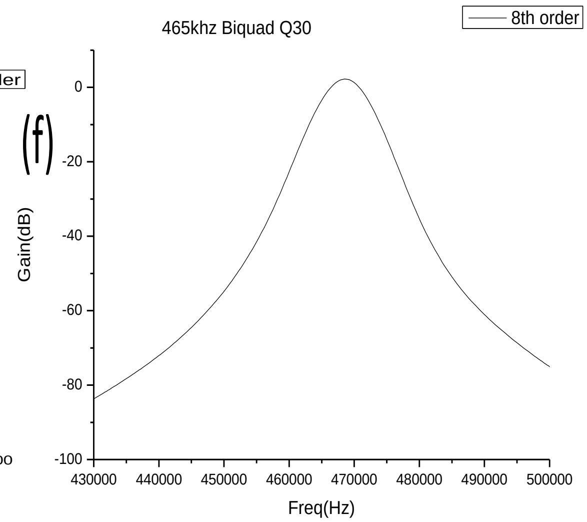
Figure 5: Eighth-Order Active-R Bandpass Filter using Biquadratic Topology at Centre Frequencies, (a) F_0=40 kHz, (b) F_o=107 kHz, (c) F_o=160 kHz, (d) F_0= 256 kHz, (e) F_0= 320 kHz, (f) F_0= 465 kHz, (g) F_0= 640 kHz,and Quality Factor Q=25

Simulated (theoretical) results for eighth-order active-r bandpass filter using biquadratic topology at q = 30 at varying centre frequencies

The results obtained from the simulated (theoretical) resistor values of the eighth – order active-R bandpass filter using biquadratic topology at constant quality factor of Q = 30 and varying centre frequencies in Table 2 is presented in Figure 6.


(a)
40khz Biquadratic Q30
8th order
Gain(dB)
Freq(Hz)
(b)
107khz Biquad Q30
8th order
Gain(dB)
Freq(Hz)
(c)
160khz Biquad Q30
8th order
Gain(dB)
Freq(Hz)
(d)
256khz Biquad Q30
8th order
Gain(dB)
Freq(Hz)





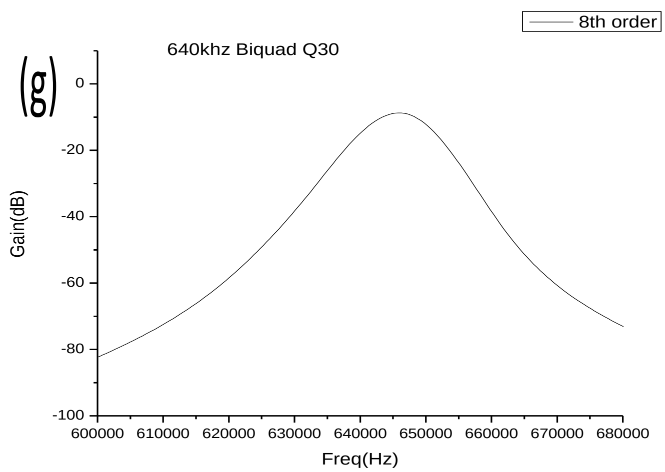


Figure 6: Eighth-Order Active-R Bandpass Filter using Biquadratic Topology at Centre Frequencies, (a) F_0=40 kHz, (b) F_o=107 kHz, (c) F_o=160 kHz, (d) F_0= 256 kHz, (e) F_0= 320 kHz, (f) F_0= 465 kHz, (g) F_0= 640 kHz,and Quality Factor Q=30

Simulated (theoretical) filter for eighth-order active-r bandpass filter using biquadratic topology at q=25 and q=30 at varying centre frequencies

The mid band gain, -3 dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L), bandwidth (BW) and roll-off obtained from Figure 6 for the simulated eighth-order active-R bandpass filter using biquadratic topology at Q= 25 and Q= 30 at varying centre frequencies is discussed.

Simulated filter for biquadratic topology at q=25 at varying centre frequencies (f_0)

From (Figure 5) the simulated results, the mid band gain, -3dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L) bandwidth (BW) and Roll-off values obtained at different centre frequencies are shown in Table 3.

