A Novel Approach to Integrating Communication and Technical Skills Creating a Seamless Transition into Today's State of the Art Engineering Technology Industrial Environment

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Abstract - Today's engineering professionals are faced with many technical challenges. It can be agreed that the majority of colleges and universities across the country do an excellent job of educating our engineering and engineering technology students. However, not all technically competent students are taught the *art* of verbal and written communication correctly. Yes, there are courses that attempt to instill these techniques into the student, but are students really getting the point? In fact, are the teachers who are teaching technical communications to these students providing adequate examples and demonstrating proper technique that specifically focuses on the student's future job market? From personal experience, it seems that only the very top students seem to be adequately prepared in this area. What about the rest? These folks seem to be falling behind the learning curve. This situation may take some time for these students to recover from. In industry, time is money. Only those students who have been prepared properly will advance quickly in an engineering environment. What can be done about this, if anything? The answer lies in a very simple concept – adequate practice and sufficient tools. Students must be prepared by being able to present technical ideas in professionally written and verbal formats. In order to do so, appropriate software tools of the trade must be mastered and practiced by the student to be successful. This paper chronicles the creation of a course that requires students to apply these software tools in a real industrially oriented venue. Software tools are discussed and examples shown. Students, currently working in industry, who have been exposed to this type of learning experience, in similar course venues, provide insight into the importance of such a course venue. An example of a project completed by a recent graduate is given to support this thesis.

Foundational Needs

Students, at all levels, acquire concepts more easily by putting in a sufficient amount of time in the art of practice. This idea may seem trivial, but many experts have said that continued practice is a major contributor to being successful in any field. Students can be made proficient in this art if they are required to present technical ideas in professionally prepared reports.

Industrial experience has proven that communication skills will be the largest contributor to enhancing a student's technical career and advancement. Instilling this concept into students early on should be a top priority. In order for students to prepare properly written materials, they must have the appropriate tools to do so, be instructed on the operation and application of these tools, and be given the chance to practice.

The Venue

Several years back a need existed in the School of Engineering Technology at Northeastern University for the development of several technical elective courses within the Electrical

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Engineering Technology (EET) and Computer Engineering Technology (CET) departments. One of the courses that was developed is called *Analog Circuit Computer Simulation*. The idea was simple - create a course that utilized knowledge gained from prior courses and put this to work in a *practice-application* scenario. The practice-application scenario “venue” was to simulate an actual industry forum. That is, students were treated as design engineers who would report to an engineering manager (the instructor) and given weekly design assignments. At the end of each week, each student must provide a full-blown design in the form of a complete professional report containing the following items:

- Professional and Relevant Report Cover
- Table of Contents
- Introduction
- Design Criteria
- Methodology
- Design Equations
- Signal Flowgraphs
- Schematics and Diagrams as necessary
- Circuit Responses
- Summary or Conclusion

Additionally, other pictorially descriptive materials that the *student designer* deems necessary to get the point across to the reader should also be included. This report must be grammatically correct and organized as professionally as possible. These reports were not meant to be the quick and dirty *physics laboratory reports* of old, but rather state-of-the-art professional documents.

Students must also produce a PowerPoint presentation and present it in front of their engineering peers (classmates). This may also seem trivial for those academics reading this article, but it is really a traumatic experience for those students who take this stuff seriously. None of them want to make any mistakes as competition and intensity runs high during presentations. However, they are told that this is the *proving ground* for honing their communication skills and there is no such thing as a perfect report or presentation. That is something they must continue to strive for.

The presenter’s reviewers consist of the presenter’s fellow students and the course instructor. It does not take long for students to comprehend what is right and what is wrong, as extreme enthusiasm reigns supreme during weekly presentation periods. As the term moves forward, reports and presentations can easily be seen to evolve in the direction of professionalism. It is a real metamorphosis that would excite the most mundane educator. It is obvious that front line practice can really make the difference in the quality of production and professionalism in a student’s technical growth.

The Tools

Each student is required to utilize a host of software tools to aid in their creation of a report and presentation that is to be considered professional. Among these tools are:

- **Microsoft Word©** – This is the primary writing tool of choice. Students, by the time they get to this advanced class, will have had a great deal of experience in the mechanics of using this product. There are some technical elements that they may not be familiar with as a freshmen course in "Word" usually includes only the basics. Among these more advanced items, for example, is the "equation editor." This item is important, as students must be able to reproduce equations that are used in the design of their projects. Remember, these reports and presentations are to be nothing less then professional works. This means that they must look professional and be photo-ready to be published if necessary.

- **MultiSim©** – This is an excellent tool for assisting students with their actual designs – especially in EET programs. MultiSim© is a multifaceted software program designed to allow designers to construct, in virtual space, analog and or digital circuits and simulate their response behavior. It also allows the user to observe and measure various circuit parameters via a host of "virtual instruments." Students are required to "paper design" their projects and then prepare a MultiSim© computer simulation of that design. This computer simulation tool is initially used to verify the students' preliminary paper designs. In other words, will their application of equations and theory, as acquired in class lectures and associated laboratories actually lead to a workable piece of hardware? Students quickly learn that it is a lot easier to move a wire or change a component when they are in a virtual design space.

  One of the great advantages and features of MultiSim© is its ability to allow the user to capture its graphics. A major strength of a professional report is the visual presented to the reader. It is true that "one picture is worth a thousand equations."[1] Just take a look at a bridge or large building the next time you pass one. Each of these represents literally thousands of complex equations of which you are viewing the results. Among MultiSim©'s capture capabilities is its ability to capture a schematic under design, in addition to capturing a whole host of responses such as *transient*, *AC*, *DC sweep*, etc. Its complement of virtual instruments is also one of its robust assets. Students can also capture the faces of instruments and place then in their reports providing unsurpassed realism. This allows the reader to see first hand the particular measurement being used. There is nothing like reading a technical report that presents material in a realistic manner. MultiSim© contributes to this superbly.

- **PowerPoint©** – This is the presentation tool of choice. Students are required to present their reports in summary form via a PowerPoint© presentation. Integrating the <u>three pieces of software</u> mentioned is ideal as each is Microsoft Windows© compatible. Being such, text, photos, diagrams and the like can be *copied* from and *pasted* into one another with relative ease. Students creating PowerPoint© presentations as companion materials get to practice two important items via PowerPoint©.

  - Artistic ability
  - Presentation worthiness

This allows the students to not only present their own ideas on their own weekly design projects, but allows them to see first hand the ideas of others. This seems to make for an ideal learning environment in that students can garner the pros and cons from fellow student's presentations and use this to their advantage. Often, it is not enough for an instructor to criticize a student's work, as that student may shrug off the instructor's comments. But, the comments of a peer are taken and viewed by the student in a much different light. Students by nature, especially engineering students, are very competitive. Being such, each is always trying to out do the other. There is a great advantage in this, as there seems to be some "natural" positive momentum at work by unintentionally forcing the student to be better at what they do by virtue of peer pressure.

Others have seen the importance of good communication skills by using Multimedia to enhance the teaching environment.[1,2,3,4,5,6,7] All seem to come to the same conclusion. Students seem to learn more by using such tools. This is demonstrated by their ability to present presentation packages that are extremely mature.

