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Design and Simulation of a Modified Universal Active-R Bandpass Filter For Ultra High Frequency (UHF) Radio Frequency Identification (RFID) Systems

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Abstract: *In this paper, a second order active-R band-pass filter using universal active-R type that was slightly modified was designed and simulated. The filter utilized a single pole mode op-amp and nine resistors which were realized from the calculations using the design equations. Result in table 2 showed that the centre frequencies were all shifted a little from the normal backscattered frequencies, f_p of 40 kHz with 39.75 kHz to f_p=640kHz with 632 kHz. Although the shifted frequencies were well within the recommended range of deviation from the EPC class 1 Generation 2 protocol for UHF RFID systems. Also the result showed that the mid band gain was low and increased from a value of 0.21dB at f_p=40 kHz to 8.37dB at f_p=256 KHz and then decreased from f_p=320 kHz to 6.12dB at f_p=640 kHz. This is a departure from filter theory. Again the bandwidth was at a high at f_p=40 kHz with a value of 106.35 kHz and decrease to a value of 37.11 kHz at f_p=256 kHz and then increases from a value of 43.28 kHz at f_p=320 kHz to 54.59 kHz at f_p=465 KHz and then drops to 54.31 kHz at f_p=640 kHz. This behaviour is not in line with filter theory. Furthermore, the roll-off rate is observed to approach a single pole roll-off of 20dB/decade with the filter roll-off rate at fp = 40 kHz of -20.94 dB/decade to f_p=640 KHz of -24.61db/decade. The filter's irregular behaviour at mid band gain and bandwidth could be attributed to parasitic effect and circuit components which could be chosen carefully if a desired result is required. Therefore from the result, we can conclude that the filter can be used for UHF RFID systems implementation since UHF band of backscattered frequencies are accommodated.*

Keywords: Modified, Universal, Active – R , Band-pass filter, UHF, RFID.

Introduction

With the development of internet of things technology, the Radio Frequency Identification (RFID) communication has been widely applied to daily life (Yan, 2006). Internationally, RFID communication is mainly divided into such four frequency bands as low frequency (125-134kHz), high frequency (13.6MHz), ultra-high frequency (860-960MHz) and micro wave (2.45GHz and above) (Yang, 2013; Zhao & Zhang, 2010). wherein, low frequency and high frequency RFID communications are characterised by strong penetrating ability, slow transmission speed and short operating range, both of which are generally applied in access control security system (Yang, 2013), library management (Zhang, et al., 2015), electronic consumption and other areas. Microwave RFID communication generally takes an active approach, characterised by the short operating range, suitable for road tolls, vehicle management and other fields. Comparatively, ultra-high frequency RFID communication has been widely used in warehouse management logistics tracking and industrial production and the likes. Thanks to its characteristics like fast speed and far operating range (Xiangquan, et.al., 2018).

RFID system consists of reader and a large number of tags. A tag has an identification number (ID) and a reader recognizes an object through consecutive communications with the tag attached to it. The reader sends out a signal which supplies power and instructions to a tag. The tag transmits its ID to the reader and the reader consults an external data base with received ID to recognise the object (Zin, et.al., 2009). In the reader, the front end system needs a RC filter, an active band pass filter and an active low-pass filter to reject the undesired signals. In modern electronics circuits today, unwanted signals are the major challenges to contend with. This is due to interferences, in the form of noise and harmonics which these unwanted signals pose to certain specified wanted signal frequencies in a band in electronics systems. Filters are used in a wide variety of applications. In the field of telecommunication, band-pass filters are used in the audio frequency range (0 kHz-20 kHz) for modems and speech processing (Kugelstadt, 2008). In 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 the effects of harmonics after the mixing operation which attenuates the desired signals Zin, et.al., 2009(as cited in Teryima, et.al., 2014). Filters therefore are circuits that are capable of passing signals with certain selected frequencies while rejecting signals with other frequencies (San -Hlarng & Khin, 2018). Active filters use transistors or op. amps combined with passive RC, RL, or RLC circuits. The Active devices provide voltage gain, and the passive circuits provide frequency selectivity. In, general, it can be defined that band pass filters pass all frequencies bounded by a lower frequency limit and an upper frequency limit and reject all others lying outside this specified band. (San- Hlaing & Khin, 2018). In this paper, an active band-pass filter of an active- R type is designed and simulated to reject all signals outside the backscattered frequencies of an UHF band (40 kHz-640 kHz) to be used for the RFID systems. A Butterworth filter is the first and probably best known filter approximation with a maximally flat response. It exhibits a nearly flat-pass band with no ripple. The roll-off is smooth and monotonic, with a low pas or high pass roll off rate of 20dB/decade (6dB/octave) for every pole.

