INSTRUMENTATION COURSEWORK

Report 1

Group Number 7
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Abstract: The first part of this report contains the initial spice exercises that were to be designed and analysed on LTSpice. The first circuit is an auto-balancing bridge. The performance of the inverting amplifier was examined using different resistor values to obtain different gain settings. The gain magnitude and phase and the real and input impedance for the various values were plotted and analysed. The second circuit is a series RLC bandpass filter. The inductance and capacitance values were varied to achieve a specific centre frequency and quality factor. The same four graphs that were plotted for the first circuit have been plotted again and analysed. The second part of this report contains the design overview of a complex impedance meter that we have designed. A detailed breakdown has been given of each part of the meter and its functionality. This designed block diagram is the future design that will be tested and implemented in the future.

Section 1 – SPICE Exercises

Part 1) A) Auto Balancing Bridge

The circuit designed in an op amp inverting amplifier. This circuit is also known as the auto-balancing bridge. To measure the characteristics of this amplifier, a freeware known as LTSpice has been used. The software can be used to design circuits and implement them and analyse with the help of different simulation settings. The inverting amplifier was implemented into a sub-circuit and the symbol was generated along with the modified netlists as seen in Figure 1.

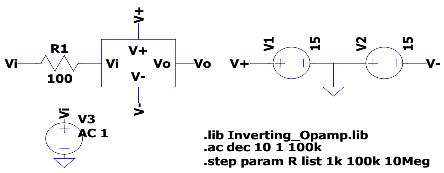

Figure 1 Schematic including directives and subcircuit

The value of R1 was fixed at 100Ω, and the value of the feedback resistor R2 was varied to achieve different gain values. The equation to calculate the R2 values is $A = -\left(\frac{R2}{R1}\right)$. The calculated R2 values obtained are 1kΩ, 100kΩ and 10MΩ for gain values of 10, 1k and 100k respectively. An AC analysis is performed as seen from the step directives in Figure 1, with the settings as decade and the starting value of 1Hz and ending value of 100kHz. The R2 is designed to be within the subcircuit, and R1 is outside the subcircuit to assist with changing the type of device to an inductor or capacitor in future steps.

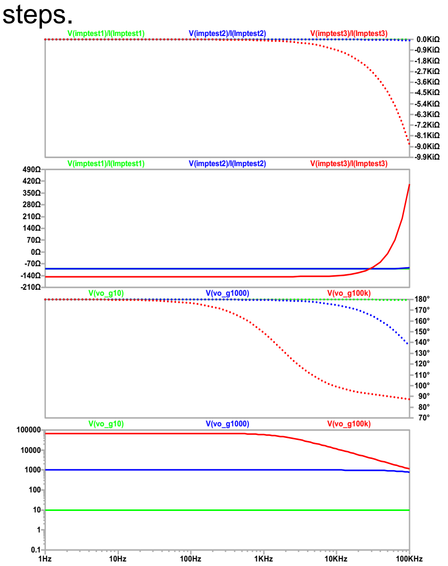

Figure 2 Plots from AC simulation

The simulation was the done and the following output graphs were obtained which contained the (bottom to top) gain magnitude, gain phase, real input impedance, and the imaginary input impedance values as shown in Figure 2. The op-amp used is a RH101A op-amp in inverting configuration and simulated through a frequency range of 1Hz to 100kHz. Following the gain equation $A = -\left(\frac{R2}{R1}\right)$ to calculate the correct resistor values, the gain of 10 and 100 represents correct magnitude at low frequencies (>100kHz), with the expected input impedance magnitudes representing '100Ω' (R1) at 1kHz for both settings. However, for the situation with high gain (100kΩ) and a 100MΩ R2 resistor, the gain is found to be below 100k (~70k), and the input impedance is at an increased ~170Ω at 1kHz. This change due to op-amp performance and high feedback resistance (in comparison to R1) that needs to be addressed in the final instrument, through methods like range resistors to achieve accurate input impedance measurements. To measure input impedance, the magnitude of impedance at a certain frequency is analysed. For input impedance magnitude, impedance is constant at frequencies below 100kHz, where the transition to a total impedance of 'R1+R2' begins. Different devices present different characteristics, however using relevant impedance/admittance equations at certain frequencies the input impedance is found. The next step was to change the R1 to different values and devices and check the performance of the auto balancing bridge. As shown in Figure 3, the value of R1 was changed to 500Ω and the simulation was run. The real input impedance value was observed to be at 500Ω as expected.