Table 3: Maximum Gain and Bandwidth of Eighth-Order Active-R Bandpass Filter using Biquadratic Topology at variable Centre Frequency and Constant Quality Factor of Q = 25 (Multisim)

F_0(kHz)	Mid Band Gain (dB)	-3dB Gain (dB)	F_H (kHz)	F_L (kHz)	BW (kHz)	Roll-off (dB/decade)
40	34.353	31.353	41.928	40.861	1.067	-161.065
107	17.477	14.477	107.672	105.913	1.759	-189.851
160	9.203	6.203	161.120	158.347	2.773	-199.732
256	-0.579	-3.579	261.368	256.890	4.478	-210.714
320	7.351	4.351	319.165	315.540	3.625	-215.200
465	-7.559	-10.559	470.489	463.025	7.464	-222.379
640	-16.395	-19.395	644.602	633.301	11.301	-227.118

From Table 3, the filter has a maximum pass band gain of 34.353 dB at centre frequency of 40 kHz and decreased inversely with centre frequency until it gets to 320 kHz from where it assumed direct proportionality. The minimum band gain is -16.395 dB at 640 kHz centre frequency. The bandwidth increases with centre frequency except at centre frequency of 256 kHz when the bandwidth decreased from 4.478 kHz to 3.625 kHz at F_o=320 kHz. The minimum bandwidth is 1.067 kHz. The roll off rate decreased progressively with centre frequency to -227.118 dB/dec at centre frequency of 640 kHz. From Figure 22 to 28 we observed that there is no shift in centre frequency at Fo= 40 kHz but is shifted a little from 107,032 Hz at F_o= 107 kHz to 638,419 Hz at F_o= 640 kHz.

The filter theory states that "when centre frequency of a filter increases, it causes an increase in bandwidth" whereas "The Mid Band Gain (G_{max}) decreases as the centre frequency increases". The mid band gain performs to specification up to the centre frequency 256 kHz and then deviates at a centre frequency of F_o= 320 kHz up to F_o= 640 kHz. The bandwidth of the filter does not conform to the filter theory despite the minor deviation at F_o= 320 kHz. The roll-off rate behaves like an eighth – order filter from the values obtained, a single pole filter rolls off gives 20xn dB/dec, where n is the filter order, the eighth- order should give 160 dB/dec. The centre frequencies of the filter at this quality factor are slightly shifted from 0.03% at F_o= 40 kHz to -0.25% at F_o= 640 kHz, but this is still within the specification of the epc global class I generation 2 protocol of ± 22 % for UHF RFID systems. Therefore, the filter can be used in the reader of ultra-high frequency radio frequency identification systems. All the deviations noticed with this filter can be attributed to the high sensitivity of MFB topology to resistor values that cause parasitic effect to the filter.

Simulated filter for biquadratic topology at q=30 at varying centre frequencies (f_0)

From (Figure 6) the simulated results, the mid band gain, -3dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L) bandwidth (BW) and Roll-off values obtained at different centre frequencies are shown in Table 4. From Table 4, the filter has a maximum pass band gain of 33.452 dB at centre frequency of 40 kHz and decreased inversely with centre frequency until it gets to 465 kHz from where it assumed direct proportionality. The minimum band gain is -8.820 dB at 640 kHz centre frequency. The bandwidth increases with direct proportionality to centre frequency from a centre frequency of 40 kHz to 640 kHz. The minimum bandwidth is 0.640 kHz. The roll off rate decreased progressively with centre frequency to -230.932dB/dec, at centre frequency of 640 kHz. From Figure 12 to 18 we observed that the centre frequency is shifted a little from 40,009 Hz at F_o= 40 kHz to 645,989 Hz at F_o= 640 kHz.

The behavior of the filter at this quality factor in terms of mid band gain can therefore be said to perfom to specification up to a centre frequency (F_o) of 640 kHz but deviates at centre frequency of 465 kHz. From filter theory, "The Mid Band Gain (G_{max}) decreases as the centre frequency increases" [2]. We can attribute the deviation to parasitic effect.