Former Student Speaks Out

Having taught this course over the past several years has allowed one of the authors to gain precious insight into whether the course itself is fulfilling its initial goal – that of preparing students for a seamless transition into the real world of engineering. Having interviewed many graduates a year after their graduation and well into their engineering job careers, it was clear that these students all agreed that being given the opportunity to create and write in this forum gave them a serious leg up on other peer co-workers who had not had this opportunity at their own schools. One such comment came from a former student, who had made an unannounced classroom visit, stated the following to the students in that particular class.

> "……….I must admit that I was pretty upset over the prospect of writing weekly reports that were 40 to 60 pages long. I now realize that if it were not for that practice, I would really be behind the eight ball in my current job. A good deal of what I do requires communications with others, co-workers, outside vendors, corporate management, and of course most importantly – our customers. So pay attention and create the best you can. You are not wasting you time, quite the opposite."
>
> Alan Lau, *Test Engineer*
> *(2002 Graduate – Electrical Engineering Technology, Northeastern University)*
> Ionics Corporation
> Watertown, Massachusetts

A Typical Project

An example project can be found in the appendix A of this paper. It is an example of a project that was assigned to the students in the "Analog Circuit Computer Simulation" EET U511 course in the Spring Session of this past year. This report is self-explanatory in that it contains all of the elements of a professionally developed report. Of course, as stated earlier, there is no such thing as a perfect report. But the one given in the appendix is none the less exceptional and a good example of what can be expected of a good undergraduate technical report when using the correct writing tools.

Summary

As one can imagine, a great deal of work goes into such student reports. Once the students get used to this type of technical "grind," they will have made the first great transition into the realm of "real" engineering and be able to seamlessly transition into that profession without great fanfare, but with great promise. From experience, students seem to complain a great deal about the time required to perform such weekly feats. However, when all is said and done, they all without exception, affirm the need for such a course with rigorous requirements such as these. Many students have passed through these courses to date and all, in the final analysis, concur that this part of their learning experience was most valuable. Without appropriate communication skills, we might as well be trees blowing in the wind.

Conclusion and Recommendation

The idea of seamless integration from an academic undergraduate environment to the world of industry is a large leap that should not be underestimated. The more diverse we as academicians make it for our students, by providing an environment as close as possible to industry, the better off they will be. By creating an environment of professionalism that emulates industry, students will assimilate more easily to that environment. By providing a venue that allows them to practice ideas and concepts first hand will no doubt give these students a leg up on their academic counterparts from other institutions. This idea is great in concept. However, it is inevitable that academic inertial progress seems to always move forward. If what is proposed here is followed, all students, down the road, will be equal in this seamless transition. That is a good thing!

Although it may in fact be a great deal of work to require students to follow this prescription, the positive seems to outweigh the negative. The amount of work required by the student is a small price to pay for a seamless foot in the door to industry. Grading such lengthy reports does take a considerable amount of time. To be successful, this time needs to be found. This would be a good time to give it a try, even in some modified form.

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Appendix A

Student Report Example

The authors gratefully acknowledge Mr. Nick Saflund for allowing the reprinting of his report in this paper. Mr Saflund is now attending Officer training and associated training in the United States Nuclear Navy program

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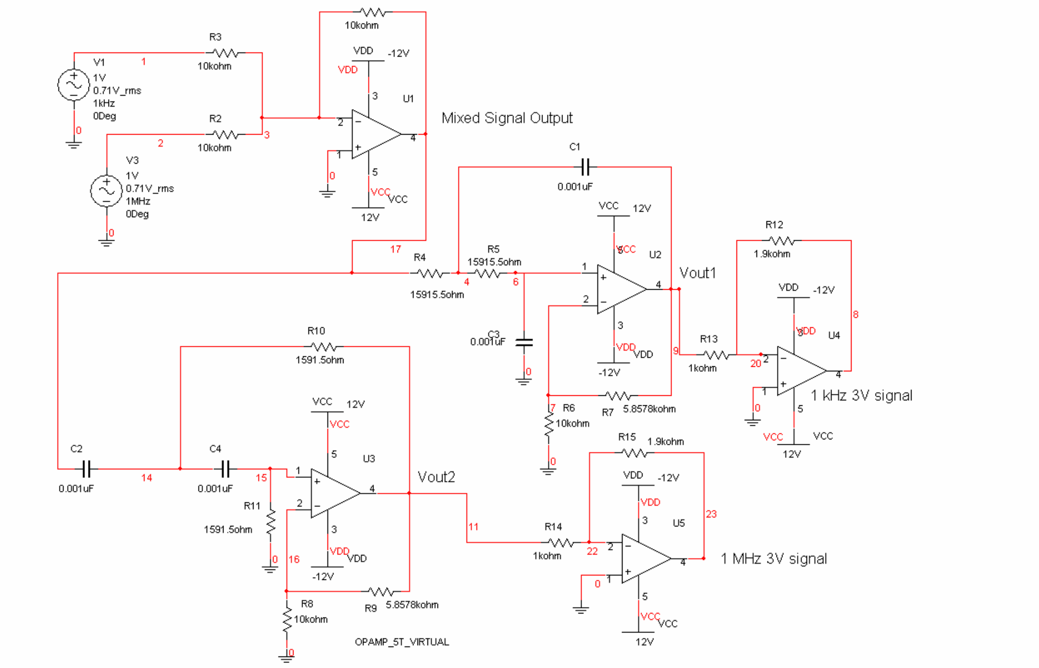

Final Project Report

Submitted by:

Nicholas E. Saflund

June 3, 2003

EET U566 Analog Circuit Simulation
Professor: J. Tapper

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Table of Contents

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Introduction

This is our 7th and final simulation report for Professor J. Tapper's Analog Circuit Simulation class. This project requires us to use many of the skills we learned throughout the class and combine them to create a fully functioning signal separation circuit using MultiSim2001. We are also required to create the input stage ourselves by mixing two sinusoidal signals and using the output of this circuit as the input to the signal separator.

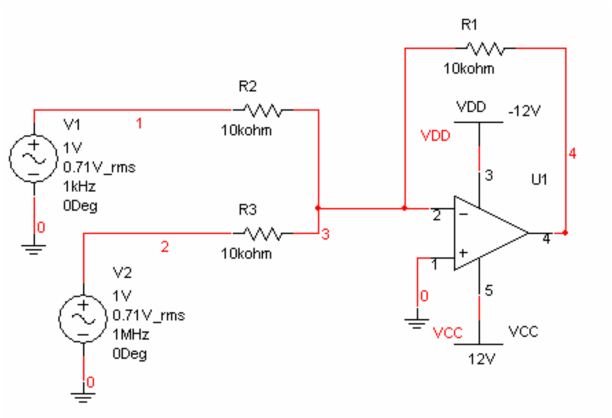
In order to add two sinusoidal signals, we used an analog summing circuit. This circuit, through the use of an Op-Amp in the inverting configuration, allowed us to arithmetically add the driving 1 KHz and 1 MHz signals, both with amplitudes of 1 volt. We will show graphs of the driving signals along with the mixed signal.

The next step was to separate these signals. To do this, we used two Sallen and Key Filters set up as 2nd order Butterworth filters. By connecting a high pass filter and a low pass filter in parallel, we can drive them with the same source. The Low pass filter will be used to isolate the 1 KHz signal component and the high pass filter will be used to isolate the 1 MHz signal component.