DESIGN CONSIDERATION

The design considered for this research is the work done by Ahmed, & Mahmoud (1977) with a little modification. This was chosen because, it's an active -R filter that realizes inverting bandpass and low pass transfer characteristics of any arbitrary gain at two different output terminals, at a third output terminal, a general biquadratic transfer characteristics was obtained, namely a non-minimum phase, a generalizes notch or a high pass transfer function. This architecture was particularly chosen since from available literature, it has not been found to be implemented in the UHF RFID systems.

A Circuit diagram for the second order Universal Active –R filter which was slightly modified is presented in fig 1.

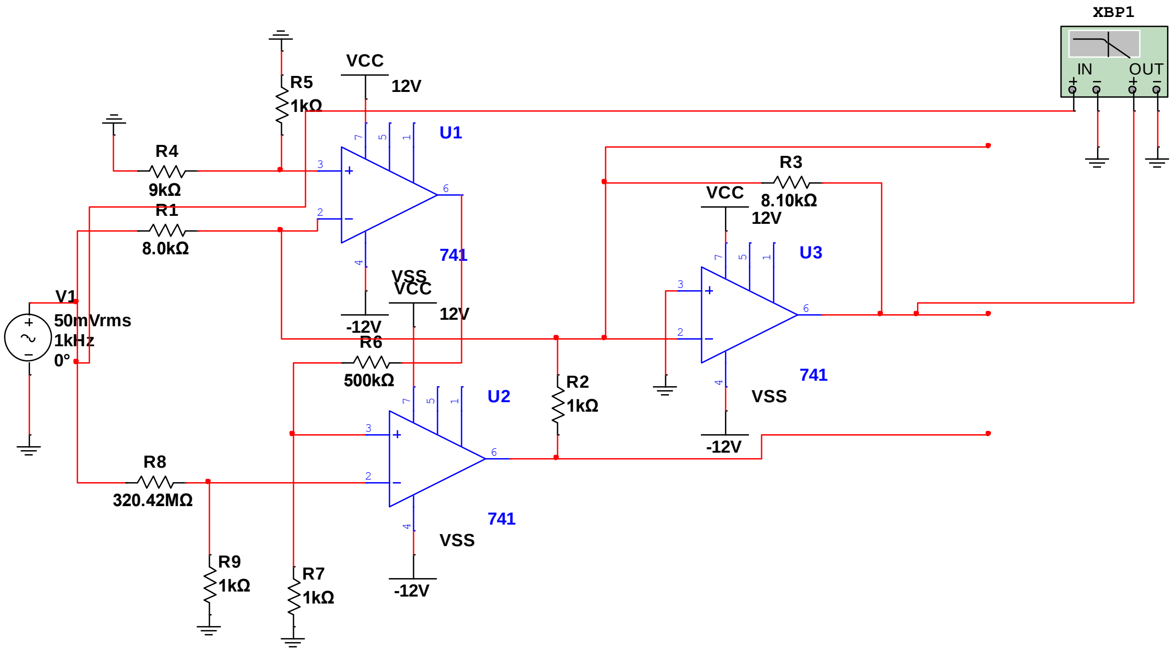

Fig. 1: A Modified Second Order Universal Active-R Filter

DESIGN IMPLEMENTATION

$$Ai = \frac{GBi}{S}(i = 1,23, \ldots..) \qquad (1)$$

Where the GB is the gain bandwidth product of the operational amplifier, the transfer function at different output terminals can be calculated by direct analysis as:

$$Ti(S) = \frac{V_2}{V_1} = K\frac{S^2 - S\left(\frac{W_z}{Q_z}\right) + W_z^2}{s^2 + s\left(\frac{W_p}{Q_p}\right) + {W_p}^2} \qquad (2)$$

Where S=complex pole conjugate, W_z=frequency at zeros and Q_z=quality factor at zeros, W_p=pole frequency and Q_p= quality factor at pole.