Table 4: Maximum Gain and Bandwidth of Eighth-Order Active-R Bandpass Filter using Biquadratic Topology at variable Centre Frequency and Constant Quality Factor of Q = 30 (Multisim)

F_0(kHz)	Mid Band Gain (dB)	-3dB Gain (dB)	F_H (kHz)	F_L (kHz)	BW (kHz)	Roll-off (dB)
40	33.452	30.452	40.329	39.689	0.640	-163.055
107	14.691	11.691	107.672	105.833	1.839	-193.00
160	12.277	9.277	160.515	157.957	2.558	-203.432
256	10.792	7.792	258.916	256.144	2.772	-213.243
320	-3.673	-6.673	325.136	320.658	4.478	-218.243
465	2.062	-0.938	471.297	465.886	5.411	-225.380
640	-8.820	-11.820	650.040	641.724	8.316	-230.932

Also, the bandwidths of the filter conform to filter theory without deviation. Filter. The roll-off rate behaves like an eighth –order filter from the values obtained, a single pole filter rolls off gives 20xn dB/dec, where n is the filter order, the eighth- order should give 160 dB/dec [27]. The centre frequencies of the filter at this quality factor are slightly shifted from ± 0.02% at F_o= 40 kHz to ± 0.94% at F_o= 640 kHz, but this is still within the specification of the epc global class I generation 2 protocol of ± 22 % for UHF RFID systems. Therefore, the filter can be used in the reader of ultra-high frequency radio frequency identification systems. All the deviations noticed with this filter can be attributed to the high sensitivity of MFB topology to resistor values that cause parasitic effect to the filter.

Construction of the eighth- order active-r bandpass filter using biquadratic topology

The Construction (Experimental) of the Eighth - order Active - R Band pass filter using biquadratic topology was done using 16 op. amps, 3 circuit boards and connecting wires. The Filters were constructed with a 5V power supply, a signal generator and an oscilloscope to determine its performance. The input from signal generator was adjusted to 5V peak-to-peak at a frequency of 40 kHz for a start. The signal frequency was then varied in steps up to 640 kHz and the corresponding output voltage amplitude displayed on the oscilloscope was measured accordingly. The input voltage was kept at 5V throughout the experimental procedure. The filter bandwidth was determined by measuring F_H and F_L when the peak-to-peak output voltage was 0.707 times the value at the centre frequency. The roll-off was determined at -3dB point where the frequency is traced to the vertical axis (Gain). The results of the centre frequency F_o, mid band gain dB, upper frequency F_H, lower frequency F_L and the roll-off rate ROR are shown in Tables 5 and 6 respectively. The diagram for the implemented eighth order active-R bandpass biquadratic filter topology is presented on plate 1 below. While the experimental set up to measure the filter characteristics is presented on plate 2. Also, Packaging of the filter was done with simple plastic by joining them into a boxlike structure with glue as shown on plate 3 below. One transformer (12V), two regulators (LM78 05 and LM78 12), one capacitor (35V) were used at the power section to power both filters. As a precautionary measure, care was taken not to block the panel holes or lines in order not to render the circuit non-functional. Also, the connecting wires were carefully screened while joining components to avoid wrong connection to components. Finally, the input and output terminals were connected to the circuit board through a transformer and a power section as mentioned above.

Plate 1: Constructed Eighth-Order Active-R Bandpass Filter using Biquadratic Topology

Plate 2: Experimental Set-Up using Signal Generator and Oscilloscope for Biquad

Experimental filter for eighth-order active-r bandpass filter using biquadratic topology and quality factors q=25 and q=30 at varying centre frequencies

The mid band gain, -3 dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L), bandwidth (BW) and roll-off obtained from the set up on appendix B for the constructed eighth- order active-R bandpass filter using biquadratic topology at Q= 25 and Q= 30 at varying centre frequencies is discussed.

