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Design and Simulation of Composite Operational Amplifier Based Active Band Pass Filter for Ultra-High Frequency RFID Systems

Atsuwe , B.A.[1] and Mom, J.M.[2]

[1]*Department of Science Education, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria. Email: Corresponding Author E-Mail:atsuwe.bernard@uam.edu.ng.*

[2] *Department of Electrical and Electronics Engineering, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria Email: joe.mom@uam.edu.ng*

Abstract: *The radio frequency identification (RFID) systems reader is mainly made up of a bandpass filter, an amplifier, a rectifier, low pass filter and a comparator. In today's world the RFID plays a vital role in communications and technology and in all forms of electrical equipment. RFID works in the low frequency (30-500 kHz) band, high frequency (10-15MHz) band, ultra-high frequency (860-960MHz) band and super high frequency (2.4-5.8GHz) band. This paper presents the design and simulation of active bandpass filter utilizing the composite operational amplifier (op. amp) for Ultra high frequency RFID systems. This filter helps to achieve an improvement over single op.amp in terms of extended useful bandwidth, low sensitivity to components, op.amp mismatch and wide dynamic range which suits its application in the ultra-high frequency (UHF) RFID usage. Results presented shows through the magnitude plot by NI Multisim software that the active bandpass filter works to specification using the electronic product code (EPC) class 1 generation 2 protocols for RFID usage. Since the centre frequencies fo =40kHz to fo=640kHz which are the backscatter frequencies for UHF range are accommodated. Also the other filter parameters like: Gain, Roll-off rate, bandwidth, sensitivity are all in agreement with theory, which informs the conclusion that the filter performs well and can be deployed in the UHF RFID systems*

Keywords: Composite Op. amp, Active Bandpass Filter, UHF Systems, RFID.

Introduction

Radio Frequency identification (RFID) systems are used in metering applications such as electronic toll collection, inventory control and tracking, merchandise control, assets tracking and recovery, tracking parts moving through a manufacturing process, and tracking goods in a supply chain. Typically, an RFID system consists of an RF tag containing an IC chip that transmits data about the object, a reader that receives transmitted data from the tag, and a data processing system that processes and stores the data passed to it by the reader (San & Khin 2018). Data is stored on the RFID tag in digital form and is transmitted to the reader as a modulated signal. The RFID Reader requires an active band pass filter which is used to reject the frequency outside of the ultra-high frequency(UHF) range.

In earlier research, many types of filter designs for RFID were proposed (Zin, et.al., 2009: Shalab & Vahid, 2012: Teryima, et.al., 2014: Abdul, 2014). (Zin,et al., 2009) In 2009 proposed an Active band pass filter for low frequency (10-20 kHz) RFID band. (Shahab & Vahid, 2012) In 2012 proposed a bandpass filter design for 13.56MHz RFID reader. (Teryima, et al., 2014) In 2014 designed an active RC bandpass filter. The filter was designed from given specification of the filter centre frequency of 15 kHz and roll off fate of -20db/decade. Also (Abdul -Hussein –Adul, 2014), proposed the 4^{th} order active band pass filter using multiple feedback and Sallen- key topologies which was designed and fabricated for RFID system reader to reject all signals outside the band of frequencies from 10-20kHz. Also in 2017 (Vijay & Swati, 2017), A Current Feedback Op Amp (CFOA) based active bandpass filter for high frequency band (10-15MHz) using AD844 IC was proposed. Again, in 2018 (Atsuwe, 2018), An active –R band pass filter of 8^{th} order for UHF RFID system using Multiple Feedback (MFB) topology was also proposed.

In this paper, a second order active –RC bandpass filter using composite operational amplifier was designed and simulated for UHF RFID systems usage.