Where the gain factor K=a/b (3)

For a band pass realization, when

$\frac{V_2}{V_1}$ Represents a high pass filter ($i.e\ P = 0, n = 0$), then we consider the transfer function.

$$T_{2(S)} = \frac{V_3}{V_1} = \frac{-H_1.S}{S^2+S\left(\frac{W_P}{Q_p}\right)+W_p^2} \quad (4)$$

Which represents a band pass filter where

$$H_1 = K.GB_2 \quad (5)$$

The mid band pass is given by:

$$|G_O| = \frac{a}{b-a-1} = \frac{R_3}{R_1} \quad (6)$$

This can take any arbitrary value.

DESIGN EQUATIONS

For a band-pass filter design for a given centre frequency (fp), pole quality factor (Qp) and mid-band gain (|Go|), the resistor values can be calculated using the equations shown below.

$$\frac{R_3}{R_1} = |G_O| \quad (7)$$

$$\frac{R_1}{R_2} = \frac{D-1}{|G_O|} - 1 \quad (8)$$

$$\frac{R_6}{R_7} = \frac{f_{c2} \times f_{c2}}{F_P{}^2}.\left(1 - \frac{1+|G_o|}{D}\right) - 1 \quad (9)$$

$$\frac{R_3}{R_2} = D(1-K) - 1 \quad (10)$$

$$\frac{R_1}{R_2} = \frac{1}{K}\left(1 - K - \frac{1}{D}\right) \quad (11)$$

$$\frac{R_6}{R_7} = \frac{F_{C_{i.}} F_{C2}}{F_P{}^2}\left(1 - K - \frac{1}{D}\right) - 1 \quad (12)$$

$$\frac{R_4}{R_5} = \frac{1}{K}\left[\frac{F_P}{F_Z}\right]^2 - 1 \quad (13)$$

$$\frac{R_8}{R_9} = \frac{F_{C_2}}{F_2}.\frac{F_P}{K}.\left(1 - K - \frac{1}{D}\right) - 1 \quad (14)$$

Where:

$$D = Q_p \times \frac{f_{c2}}{f_p} \quad (15)$$

$$F_{C_i} = \frac{GB}{2\pi}(i = 1,2,3 \dots\dots) \quad (16)$$

Where a & b are the band pass coefficient, D is the damping factor and fc_i, fz, are the frequency of the op. amp.

In this design, it is proposed that a second order Active- R band pass filter for UHF RFID systems using the universal active- R filter circuit be considered. The filter is to reject all signals backscattered by the tag in the UHF region (40 kHz – 640kHz) for RFID systems, therefore the parameters used are K=0.1 a=1, b=10, Q_p=30, GB=5.0x10^6Hz and f_p=40kHz, 107kHz, 160kHz, 256kHz, 320kHz, 465kHz, and 640kHz.

The resistor values were then calculated using equations 7 to 16 as shown below.

K=0.1, a=1, b=10, Q_p=30, f_p=40x10^3Hz GB=50x10^6Hz

$$D = Qp - \frac{fc_3}{fp}$$

$$fci = \frac{GBi}{2\pi}(i = 1,2,3 \dots\dots)$$

$$fc_{3} = \frac{5.0x10^6}{2\pi} = \frac{5.0x10^6}{2x3.142} = 795798.1856$$

$$D = 30 - \frac{795798.1856}{40X10^3}$$

$$= 30 - 19.895$$

$$= 10.105$$

$$\frac{R3}{R2} = D(1-K) - 1$$

$$= 10.105(1-0.1) - 1$$

= 10.105 (0.9) – 1

=9.0945 – 1

$\frac{R3}{R2} = 8.0945 =\rightarrow R3 = 8.0945R_2$

$let\ R_2 = 1k\Omega = R_3 = 8.0945X1X10^3 = 8.0945K\Omega$

$\frac{R_1}{R_2} = \frac{1}{K}(1 - K - \frac{1}{D})$

$= \frac{1}{0.1}(1 - 0.1 - \frac{1}{10.105})$

$= \frac{1}{0.1}(1 - 0.1 - 0.099)$

$= \frac{1}{0.1}(0.801)$

$\frac{R_1}{R_2} = 8.01\ but\ R_2$=1KΩ= $R_1 = 8.0X\ 1K\Omega$

$= 8.0K\Omega$

$\frac{R_4}{R_5} = \frac{1}{K}\left[\frac{F_P}{f_z}\right]^2 - 1$

$= \frac{1}{0.1}\left[\frac{40000}{40000}\right]^2 - 1$

$= 9 = R_4 = 9R_5 Let\ R_5 = 1K\Omega$

$= R_4 = 9K\Omega$

$\frac{R_6}{R_7} = \frac{F_{C_i.}f_{c_2}}{{f_p}^2}\left(1 - k - \frac{1}{d}\right) - 1$