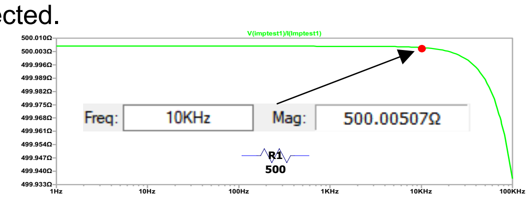

Figure 3 Real Input impedance with R1 as 500Ω

The next analysis performed was to replace R1 with a capacitor of value 0.03µF. The following equation was used to calculate the value of impedance at a specific frequency of 10kHz is $Z_C = \left(\frac{1}{2\pi f C}\right)$.

The calculated value of impedance is 530.5Ω and the simulated value obtained is 530.41Ω

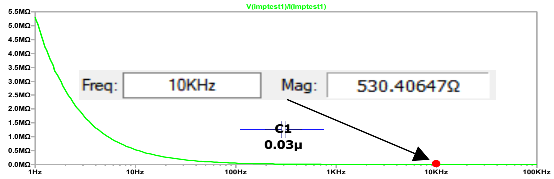

Figure 4 Input Impedance with C1 as 0.03µF

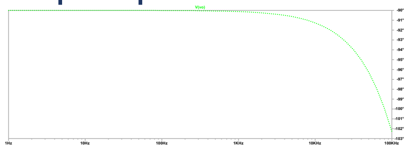

Figure 5 Gain phase with C1

As seen in Figure 5, the phase of the output voltage at lower frequencies is equal to -90degrees as expected from a C where the voltage lags the current.

The next analysis performed was replacing R1 with an inductor L1. The inductor value used was 8mH and using the equation $Z_L = 2\pi f L$ to calculate the impedance value at a specific frequency of 10kHz. The calculated value is 502.4Ω and the simulated value obtained is 502.76Ω as seen in Figure 6.

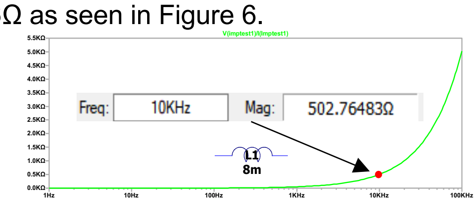

Figure 6 Input Impedance with L1 as 8mH

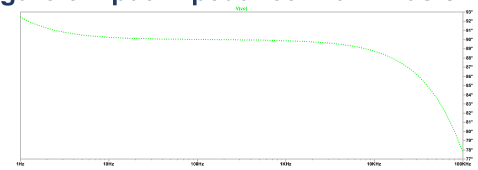

Figure 7 Gain phase with L1

As seen in Figure 7, the phase of the output voltage at lower frequencies 90degrees as expected from an inductor where voltage leads the current.

The last and final analysis performed for the auto-balancing bridge was for a series RLC circuit. The values selected are arbitrary and just for simulation purpose, the idea is to use it as an impedance measuring circuit. The R, L and C values that were chosen are of 50Ω, 8mH and 3.2µF respectively. The equation used to calculate the input impedance is $|Z_{RLC}| = \sqrt{R^2 + (2\pi f L - \frac{1}{2\pi f C})^2}$, and the measured value at a specific frequency of 10kHz is 500.19Ω. The simulated value of impedance is 500.3Ω which is close to our expected value as seen in Figure 8.

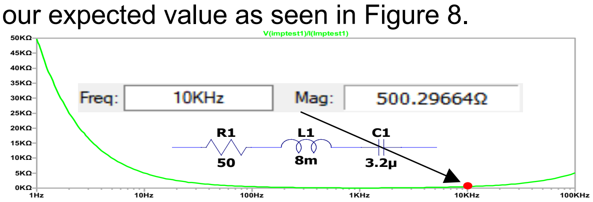

Figure 8 Input Impedance RLC series circuit

In conclusion, the auto-balancing bridge is a useful circuit that can be used to find the impedance of the device in the position of R1 as well as its phase. This is useful when trying to identify the type of device R, C or L as well as its value.