Active –RC filter is a circuit that is seen to consist only of resistors, capacitors and an active element in the form of an amplifier. An active filter of this type includes more parts than a passive LC circuit and in addition requires a power supply; accordingly, the RC active circuit must have definite advantages if it is to take the place of an LC filter, but the most significant advantages result from the absence of an inductor. In contrast to passive LC filters, RC active filters can provide impedance and low output impedance transformation: that is, they can have a high input impedance and a low output impedance, which means that the network stages are isolated and can be tuned independently without interaction. Many of the disadvantages of RC active filter result from the use of active elements, usually operational amplifiers. Amplifier outputs ordinarily have offsets that can range from a few microvolts per degree Celsius. Also, amplifiers usually have input bias currents that may flow through input circuit resistors and produce output voltage offsets. Input bias currents also are a function of temperature. Moreover, the limited frequency response of operational amplifiers defines the high frequency response of RC active filters; ordinarily the maximum bandwidth is usually about 100 kHz. In practice, the limiting factor is the slew rate of the operational amplifier. A high sew rate is necessary to prevent distortion of the output waveform at high frequencies when the output voltage is a few volts or more.

Active –RC filters are in widespread use because their advantages exceed their disadvantages in many electrical applications. It is well known that the finite gain band-width (GB) product of operational amplifiers (Op-amps) degrades the high frequency behaviour of active –RC circuits. One of the solutions proposed in the literature is the use of active compensation techniques. Many papers have dealt with the topic of proposing active compensated amplifiers. (also called composite amplifiers), like (Solima, 1980), (Huertas & Rodriguez, 1982) and a systematic study have been reported recently. (Mikhael & Michael, 1987) (Perez-Verdu, Huertas, & Rodriguez-Vazquez, 1982).

Composite amplifiers comprising two or more amplifying elements are generally designed to achieve performances unachievable by a single device (Apex Micro technology, 2012: Franco, 2002; Gerstenhaber & Tran, 2002; Mikhael & Michael, 1987; OA-07 current feedback, 2002; Redmayne, 2002; Stofka, 2008; Williams, 1986).

These modules usually involve the operational amplifiers (Op-amps), and they have been used to increase loop gain (Franco, 2002), phase accuracy (Graeme, 1993; Wong, 1987), bandwidth (Geiger, 1977; Stofka, 2008) noise reduction (schmid, 1994) and bandwidth constancy (Maundy, Gift, & Westwick, 2009) in amplifier systems (Stephen, & Brent, 2015). They have also been applied in active filters (Budak, Wullink, & Geiger, 1980; Geiger & Budak, 1979) and oscillators (Wostyna, 1992).

The gain bandwidth product, the product of the finite gain of the operational amplifier and the 3dB frequency, is generally considered to be a constant in a given op-amp. Speed, determined by slew rate limitations, and accuracy determined by the input offset voltage are usually not a variable that can be adjusted in a single op-amp design. Composite operational amplifiers effectively extend the range of single op-amps and lessen the impact of the single op-amp limitations. (Eldon, 1993).

In this paper, single pole model second order bandpass filter using composite operational amplifier is designed and simulated for UHF RFID systems. A composite op-amp offers an improvement over single or conventional op-amp. Performance in terms of extended useful bandwidth, low sensitivity to component and op- amp mismatch and wide dynamic range which can be substantially utilized in the design of filters for the UHF RFID range. Also no literature has been found utilizing the design and implementation of a bandpass filter using composite op-amp for UHF RFID Application. Hence, this paper.

METHODOLOGY

A biquadratic active filter which uses the functional building blocks is designed and tested. It uses two inverting integrators and a differential finite – gain amplifier which are constructed using the composite operational amplifier (ADA 4870 ARRZ).