$= \frac{795798.1856.795798.1856}{40000^2}.\left(1.0.1 - \frac{1}{10.105}\right) - 1$

$\frac{R_6}{R_7} = \frac{6.33X10^{11}}{1600000000}.\left(1 - 0.1 - \frac{1}{10 - 105}\right) - 1$

$= 395.625.(1 - 0.1 - 0.09896) - 1$

$= 395.625.(0.80104) - 1$

$= 316.91145 - 1$

$\frac{R_6}{R_7} = 315.91 = R_6 = 315091R_7$

$Let\ R_7 = 1K\Omega$

$then\ R_6 = 315091K\Omega$

$\frac{R_8}{R_9} = \frac{F_{C_2}}{F_Z}.\frac{Q_Z}{K}.\left(1 - K - \frac{1}{D}\right) - 1$

$= 1.\frac{40X10^3}{0.1}.\left(1 - 0.1 - \frac{1}{10.10}\right) - 1$

$= 1.400000.(0.80104) - 1$

$= 320416 - 1 = 320415$

$\frac{R_8}{R_9} = 320415 = R_8 = 320415R_9$

$let\ R_9 = 1K\Omega$

Then R_8= 320415X1KΩ

$= 320415000$

$\approx 320.42M\Omega$

$R_1 = 8.0K\Omega, R_2 = 1K\Omega, R_3 = 8.10\text{K}\Omega, R_4 = 9\text{K}\Omega, R_5 = 1\text{K}\Omega, R_6 = 315.91\text{K}\Omega, R_7 = 1\text{K}\Omega, R_8 = 320.42\text{M}\Omega, R_9 = 1\text{K}\Omega. R_6 = 500\text{k}\Omega.$

The resistor values were first calculated using a centre frequency fp = 40 kHz as presented above and then repeated for the other values of centre frequencies fp with the Qp, a, b, K, and GB remaining the same. The calculated resistor values and preferred values are presented on Table 1.

Table 1: Calculated Resistor Values (Active-R filter)

S/n	**FLF (MHZ)**	**BLF (KHZ)**	**Calculated Resistor Values**									**Preferred Resister Values**			
			R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	R4 (kΩ)	R5 (kΩ)	R6 (Ω)	R7 (kΩ)	R8 **Ω**	R9 (kΩ)	R1 (kΩ)	R3 (kΩ)	R6 **(Ω)**	R8 **(Ω)**
1	860.00	40.00	8.00	1.00	8.10	9.00	1.00	315.91k	1.00	320.42	1.00	8.00	8.20	490..61	490.61K
2	880.00	107.00	8.56	1.00	19.31	9.00	1.00	46.43K	1.00	915.00M	1.00	8.50	19.10	72.62	1.00T
3	900.00	160.00	8.60	1.00	21.53	9.00	1.00	20.27K	1.00	1.38T	1.00	8.66	21.50	30.12K	1.00T
4	910.00	256.00	8.63	1.00	23.20	9.00	1.00	7.34K	1.00	2.20T	1.00	8.66	23.20	12.13K	2.00T
5	920.00	320.00	8.64	1.00	24.10	9.00	1.00	3.22K	1.00	3.11T	1.00	8.66	24.00	7.32K	3.11T
6	930.00	465.00	8.59	1.00	24.46	9.00	1.00	1.52K	1.00	4.00T	1.00	8.59	24.46	3.00K	4.00T
7	940.00	640.00	8.65	1.00	24.90	9.00	1.00	337.00	1.00	5.54T	1.00	8.66	24.88	1.02K	5.00T

RESULT AND DISCUSSION

The results of circuit using NI multisim software version 14.2 for the second order universal Active -R band pass filter are shown on the magnitude response curves for the different centre frequencies fp in figures 2-8.