We will derive the transfer functions for this circuit so that values can be changed to accommodate different design specifications. We will also show graphs of mixed and isolated signals as measured by MultiSim2001. We will also include graphs of the frequency response of the filter portions of the circuit.

The Analog Summing Circuit

We began our design for this project with the analog summing portion of the circuit. This was necessary because we needed the mixed signal to see of the other portions of the circuit were functioning correctly. The basic topology for an analog summing circuit is an inverting Op-Amp with a gain of 1. However, we will drive the input of the circuit with signals equal in amplitude but with different frequencies. This circuit we used is shown below.



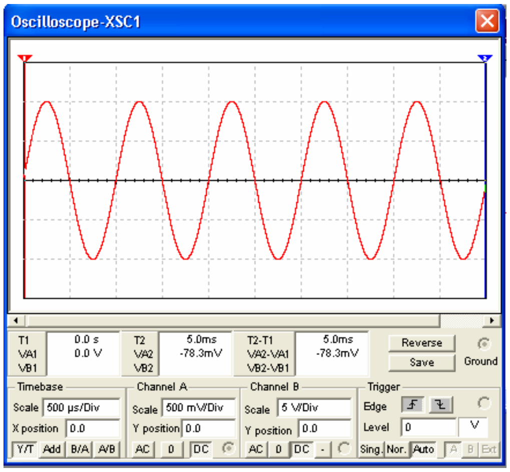
As we know, the formula for the gain of an inverting Op-Amp topology is...

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

By employing the technique of superposition, we can see very clearly how this circuit adds the two input signals. In superposition, we short all other voltage sources to see the effect of one source at a time and then add the effects together. When we short V2 to see the effect of V1, we can see the no current will flow through R3 because node 2 has virtually the same voltage potential as ground. Shorting the voltage source attaches both ends of the resistor to the same voltage potential causing there to be no current in the resistor. With no current flowing in R3, we can see that the Op-Amp circuit acts as a unity gain buffer. The only difference between V1 and V1's effect on the output is a 180-degree phase shift caused by the topology.

The same procedure can be done for V2. You will find that V2's effect on the output is simply V2 with a 180-degree phase shift. The result when you add these two signals at the output is the arithmetic addition of the two sinusoids. The two original signals and the resulting mixed signal are shown below.

V1



T1 0.0 s
VA1 0.0 V
VB1
T2 5.0ms
VA2 -78.3mV
VB2
T2-T1 5.0ms
VA2-VA1 -78.3mV
VB2-VB1

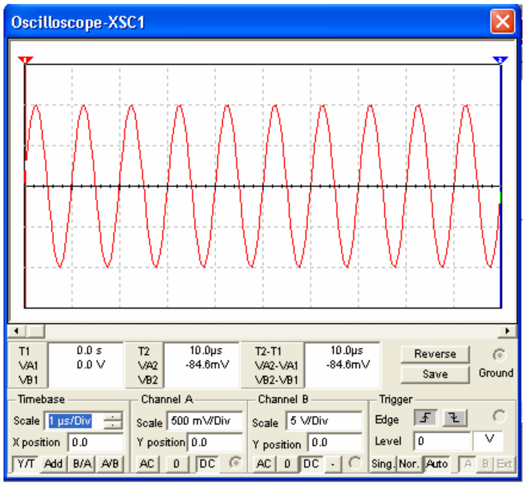
Timebase
Scale 500 µs/Div
X position 0.0

Channel A
Scale 500 mV/Div
Y position 0.0

Channel B
Scale 5 V/Div
Y position 0.0

Trigger
Level 0 V

V2



T1 0.0 s
VA1 0.0 V
VB1
T2 10.0µs
VA2 -84.6mV
VB2
T2-T1 10.0µs
VA2-VA1 -84.6mV
VB2-VB1

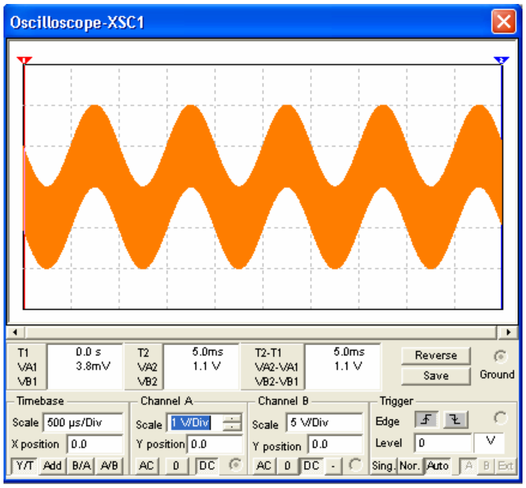
Timebase
Scale 1 µs/Div
X position 0.0

Channel A
Scale 500 mV/Div
Y position 0.0

Channel B
Scale 5 V/Div
Y position 0.0

Trigger
Level 0 V

Mixed



T1 0.0 s
VA1 3.8mV
VB1
T2 5.0ms
VA2 1.1 V
VB2
T2-T1 5.0ms
VA2-VA1 1.1 V
VB2-VB1

Timebase
Scale 500 µs/Div
X position 0.0

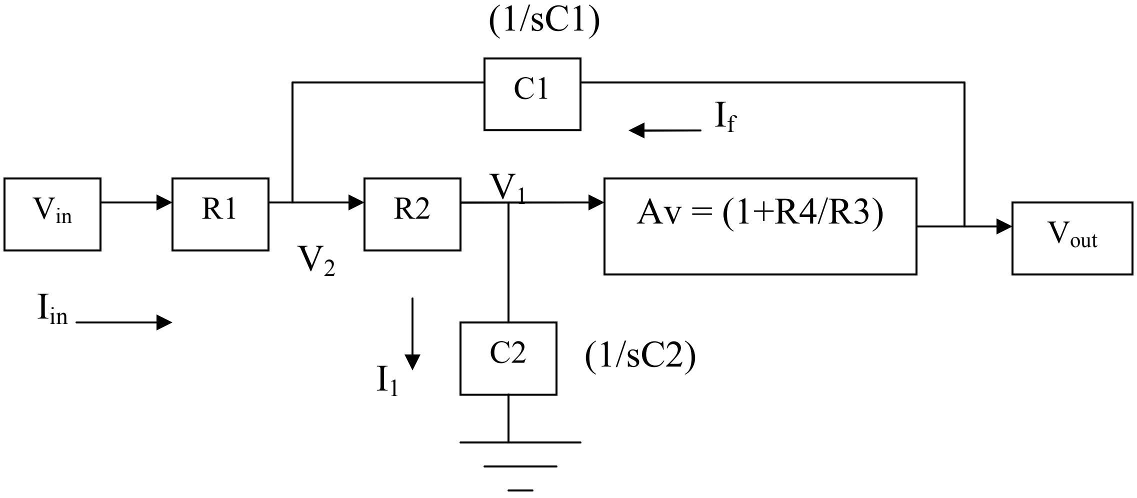
Channel A
Scale 1 V/Div
Y position 0.0

Channel B
Scale 5 V/Div
Y position 0.0

Trigger
Level 0 V

The Sallen and Key Low Pass Filter Topology

The Sallen and Key topology utilizes a second order quadratic denominator in the transfer function to create an active filter that will have a predictable cutoff frequency and a roll off slope of -40bB per decade for a low pass set up. The low pass filter function block diagram is shown below. Several variables have also been introduced to help in generating the defining equations.