The transfer function of the filter is given by:

$$\frac{V_{out}}{V_{in}} = \frac{\frac{R_2(R_3+R_4)}{R_3(R_1+R_2)} \times \left(\frac{1}{RC}\right)}{\frac{R_3}{R_{4RC}} + \left[\frac{R_1(R_3+R_4)}{R_4(R_1+R_2)} \times \frac{1}{2\pi f_c RC}\right] + \left(\frac{1}{2\pi f_c RC}\right)^2} \ldots\ldots(1)$$

The band pass is a very narrow, high Quality factor (Q). Therefore the normalised second order transfer function will be given as;

$$\frac{V_{out}}{V_{in}} = \frac{A_O\left(\frac{f}{f_O}\right)}{\left[1 + 2\aleph\frac{f}{f_o} + \left(\frac{f}{f_o}\right)^2\right]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where ℵ is the damping factor, if we make both the integrators input resistors and feedback capacitors the same, then the state variable corner frequency (f_c), can be easily tuned without affecting the overall Q. likewise the value of Q can be varied without altering the corner frequency. Then the corner frequency is given as:

$$2\pi f_c = \sqrt{\frac{R_3}{R_4(RC)^2}} \ldots\ldots\ldots\ldots\ldots(3)$$

$$f_C = \sqrt{\frac{R_3}{R_4(2\pi RC)^2}} \ldots\ldots\ldots\ldots\ldots(4)$$

Also, if we make feedback resistors $R_3 and\ R_4$ the same values, then the centre frequency of each filter output from the state variable filter simply becomes.

$$f_{c(HP)} = f_c(BP) = f_{c(Lp)} = \frac{1}{2\pi RC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Then tuning the state variable corner frequency is accomplished simply by varying either the tuning resistor, R or the capacitor C.

For a bandpass filter.

$$Q = \frac{f_C}{bandwidth(BW)} \dots\dots\dots\dots\dots\dots.(6)$$

$$Q = \frac{f_c}{BW} = \frac{1}{2\aleph} = \frac{R_1(R_3 + R_4)}{R_4(R_1 + R_2)}\sqrt{\frac{R_3}{R_4} \times \frac{RC}{RC}}$$

If the resistors R_3 *and* R_4 are equal and both integrators, components R and C are equal, then the final square root expression would reduce to $\sqrt{1}$ or simply 1.

DESIGN

The UHF, RFID backscatter frequency range for (860-960) MHz is (40-640) KHz. Therefore the design is done to cover the backscatter frequency range. The quality factor Q is chosen to be 30. If we let capacitor value C=1nF, then we use equation 5 to determine the value of the resistor for the different centre frequencies of F_o = 40kHz, 107kHz, 160kHz, 256kHz, 320kHz and 640kHz.The calculated resistor values along with the preferred values are presented in Table 1. The filter was then simulated using NI Multism Version 14.2 simulation software and results read, recorded and presented on Table 2. The simulated magnitude response curves for the band pass filters are presented in Figures 2 to 8.