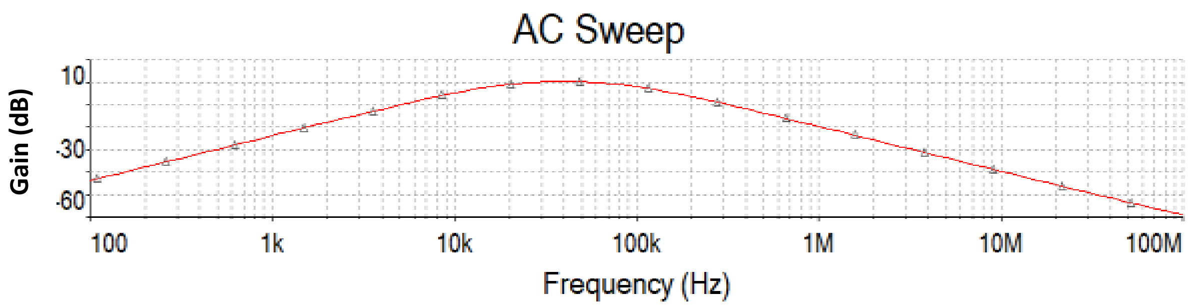

Figure 2. Active-R filter fp=40kHz

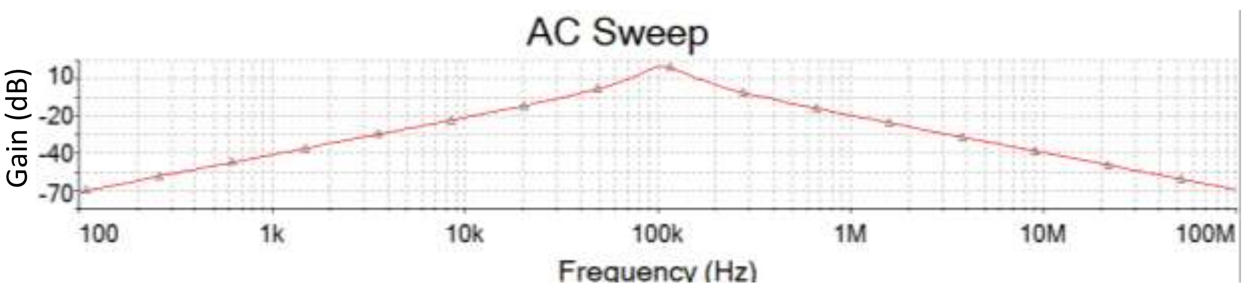

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Figure 3. Active-R filter fp=107kHz