The following equations are the defining equations for the Sallen and Key low pass filter pictured above.

1. $V_{out} = V_1 A_v$
2. $V_1 = I_1\left(\frac{1}{sC_2}\right)$
3. $I_1 = \dfrac{V_2}{R_2 + \dfrac{1}{sC_2}}$
4. $V_2 = V_{in} - I_{in}R1$
5. $I_{in} = I_1 - I_f$
6. $I_f = \dfrac{V_{out} - V_2}{\dfrac{1}{sC_1}}$

Using these defining equations, we can now draw the Mason Flow Graph (pictured below). The Mason Flow Graph will let us write down the transfer function for the Sallen and Key low pass filter.

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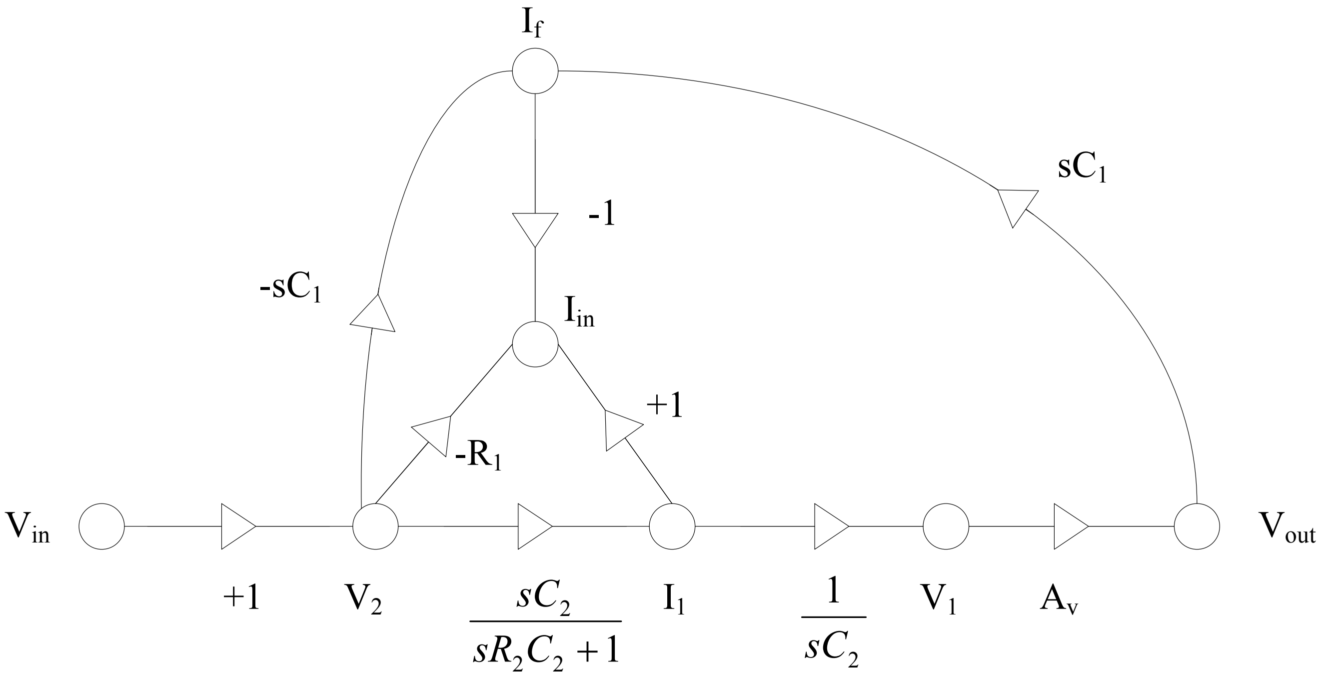

Using the rules for generating the Transfer Function H(s) from the Mason Flow Graph, we can write down the transfer function.

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{A_v}{s^2 R_1 R_2 C_1 C_2 + s\left[C_1\left(R_1 + R_2\right) + R_1 C_1\left(1 - A_v\right)\right] + 1} \qquad \text{(Eq. 1)}$$

where $A_v = 1 + \frac{R_4}{R_3}$

We have determined that A_v is equal to 1 + $\frac{R_4}{R_3}$ because we are using the non-inverting Op-Amp topology. The schematic for the full circuit is shown. As we already know, the gain for a non-inverting Op-Amp is 1 + $\frac{R_4}{R_3}$.

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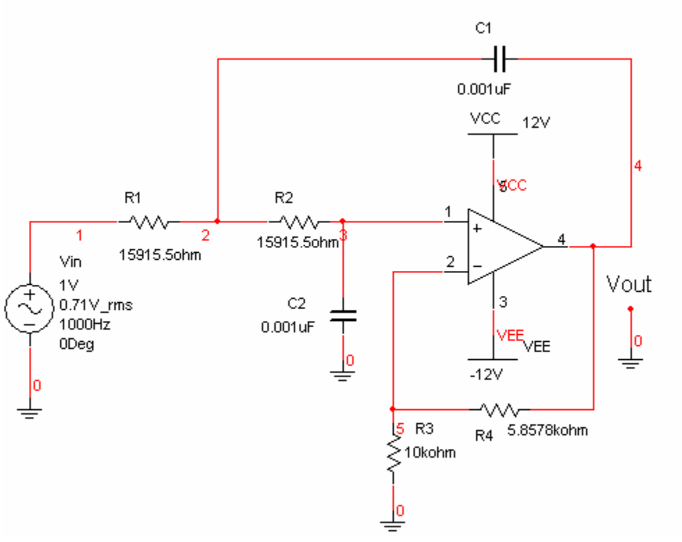


In order to determine what the values for the passive components in this filter should be, we have to examine the general 2nd order denominator for the Low Pass transfer function. The General 2nd order transfer function is shown below.

$$H(s) = \frac{K}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

In the general equation, K is the shift constant and ω_n is the -3dB cutoff frequency. By doing some algebraic manipulations, we can rewrite the transfer function we developed for the low pass filter in Eq. 1 to better fit the general form. The resulting transfer function is as follows...