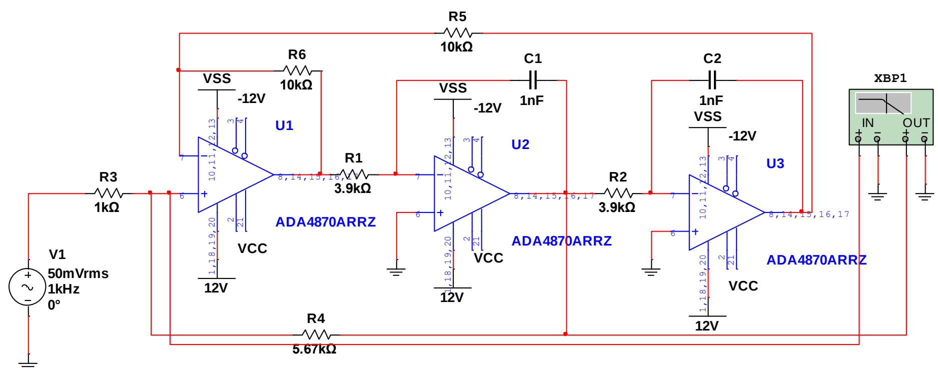

Fig 1: Second Order Bandpass Filter using Composite Operational Amplifier

Table 1: Resistor values for calculated and preferred values

s/n	FLF (MHz)	BLF (KHz)	Capacitor Value (nF)	Calculated resistor values R(kΩ)	R1(kΩ)	R2(kΩ)	R3(KΩ)	R4 (K.Ω)		Preferred Resistor Values. R.(Ω)	R1(kΩ)	R2(kΩ)	R3(kΩ)	R4(kΩ)
1	860.00	40.00	1.00	3.90k	1.00	6.67	10.00	10.00		3.90k	1.00	6.67	10.00	10.00
2	880.00	107.00	1.00	1.49k	1.00	6.67	10.00	10.00		1.50k	1.00	6.67	8.66	8.66
3	900.00	160.00	1.00	994.59	1.00	6.67	10.00	10.00		1.00k	1.00	6.67	10.00	10.00
4	910.00	256.00	1.00	621.62	1.00	6.67	10.00	10.00		620.00	1.00	6.67	10.00	10.00
5	920.00	320.00	1.00	442.04	1.00	6.67	10.00	10.00		500.00	1.00	6.67	10.00	10.00
6	930.00	465.00	1.00	342.22	1.00	6.67	10.00	10.00		249.00	1.00	6.67	10.00	10.00
7	940.00	860.00	1.00	248.65	1.00	6.67	10.00	10.00		249.00	1.00	6.67	8.87	8.87