Experimental filter for eighth-order active-r bandpass filter using biquadratic topology and quality factors q=25 at varying centre frequencies

From the constructed filter, the mid band gain, -3dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L) bandwidth (BW) and Roll-off values obtained at different centre frequencies are shown in Table 5.

The results presented in Table 5 shows obtained values for the designed active-R bandpass filter using biquadratic topology at constant quality factor of Q = 25. From Table 5, the filter has a maximum pass band gain of 37.580 dB at centre frequency of 40 kHz and decreased inversely with centre frequency until it gets to 320 kHz from where it assumed direct proportionality. The minimum band gain is -12.990 dB at 640 kHz centre frequency.

Table 5: Maximum Gain and Bandwidth of Eighth-Order Active-R Bandpass Filter Using Biquadratic Topology at Variable Centre Frequency and Constant Quality Factor of Q = 25 (EXPERIMENTAL)

F_0(kHz)	Mid Band Gain (dB)	-3dB Gain (dB)	F_H (kHz)	F_L (kHz)	BW (kHz)	Roll-off (dB/decade)
40	37.580	34.580	41.900	41.220	0.680	-160.100
107	25.000	22.000	107.602	106.913	0.689	-178.950
160	17.550	14.550	159.430	158.630	0.800	-200.000
256	-8.670	-11.670	258.680	257.190	1.490	-220.431
320	25.460	22.460	317.410	316.590	0.820	-221.674
465	-4.180	-7.180	469.480	467.570	1.910	-224.832
640	-12.990	-15.990	643.100	631.380	11.720	-229.132

The bandwidth increases with centre frequency except at centre frequencies of 256 kHz and 456 kHz when the bandwidth dropped from 800.00 Hz to 1.490 kHz and 820.000 Hz to 1.910 kHz. The minimum bandwidth is 0.680 kHz. The roll off rate also decreases progressively from -160 dB/dec. at a centre frequency of 40 kHz to -229.132 dB/dec at a centre frequency of 640 kHz. From Figure 36, we observed a slight shift in centre frequency from 41,793 Hz at F_o= 40 kHz to 647,142 Hz at F_o= 640 kHz. The quality factor in terms of mid band gain can therefore be said to perform to specification up to a centre frequency (F_o) of 256 kHz but deviates at centre frequency of 320 kHz. Also, the bandwidths of the filter conform to filter theory but with deviation at centre frequency of 465 kHz. The roll-off rate behaves like a third –order filter from the values obtained whereas it should have behaved like an eighth-order filter. Because a single pole filter rolls off gives 20xn dB/dec, where n is the filter order, the eighth- order should give 160 dB/dec [27, 28]. The centre frequencies of the filter at this quality factor are slightly shifted from ± 4.48 % at F_o= 40 kHz to ± 1.12% at F_o= 640 kHz, but this is still within the specification of the epc global class I generation 2 protocol of ± 22 % for UHF RFID systems [29]. Therefore, the filter can be used in the reader of ultra-high frequency radio frequency identification systems. All the deviations noticed with this filter can be attributed to the high sensitivity of MFB topology to resistor values that cause parasitic effect to the filter.

Experimental filter for eighth-order active-r bandpass filter using biquadratic topology and quality factor q=30 at varying centre frequencies

From the constructed filter, the mid band gain, -3dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L) bandwidth (BW) and Roll-off values obtained at different centre frequencies are shown in Table 6.

The result presented in Table 6 shows obtained values for the designed active-R bandpass filter using biquadratic topology at constant quality factor of Q = 30. From Table 6, the filter has a maximum pass band gain of 40.260 dB at centre frequency of 40 kHz and decreased inversely with centre frequency until it gets to 465 kHz from where it assumed direct proportionality. The minimum band gain is -8.610 dB at 320 kHz centre frequency. The bandwidth increases with centre frequency at all centre frequencies without dropping. The minimum bandwidth is 270.000 Hz. The roll off rate also decreases progressively to -232.014 dB/dec at a centre frequency of 640 kHz. From Figure 36, we observed a slight shift in centre frequency from 39,899 Hz at F_o= 40 kHz to 647,191 Hz at F_o= 640 kHz. The filter at this quality factor in terms of mid band gain can therefore be said to perform to specification up to a centre frequency (F_o) of 320 kHz but deviates at centre frequency of 465 kHz. Also, the bandwidths of the filter conform to filter theory, without deviation at any centre frequency.