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{\dfrac{A_v}{R_1 R_2 C_1 C_2}}{s^2 + s\dfrac{\left[C_1\left(R_1 + R_2\right) + R_1 C_1\left(1 - A_v\right)\right]}{R_1 R_2 C_1 C_2} + \dfrac{1}{R_1 R_2 C_1 C_2}} \qquad \text{(Eq. 2)}$$

By manipulating the transfer function to better fit the form of the general 2nd order equation, we can generate equations for the shift constant and the -3dB cutoff frequency.

$$K = \frac{A_v}{R_1 R_2 C_1 C_2} \qquad \text{(Eq. 3)} \qquad\qquad \omega_n^2 = \frac{1}{R_1 R_2 C_1 C_2} \qquad \text{(Eq. 4)}$$

$$2\zeta\omega_n = \frac{\left[C_1(R_1 + R_2) + R_1 C_1(1 - A_v)\right]}{R_1 R_2 C_1 C_2} \qquad \text{(Eq. 5)}$$

These equations make it possible to find equations for K and ω_n that will be in terms of R's and C's. Before we manipulate these equations to be more useful, we can make a decision that will simplify the algebra involved. If we have control over the values of R's and C's, we can decide now that the R's will be equal in value and the C's will also be equal in value. This means...

$$R_1 = R_2 = R$$

AND

$$C_1 = C_2 = C$$

By forcing the values of R to be equal and the values of C to be equal, we can further simplify the equations for K and $\omega_{n.}$ For example, Eq. 3 can be simplified to

$$\omega_n = \sqrt{\frac{1}{(RC)^2}} = \frac{1}{RC} \qquad \text{(Eq. 6)}$$

By using Eq. 6, we can now determine the -3db cutoff frequency for the filter. In order to determine what the gain needs to be, we must introduce another variable.

If we say that $Q = \dfrac{1}{2\zeta}$

We can use Eq. 2 to determine that $Q = \dfrac{\omega_n R_1 R_2 C_1 C_2}{C_1(R_1 + R_2) + R_1 C_1 (1 - A_v)}$

By continuing with out condition that the R's are equal and the C's are equal, we can reduce that equation to the following...

$$Q = \frac{\omega_n (RC)^2}{2RC + RC(1 - A_v)} = \frac{RC}{RC(2 + 1 - A_v)} = \frac{1}{3 - A_v}$$

This reduction tells us something very important about the gain of the Sallen and Key low pass filter. The gain cannot be larger than 3 because the transfer function would have a pole in right half plane of the complex coordinate plane indicating unstable behavior of the filter. Actually, in order to ensure that the roots of the denominator remain in the negative real axis region, the following condition for Q must be met.

$$Q = \frac{1}{2\zeta} = \frac{1}{\sqrt{2}} = \frac{1}{3 - A_v}$$

This means that the gain we can expect from our low pass filter is as follows...

$$A_v = 3 - \sqrt{2} = 1.58578$$

The Sallen and Key Low Pass Filter Design for Specification and Circuit Behavior

As we discussed in the explanation of the Sallen and Key Low Pass Filter Topology section, by making some simple assumptions we have generated simple algebraic expression that will allow us to predict the -3dB cutoff frequency. We must chose a cutoff frequency that will pass the 1 kHz signal and suppress the 1 MHz signal by at least -40 dB. To do this, we choose a 10 kHz cutoff frequency. As we know, the low pass filter circuit module will control this aspect of the design. To find the values of R and C that will create a -3dB cutoff frequency at 500 KHz, we will apply the equation we generated in the previous section.

$$\omega_n = 2\pi f = 2\pi(10000) = 62831.85307$$

$$\omega_n = \sqrt{\frac{1}{(RC)^2}} = \frac{1}{RC}$$

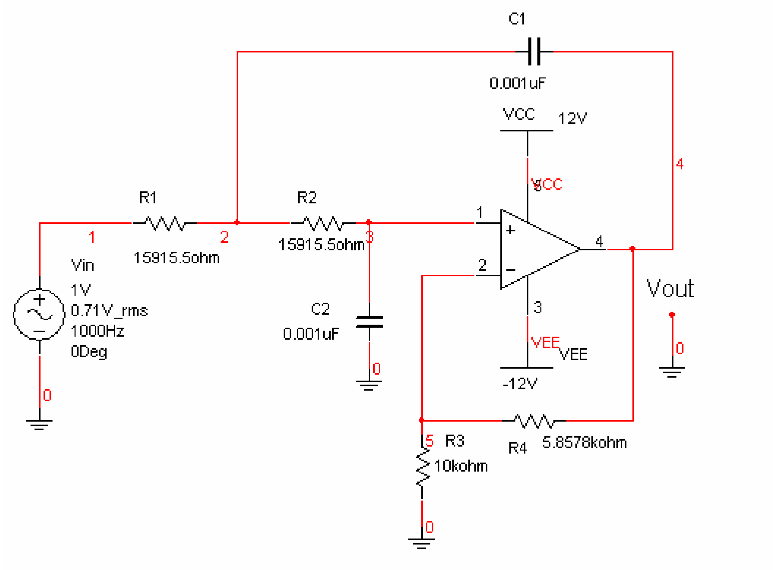
If we make

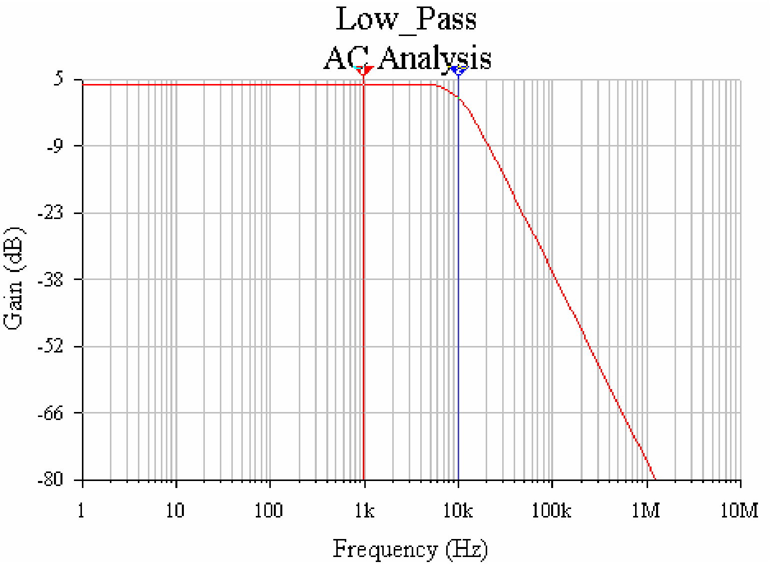
$$C = .001\mu F$$

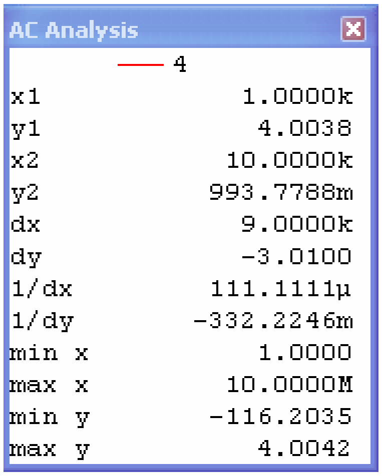
then,

$$R = \frac{1}{\omega_n C} = \frac{1}{(62831.85307)(.001\times10^{-6})} = 15915.5\Omega$$

The circuit with the correct values to accomplish project specifications is shown on the following page with a graph of the frequency response. You will see the frequency response has a -3 dB cutoff frequency at 10 KHz and a pass band gain of 4.004 dB. Also, the 1 MHZ signal we need to suppress is attenuated well-passed -40 dB