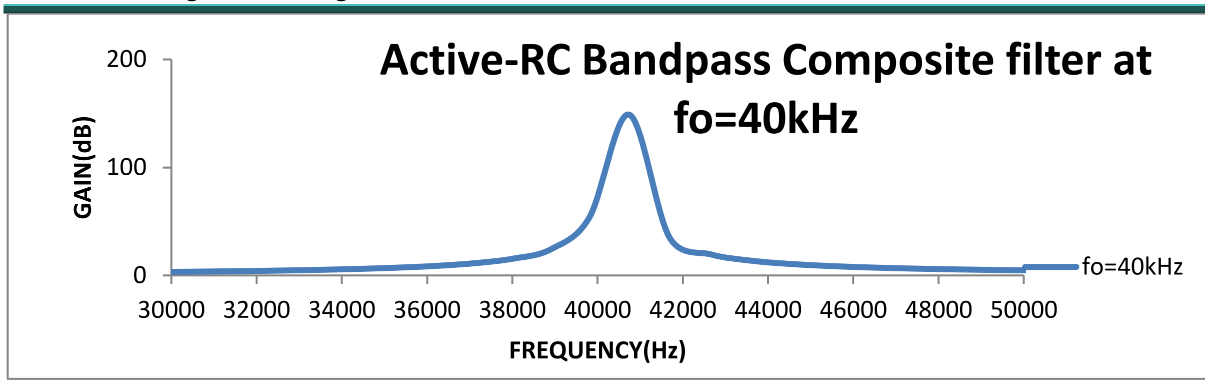

Figure 2. Magnitude response for composite filter at f_0 = 40kHz

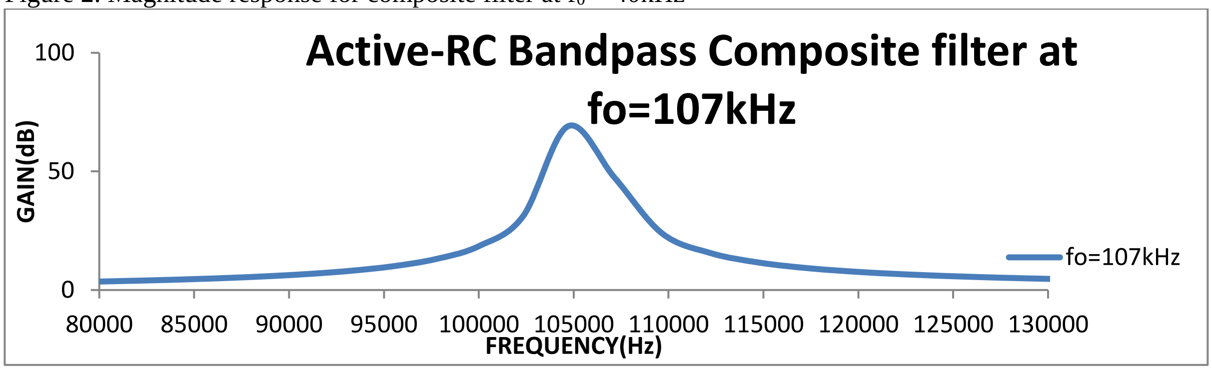

Figure 3. Magnitude response for composite filter at f_o =107kHz

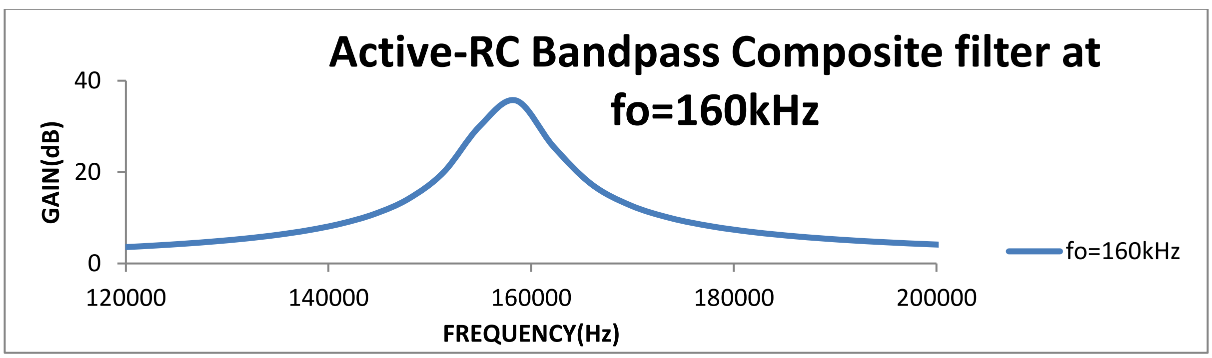

Figure 4. Magnitude response for composite filter at f_o =160kHz

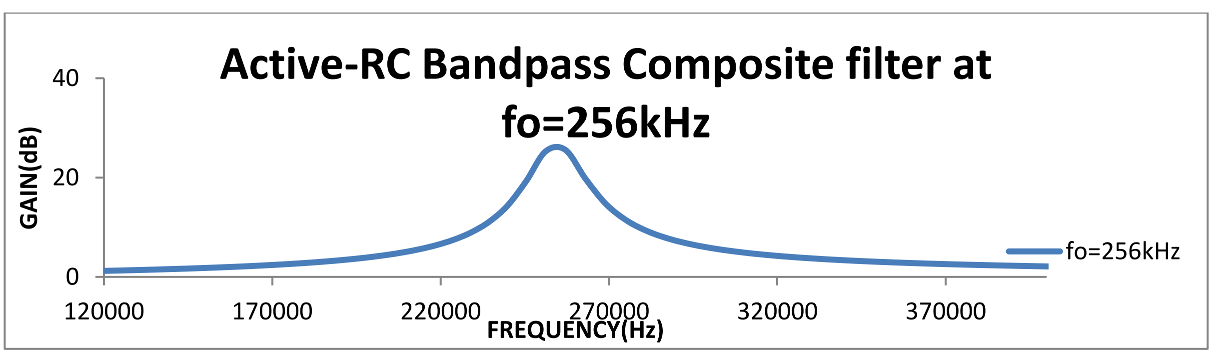

Figure 5. Magnitude response for composite filter at f_o =256kHz