Table 6: Maximum Gain and Bandwidth of Eighth-order Active-R Bandpass Filter using Biquadratic Topology at variable Centre Frequency and Constant Quality Factor of Q = 30 (EXPERIMENTAL)

F_0(kHz)	Mid Band Gain (dB)	-3dB Gain (dB)	F_H (kHz)	F_L (kHz)	BW (kHz)	Roll-off (dB/decade)
40	40.260	37.260	40.070	39.800	0.270	-161.321
107	26.270	23.270	107.570	106.920	0.650	-180.581
160	22.700	19.700	159.210	158.430	0.780	-199.607
256	18.810	15.810	257.870	256.960	0.910	-222.259
320	-8.610	-11.610	324.814	323.584	1.230	-225.000
465	22.530	19.530	469.350	467.870	1.480	-228.916
640	-7.850	-10.850	647.960	646.130	1.830	-232.014

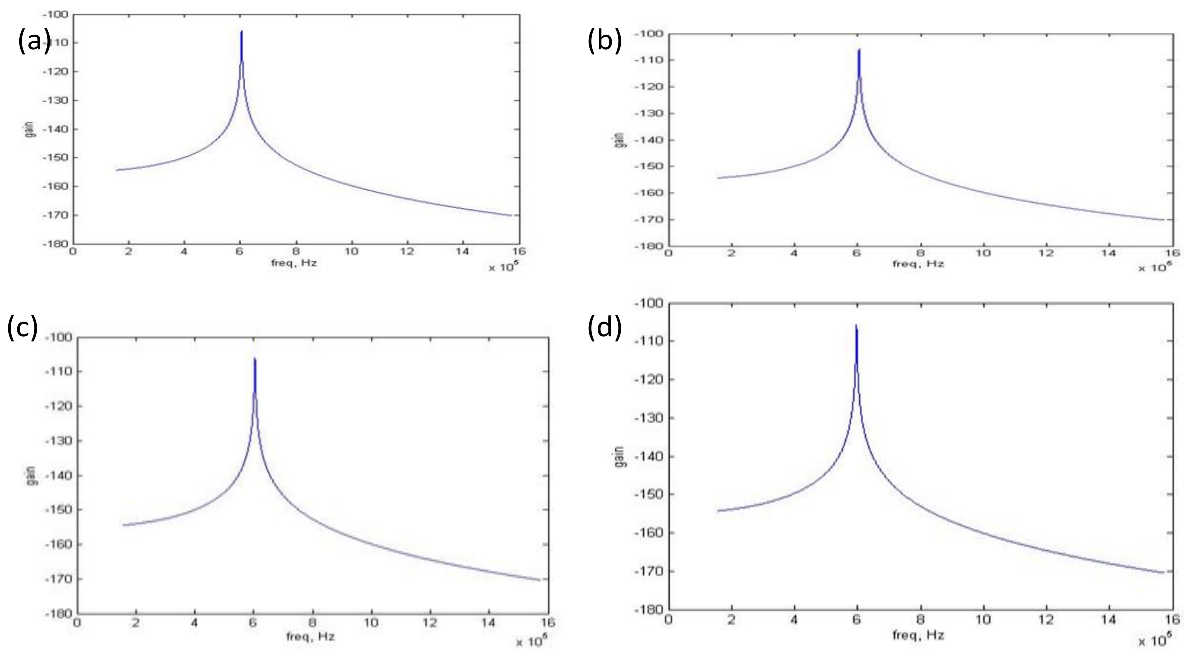
The roll-off rate behaves like an eighth–order filter from the values obtained. A single pole filter rolls off gives 20xn dB/dec, where n is the filter order, the eighth- order should give 160 dB/dec. The centre frequencies of the filter at this quality factor are slightly shifted from ± 0.25% at F_o= 40 kHz to ± 1.12% at F_o= 640 kHz, but this is still within the specification of the epc global class I generation 2 protocol of ± 22 % for UHF RFID systems. Therefore, the filter can be used in the reader of ultra-high frequency radio frequency identification systems. All the deviations noticed with this filter can be attributed to the high sensitivity of MFB topology to resistor values that cause parasitic effect to the filter.