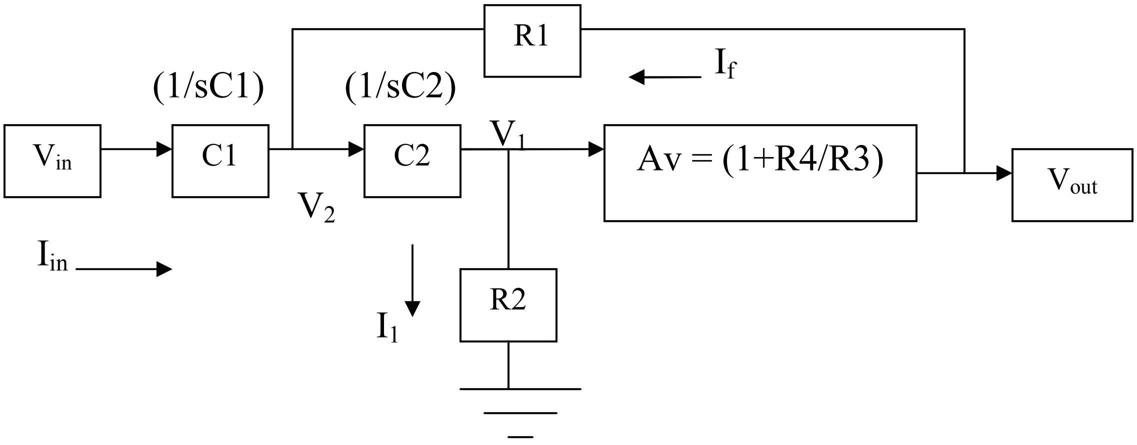




```
          4
x1          1.0000k
y1           4.0038
x2         10.0000k
y2        993.7788m
dx          9.0000k
dy          -3.0100
1/dx      111.1111µ
1/dy     -332.2246m
min x        1.0000
max x      10.0000M
min y     -116.2035
max y        4.0042
```

The Sallen and Key High Pass Filter Topology

As the second filter circuit module of the project we are designing, we must build an active high pass filter using the Sallen and key topology. You will find that the function block diagram for the circuit is the same except the R's and C's have switched places.



As we did for the low pass filter, we introduced variables that will be used in the defining equations for the circuit that follow.

1. $V_{out} = V_1 A_v$
2. $V_1 = I_1 R_2$
3. $V_2 = V_{in} - I_{in}\left(\frac{1}{sC_1}\right)$
4. $I_1 = \dfrac{V_2}{R_2 + \dfrac{1}{sC_2}}$
5. $I_{in} = I_1 - I_f$
6. $I_f = \dfrac{V_{out} - V_2}{R_1}$

Remember, because we are using a non-inverting topology,

$$A_{v1} = 1 + \frac{R_4}{R_3}$$

From these defining equations, we can construct the Mason Flow Graph, which will facilitate the generation of the transfer function.

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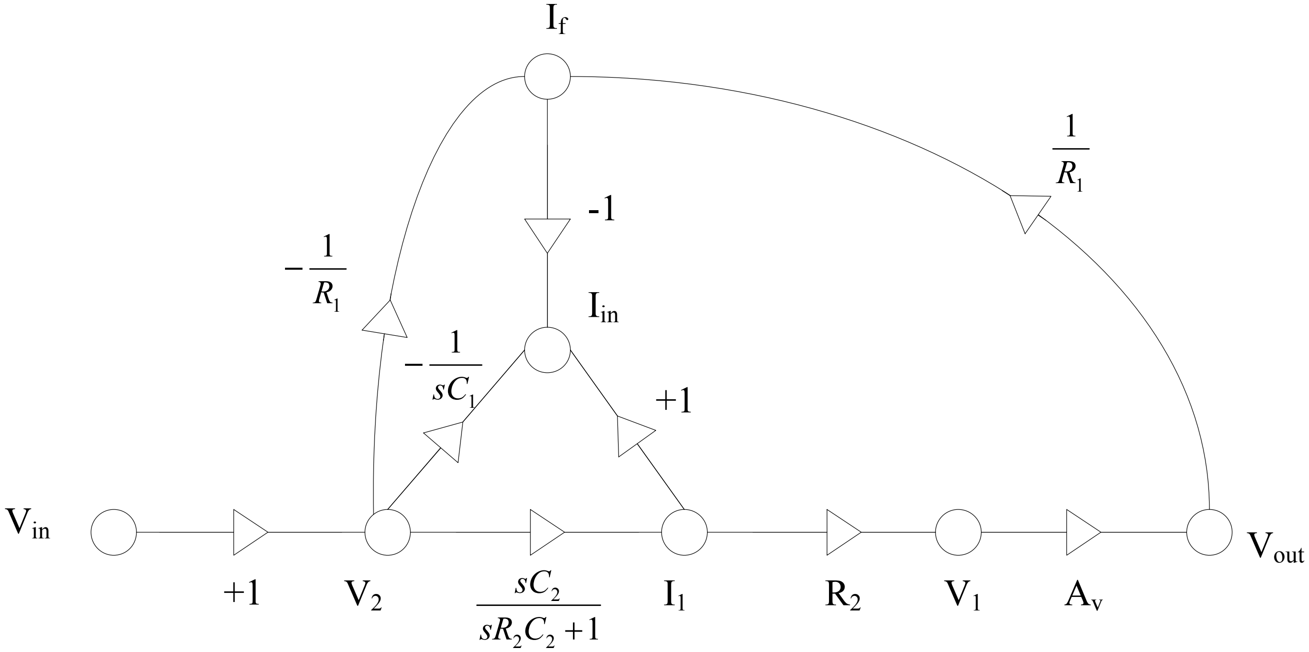


From this Mason Flow graph, we can write down the transfer function for the Sallen and key active high pass filter.

7. $$H(s)=\frac{V_{out}}{V_{in}}=\frac{s^2R_1R_2C_1C_2A_v}{s^2R_1R_2C_1C_2+s\left[R_1\left(C_1+C_2\right)+R_2C_2(1-A_v)\right]+1}$$

By making $$R_1=R_2=R$$

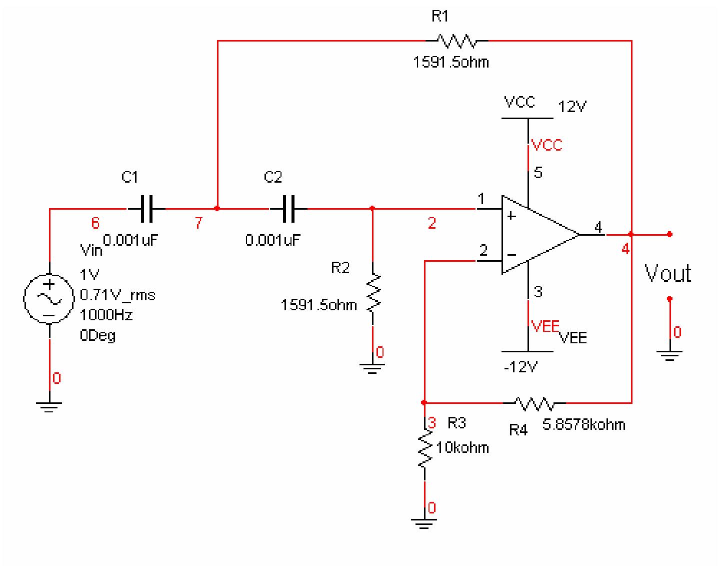
And $$C_1=C_2=C$$

and manipulating the transfer function to look like the general 2nd order transfer function, we can determine that,

So, $$\omega_n^2=\frac{1}{R_1R_2C_1C_2}=\frac{1}{(RC)^2}$$

$$\omega_n=\sqrt{\frac{1}{R_1R_2C_1C_2}}=\frac{1}{RC}$$

As we made the same assumptions to be able to simplify the transfer function and be able to develop an equation that will allow us to predict ω_n, we will expect the same limitations on gain to be present. The schematic for the high pass filter is shown below.