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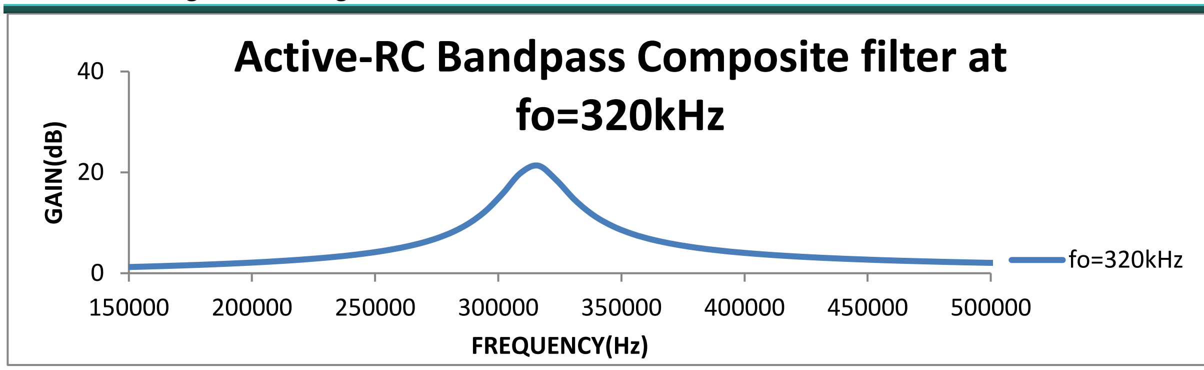

Figure 6. Magnitude response for composite filter at f_o =320kHz

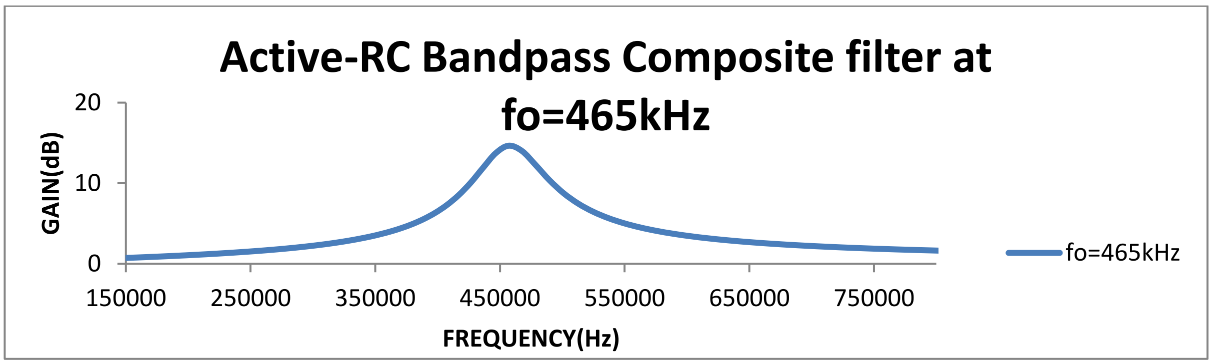

Figure 7. Magnitude response for composite filter at f_o =465kHz

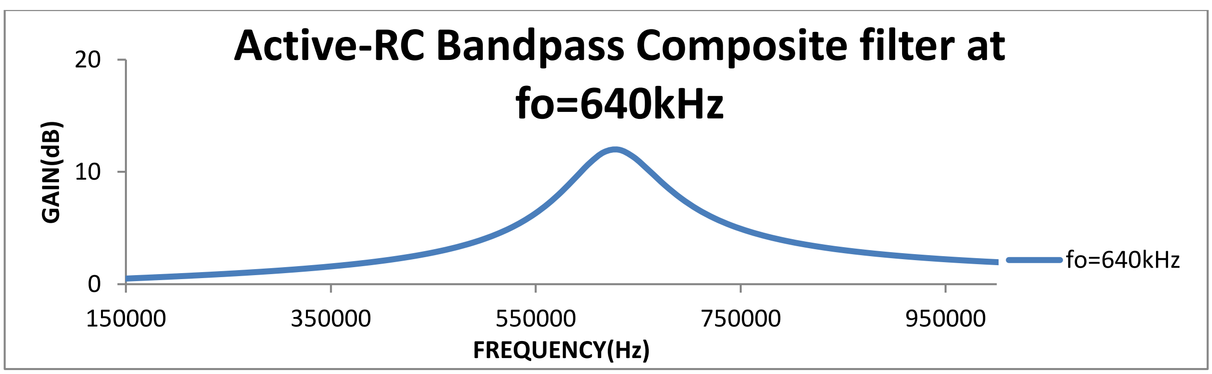

Figure 8. Magnitude response for composite filter at f_o =640kHz

Table 2: Variation of functional properties (centre frequencies, mid-band gain, Bandwidth and Roll-off rate) of designed filter