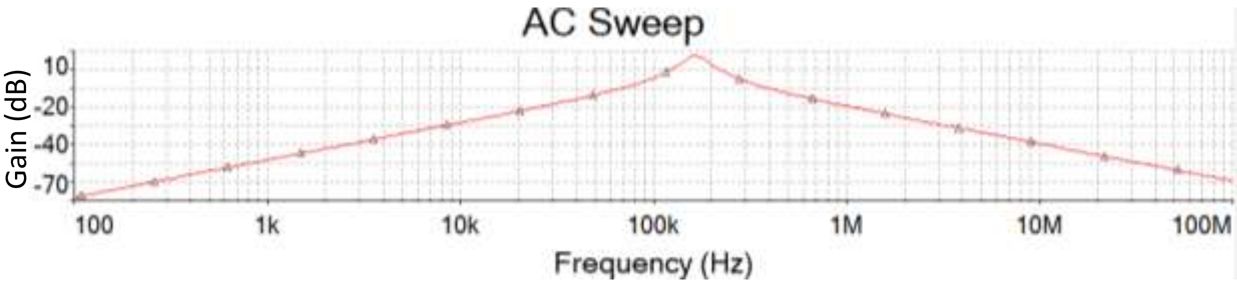

Figure 4. Active-R filter fp=160kHz

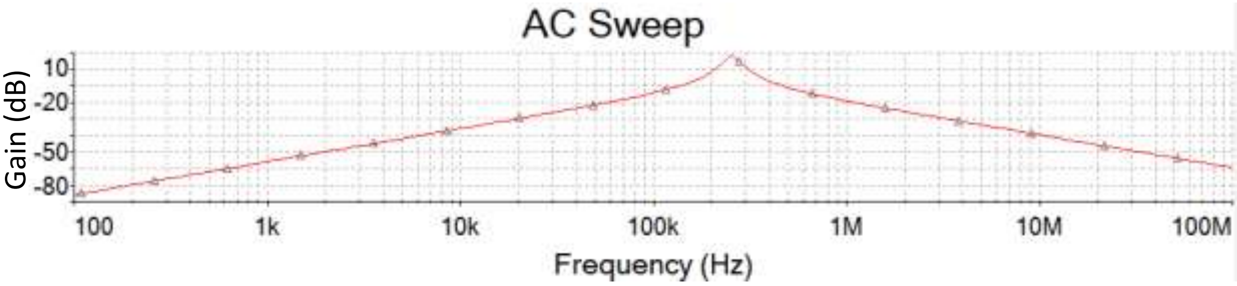

Figure 5. Active-R filter fp=256kHz

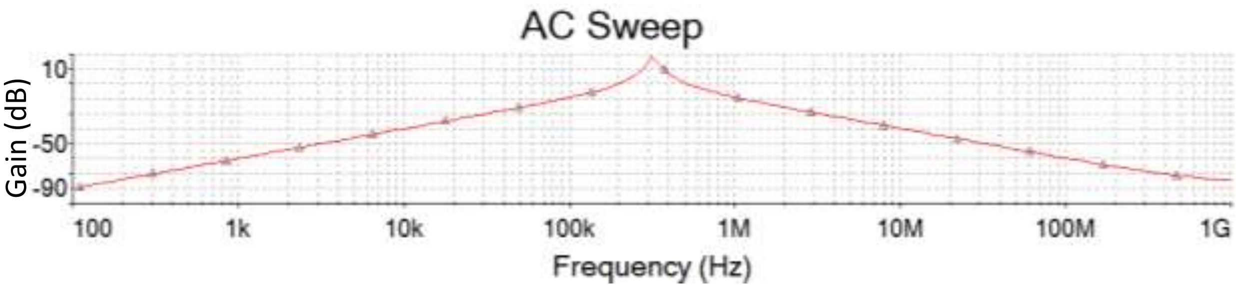

Figure 6. Active-R filter fp=320kHz

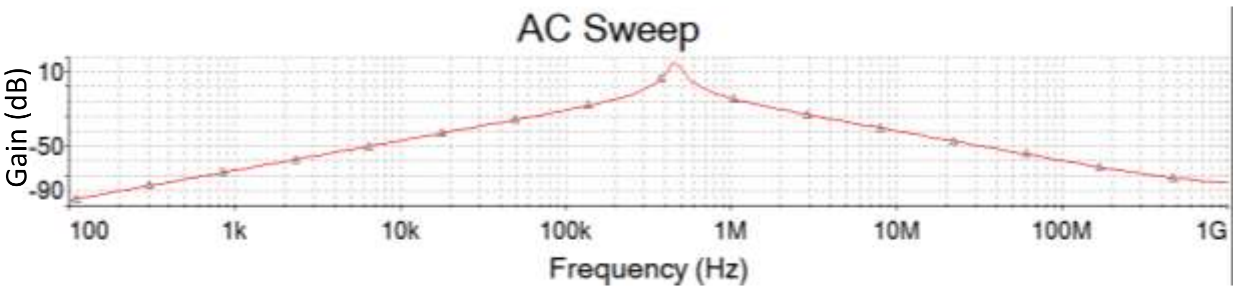

Figure 7. Active-R filter fp=465kHz

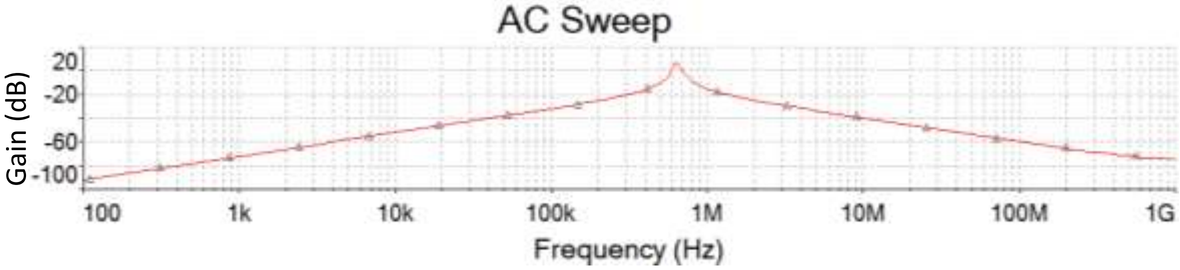

Figure 8. Active-R filter fp=640kHz

The results for the centre frequency (Fp), mid band gain, -3dB gain, bandwidth (BW) and roll-off rate in dB/decade were determined from the simulated plots and results presented in the Table 2.