The Sallen and Key High Pass Filter Design for Specification and Circuit Behavior

To continue the construction of our active band pass filter using the Sallen and Key topology, we will construct the high pass filter module to behave the same as the low pass filter with the exception of a -3dB cutoff frequency of 100 kHz. This cutoff frequency was chosen to pass the 1 MHz signal and suppress the 1 KHz signal by at least -40 dB. As we determined in the previous section, we can predict the cutoff frequency with a simple algebraic expression. We will now calculate what values of R and C are needed to produce the desired results.

$$\omega_n = \sqrt{\frac{1}{(RC)^2}} = \frac{1}{RC}$$

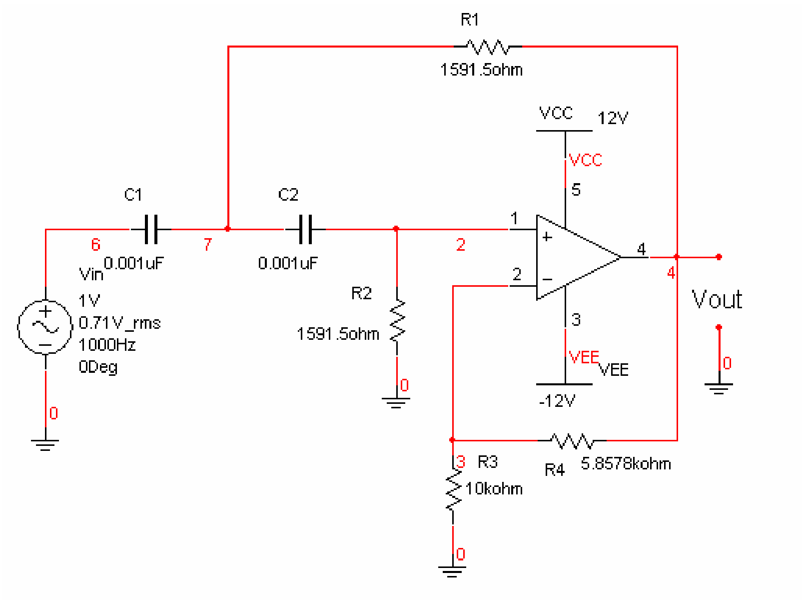
$$\omega_n = 2\pi f = 2\pi(100000) = 628318.5307$$

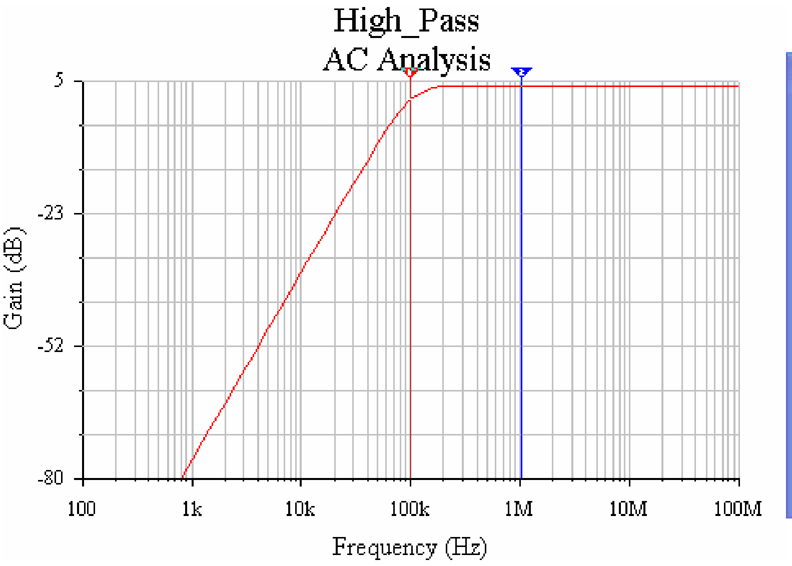
If we make $C = .001\mu F$

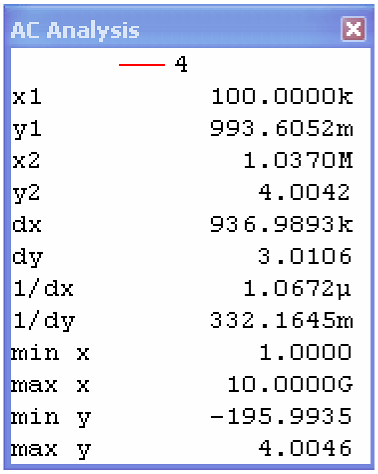
$$R = \frac{1}{\omega_n C} = \frac{1}{(628318.5307)(.001\times 10^{-6})} = 1591.5\Omega$$

$$\omega_n = 2\pi f = 2\pi(500000) = 3141592.654 Rad/\sec$$

The schematic for the Sallen and Key Active High Pass Filter with the correct values to obtain a -3dB cutoff frequency is shown below along a graph of the frequency response. You will see the frequency response has a -3 dB cutoff frequency at 100 kHz and a pass band gain of 4.004 dB. Also, the 1 KHz signal we need to suppress is attenuated well passed -40 dB



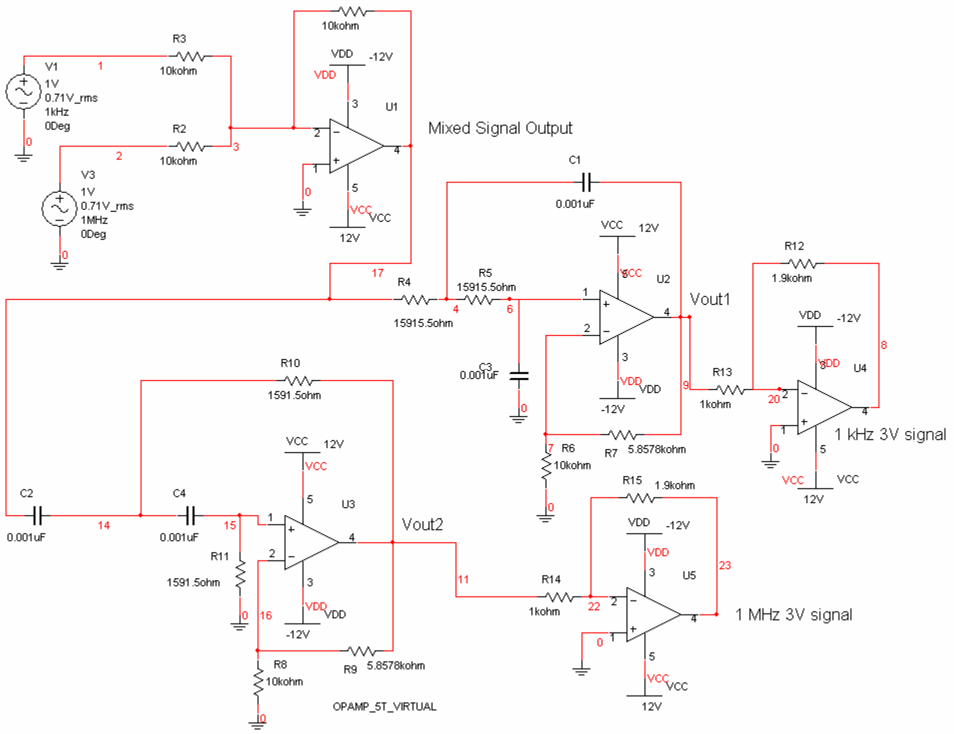




```
        4
x1          100.0000k
y1          993.6052m
x2            1.0370M
y2             4.0042
dx          936.9893k
dy             3.0106
1/dx          1.0672µ
1/dy        332.1645m
min x          1.0000
max x        10.0000G
min y       -195.9935
max y          4.0046
```