S/N	FLF (MHz)	BLF (kHz)	Centre freq (fo) (kHz)	Shifted Centre for (%)	Midband Gain (dB)	-3dB Gain (dB)	Upper cut-off Freq. (F_H)(kHz)	Lower cut-off Freq. (F_L)(kHz)	Bandwidth BW(F_H-F_L) (Hz)	Roll-off Rate dB/DECADE
1	860.00	40.00	40.74	-1.85	148.89	145.89	41.69	40.74	950.00	-21.64
2	880.00	107.00	104.71	2.14	69.09	66.09	107.15	102.33	4.82k	-20.29
3	900.00	160.00	158.49	0.94	35.68	32.68	162.18	154.88	7.30k	-20.08

4	910.00	256.00	257.04	-0.41	25.58	22.58	263.03	245.47	17.56k	-20.10
5	920.00	320.00	316.23	1.18	21.33	18.33	323.59	296.03	27.56k	-20.10
6	930.00	465.00	457.09	1.73	14.66	11.66	478.63	436.52	42.11k	-20.66
7	940.00	640.00	630.96	1.41	11.98	8.98	676.08	575.44	100.64k	-20.84

RESULT AND DISCUSSION

We have designed a second order Active-RC band pass filter using the composite operational amplifier at ultra-high frequency to reject frequencies outside the band and pass frequencies within the backscatter frequency (i.e. 40 kHz-640 kHz) band.

The calculated and preferred resistor values used in the design of the filter is shown in Table 1 and the results of the output response are shown in Table 2. The Magnitude frequency response curves are shown in Figures 2 to 8. The result shows that the centre frequencies of the filters are all shifted sightly. This shift, for all the centre frequencies are within a range of ±0.41% to ±2.14%, which is well accepted for use in the UHF RFID band. Thus, according to the EPC class 1 Gen.2 protocol for UHF RFID usage specifies that, deviations should not be outside ± 22%.

The Midband gain of the filter is seen to decrease from a value of f_o = 40kHz at 148.89dB to 11.98dB at 640kHz. This result also confirms filter theory that, when centre frequency of filter increase, the mid band gain decreases (Atsuwe, 2018; Atsuwe, et al. 2021).

The roll-off from f_o= 40kHz approaches 21.64dB/decade showing a single pole, second order filter which is used for the design of this filter. The roll off rate for all the centre frequencies also approaches a single pole, second order filter as shown in Table 2. This also confirms filter theory.

The bandwidth of the filter increases from a centre frequency of f_o = 40kHz at 950Hz to f_o = 640kHz at 100.64kHz, showing an extended bandwidth of the filter which is one of the advantages of the composite operational amplifier. This also confirms filter theory that as centre frequency of filters increase, bandwidth also increase (Atsuwe, 2018; Atsuwe, et al. 2021).

The designed filter also exhibited low stability and was not sensitive to components in the circuit.

Therefore the deigned circuit can be said to function properly by rejecting all other frequencies outside the UHF RFID band and only passed the backscattered frequencies from 40 kHz to 640 kHz without degradation.

CONCLUSION

The second-order Active band pass filter using composite operational amplifier has been designed, simulated and presented. From the output results shown in Table 2, the filter was found to conform to all the desired parameters of decreased mid band gain, increase bandwidth and roll-off rate that approached a single pole, second order filter. Furthermore, the shift in frequencies could be attributed to the values of the resistors which are not exact and also due to parasitic effect experienced. Therefore, it can be concluded that the filter functioned according to specification and can be used in the UHF RFID system.

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