Programme code in matlab programming software

The MATLAB programming software was used to write a programme and implement for the best filter topology in terms of performance. This resulted from the comparisons made using filter characteristics of Gmax, BW and ROR. The MATLAB software was used because it enables the user to perform extremely complex mathematical analysis efficiently. In addition, MATLAB has many functions capable of generating exceptionally insightful graphs. Since the filter is an eighth-order system, it was realized by the cascade of four second order filters. Each of the second order filters has a characteristic equation called transfer function which was written by convolution to give the eighth-order. The complete programme of the best performed filter together is presented in Figure 7, while the Table of result is presented in Table 7.

Programme code for eighth-order active-r bandpass filter using biquadratic topology at variable centre frequencies and constant quality factor of q=30

The results obtained from the simulated filter using resistor values in Tables 1 to 4 for the eighth - order active-R bandpass filter using biquadratic topology at constant quality factor of Q = 30 and varying centre frequencies is presented in Figure 7.



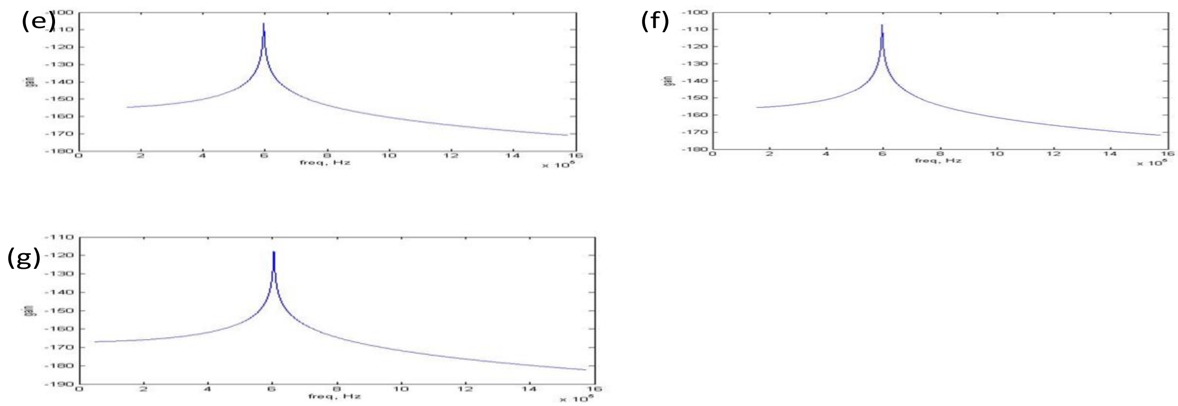


Figure 7: Magnitude Plot of Eighth-Order Active-R Bandpass Filter using Biquadratic Topology at Centre Frequencies of (a) F_o = 40 kHz, (b) F_o = 107 kHz, (c) F_o = 160 kHz, (d) F_o = 256 kHz, (e) F_o = 320 kHz, (f) F_o = 465 kHz, (g) F_o = 640 kHz and Quality Factor of Q = 30 using MATLAB

Programme code for eighth-order active-r bandpass filter using biquadratic topology at variable centre frequencies and constant quality factor of q=30