Final and Complete Circuit

By connecting the low pass and high pass Sallen and Key filters in parallel, we can separate the two signals that were added together in the analog summing circuit. We have also added inverting topology gain stages to the output of each filter to achieve the desired 3V output amplitudes for each signal. The values for R_f and R_{in} for these gain stages are set up to supplement the gain of 4.004 dB provided by the filter stages. If we need a total gain of 3 to amplify the 1 volt peak input signals to 3 volt peak signals, we need a gain in dB of 9.54 dB. We already have a gain of 4.004 dB from the gains of the filter stages. The final gain stages must have a gain of 5.538 dB. This can be accomplished with the resistor values chosen for the final stages. We will now show the final and complete circuit schematic. We will also show the signals at the output of each parallel branch of the circuit to show that this circuit design will produce the 1 KHz and 1 MHz signals separately and with 3V peak amplitudes.



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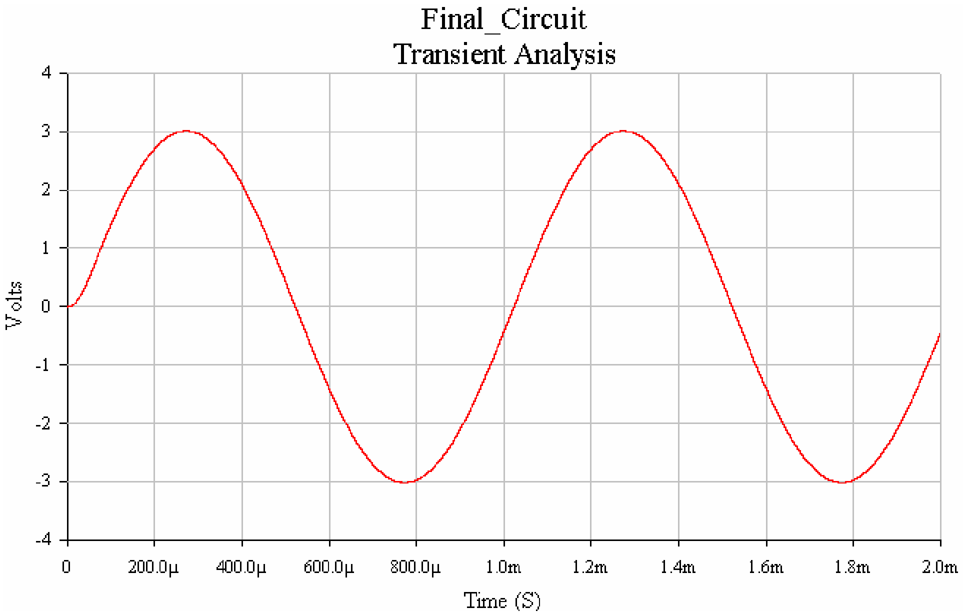
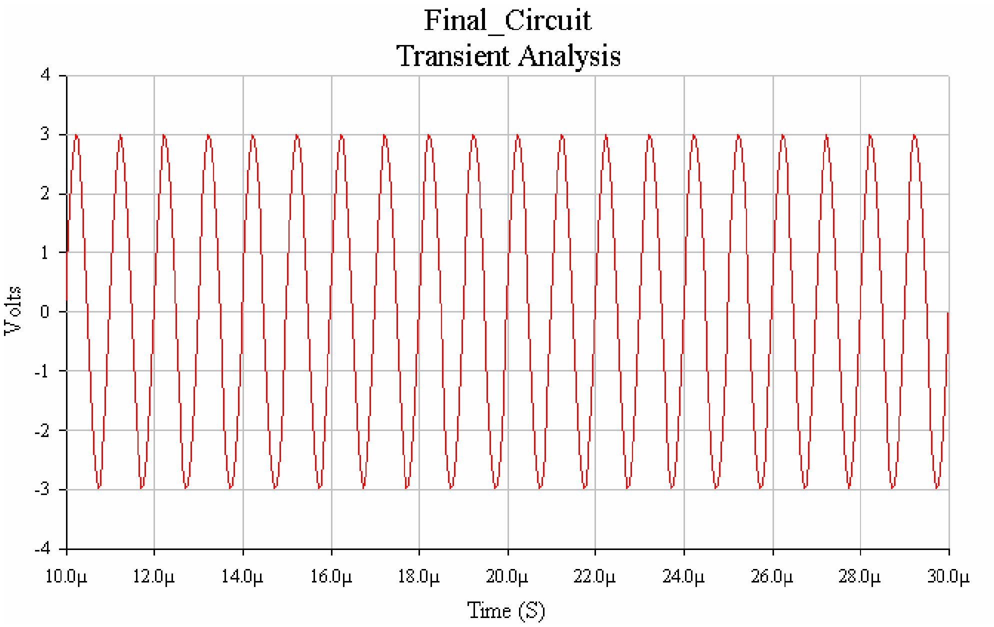
The separated 1 KHz 3V signal as measured by MultiSim2001 is shown below.



The separated 1 MHz 3V signal is shown below as measured by MulitSim2001.



Conclusion

We have successfully demonstrated how two signals can be mixed (added or summed) together and then separated. We simulated the circuit in MultiSim2001 and used both the AC analysis and Transient analysis tools to evaluate the circuit's behavior.

We mixed the 1 KHz 1V signal and the 1 MHz 1V signal using an analog summing circuit. This circuit used an Op-Amp in the inverting topology to arithmetically add the two signals. We explained the function of this circuit using the principle of superposition and demonstrated the function of the circuit using the transient analysis tool in MultiSim2001. We were able to show both input signals and the resulting mixed signal.

In order to separate these signals we connected two Sallen and Key 2nd order filters, one high pass and one low pass, in parallel. The low pass filter allowed the 1 KHz signal to pass but suppressed the 1 MHz signal. The high pass filter allowed the 1 MHz signal to pass but suppressed 1 KHz signal. We derived the general design equations for both of these filters using the *Defining Equations* and Mason Flow graphs. We then used these formulas to construct filters that would perform to fit the design requirements.

Lastly, the final amplification stages were added to each parallel path to ensure the desired output voltages would have peak amplitudes of 3V. We used Op-Amp amplifiers in the inverting topology to accomplish the necessary 1.9 gain. We have successfully fulfilled all the design requirements outlined in the final project specifications.