Table 2: Variation of Functional Properties (centre frequencies (f_p), Midband gain, Bandwidth and Roll-Off Rate) of the designed filter

S/n	FLF (MHZ)	BLF (kHZ)	Shifted centre frequency(kHz)	% shifted centre frequency	Mid band gain (dB)	-3db (dB)	Upper cut off frequency F_H (kHz)	Lower cut off frequency F_L (kHz)	Bandwidth Bld (F_H-F_L) (kHz)	Roll-off rate dB/decade.
1	860.00	40.00	39.75	0.63	0.21	-2.79	119.91	13.56	106.35	-20.94
2	880.00	107.00	111.51	-4.21	6.82	3.82	132.75	85.85	46.90	-20.02
3	900.00	160.00	160.34	-0.21	7.35	4.35	188.13	144.84	43.29	-20.17
4	910.00	256.00	251.56	1.73	8.37	5.37	274.46	237.35	37.11	-20.62
5	920.00	320.00	318.92	0.34	8.25	5.25	341.29	298.01	43.28	-20.78
6	930.00	465.00	447.61	3.74	6.89	3.89	479.00	425.41	53.59	-22.02
7	940.00	640.00	632.00	1.25	6.12	3.12	661.02	606.02	54.31	-24.61

Table 2, presents result from plots using Ac sweep from a bode plotter of an NI Multisim version 14.2 which shows that all the centre frequencies (Fp) from 40kHz to 640kHz are all shifted with a value of 39.75kHz to 632.00kHz respectively with a percentage shift of 0.63% to 1.73%. This shift could be attributed to the value of resistors used since the calculated values of the resistors are not readily available; we used a preferred value as indicated in table 1 above. Although the shift in the centre frequencies is well within the range of $\pm$ 22% recommended in the EPC class 1 generation 2 protocols for UHF RFID use. The filter thus could be said to be work well for use. The filter thus could be said works well for use in the UHF RFID systems.

Again, the mid band gain of the filter as presented in Table 2 is observed to record low gain which increased gradually as the centre frequency increases from 40kHz to 256kHz with a value of 0.21dB to 8.35dB and then decreased from 320kHz to 640kHz with a value of 8.25dB to 6.12dB. This does not behave in conformation to filter theory which states that, as the centre frequency increases, the midband gain should be decreasing (Atsuwe, 2018; Atsuwe, et.al., 2021).

This behaviour can be attributed to parasitic effect of the op.amp used or circuit components used. Although with appropriate care in choosing circuit components, one can achieve that desired result.

Furthermore, the roll-off rate of the filter approaches a single pole, second –order filter with a value of -20.94dB/decade at f_p=40kHz, -20.02dB/decade at f_p=107kHz, -20.17dB/decade at f_p=160kHz, -20.62dB/decade at f_p=256kHz, f_p=320kHz , -22.02dB/decade at f_p=465kHz and -24.61dB/decade at f_p=640kHz. The result confirms the type of op. amp used for the research.

More so, the results shows a decrease in the bandwidth of the filter from a value of 106.35 kHz at $f_p = 40kHz$ to a value of 37.11 kHz at f_p=256 kHz and then increases to 43.28 kHz at f_p=320 kHz to 54.31 kHz at f_p=640 kHz. The observed behaviour is irregular and only works from f_p=320 kHz to f_p=640 kHz which supports filter theory that states that "if centre frequency increases, bandwidth of the filter should increase" (Atsuwe, 2018; Atsuwe, et.al., 2021).

The behaviour could be attributed also to parasitic effects of the circuit which could be corrected with careful selection of circuit components.

CONCLUSION

A modified Universal Active-R band-pass filter for UHF RFID systems has been designed and simulated as presented in this paper. These circuits are composed of three op amps nine (9) resistors. The op. amps are based on commonly available µA741. The simulated result could be used in the UHF RFID systems since the frequency range for the backscattered signals(i.e 40kHz to 640kHz) is accommodated. If more accurate result is desired, then circuit components like the op. amp could be carefully selected in order to meet the specification desired.

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