The filters were designed and constructed for both MFB and biquadratic topologies and comparisons made using filter characteristics of mid band gain (maximum pass band gain), bandwidth and roll-off rates in order to select the best in terms of performance. At the end the eighth-order active-R band pass filter using biquadratic topology at a quality factor of 30 was selected. This is why the programme code in MATLAB is only written for the implementation of this filter. Therefore from (Figures 7a-g) the mid band gain, -3dB gain, higher cut-off frequency (F_H), lower cut-off frequency (F_L) and bandwidth (BW) values obtained at different centre frequencies for the programmed eighth- order active-R bandpass filter using biquadratic topology at Q= 30 and varying centre frequencies are shown in Table 7. Table 7 shows that the maximum pass band gain (G_{max}) had a trend that increased proportionately with the centre frequency. This trend is contrary to filter theory which states that 'as the centre frequency increases, the maximum pass band gain decreases' [2]. This means that the programme code deviates from filter theory so the filter does not work to specification. The bandwidth on the other hand increases all through as centre frequency (F_o) increases. This is in line with the filter theory which stipulates that as centre frequency increases, bandwidth also increases. Hence the filter works to specification in terms of bandwidth.

Table 7: Programme Code in Matlab for Eighth-Order Active-R Bandpass Filter using Biquadratic at Q=30

S/N	F_0 (kHz)	Mid Band Gain (dB)	-3dB Gain (dB)	Upper Cut-Off Freq F_H (Hz)	Lower Cut-Off Freq F_L (Hz)	BW (Hz)
1	40	-118.0	-121.0	6.055X10^5	6.033X10^5	2200
2	107	-107.4	-110.4	5.969X10^5	5.946X10^5	2300
3	160	-106.3	-109.3	5.969X10^5	5.944X10^5	2500
4	256	-105.8	-108.8	5.978X10^5	5.950X10^5	2800
5	320	-105.9	-108.9	6.053X10^5	6.020X10^5	3300
6	465	-105.9	-108.9	6.061X10^5	6.026X10^5	3500
7	640	-105.7	-108.7	6.060X10^5	6.023X10^5	3700

The programme Code using MATLAB programming code has been developed. If we compare the results on Tables 5 to 8 and that on Tables 9 to 12, we observed that the filter has its maximum pass band gain decreasing as centre frequency increases. The Bandwidth on the other hand increases in both cases as centre frequency increases while the roll-off rate of both filters resembles that of a double-pole eighth-order active-R bandpass filter. We also observed from the results that even though the filters pass band gain deviates from filter theory, the bandwidth and the roll-off rates conform to filter theory. This implies that the filter partially works to specification using MATLAB programme software. Consequently, the filter can be improved upon when resistor values are properly chosen so as to meet up with the specification.

Conclusion

The eighth-order active-R bandpass filter using biquadratic topology at variable centre frequencies and quality factors of Q = 25 and Q = 30 were designed and developed as presented above. The tag to reader transmission is performed in a frequency band commonly used in many other applications, which might interfere in the RFID communication. Therefore, taking into cognisance the wide range of link frequencies that the UHF EPC for UHF RFID allows to use, it is necessary to develop a filter with tight bandwidth to receive the FRID signal. The EPC standard for UHF RFID permits the communication from the RFID tag to the RFID reader in a modulation frequency that ranges from 40 kHz to 640 kHz. The results obtained and presented in above shows that the active-R bandpass filter using biquadratic topology at variable centre frequencies and constant quality factor of Q = 30 worked well and better as specified in the filter theory and EPC Global Class I Generation 2 protocol. This filter is characterized by low gain, bandwidth is in good agreement with filter theory and the roll-off rate is very good as it is characterized by a roll-off rate that gave an eighth-order active filter. But there were deviations from the centre frequencies which were not outside the ±2.5% of the allowed deviations approved by the EPC Code. This filter therefore can be used for Ultra-High Frequency (UHF) Radio Frequency Identification (RFID) systems. Recommendations given are that; the filter characteristics are realized by resistance ratios; therefore, the resistance should be carefully selected so as to avoid attaining Slew rate; The ratio of the resistance must be chosen so as to conform to $R_{1a} = \frac{R_2 R_3}{R_4}$ to avoid entering into high sensitivity of the filter and that; the low roll-off recorded by the MFB topology can be modified to provide a higher roll-off when desired. Further studies should be done on a synchronization method and its hardware implementation for Miller Codes.

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