Part 1) B) RLC Bandpass Filter

The next circuit that is implemented in LTSpice is the series RLC bandpass filter. The use of a bandpass filter is to only pass the signals of the frequency within a specific band. The centre frequency is obtained by varying the R, L and C components. The equations for the bandpass filter are given below

$$w = 1/\sqrt{LC} \quad Q = wL/R$$

where w is the centre frequency and Q is the quality factor. The simulations were done on 3 sets of inputs to achieve the following cases: 1) fc = 1kHz, Q=1; 2) fc = 10kHz, Q=5; 3) fc= 100kHz, Q =10; where fc is the centre frequency. The calculated values for L and C for the three cases using the equations are 1)8mH, 3.2µF; 2)4mH, 0.064µF; 3)0.8mH, 0.0032µF respectively.

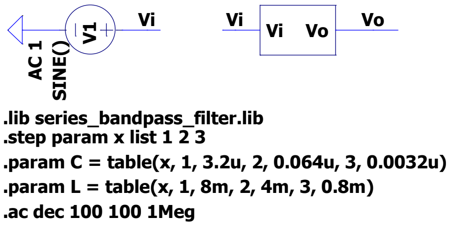

Figure 9 Schematic including subcircuit and directives

The bandpass filter was made into a subcircuit and then placed on the schematic to perform the various simulations for analysis. As shown in Figure 9, the directives for an AC simulation with settings as decade and a starting frequency of 100Hz up to a frequency of 1MHz was performed.

The simulation was done, and the following graphs were obtained (bottom to top) gain magnitude, gain phase, real input impedance and imaginary input impedance as seen in Figure 10.

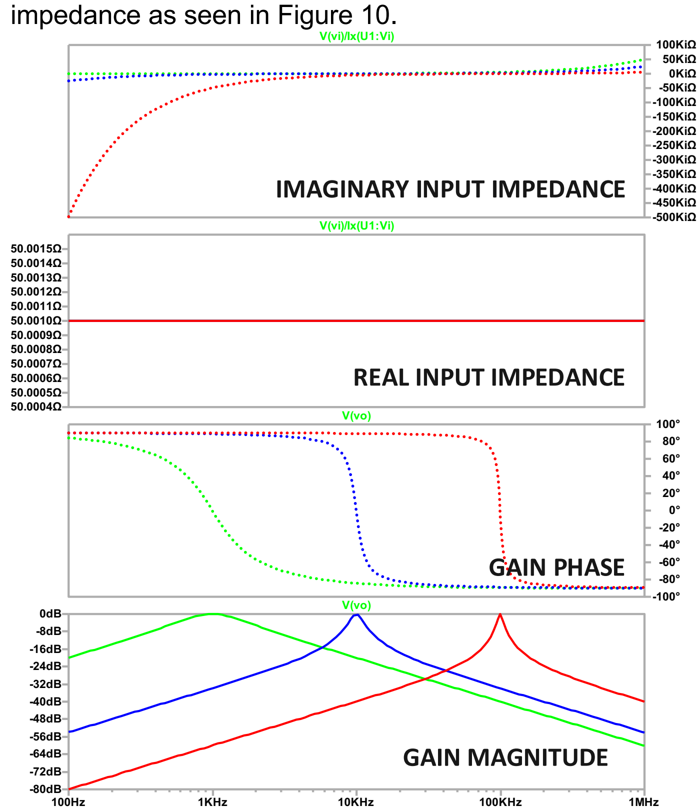

Figure 10 Plots from AC Simulation

As shown in Figure 10, the green line is for the first case in which the aim is to achieve a centre frequency of 1kHz and a quality factor of 1. Similarly, the blue line is the second case with centre frequency of 10kHz and quality factor of 5, and finally the red line is for the third case with centre frequency of 100kHz and quality factor 10. As expected, the signals are centred at their respective frequencies. The quality factors effect on the signal is also behaving as expected as it narrows down the corner frequencies which are shown by the following equations.

$$w_L = \frac{-R}{2L} + \sqrt{(\frac{R}{2L})^2 + \frac{1}{w^2}}$$

$$w_H = \frac{R}{2L} + \sqrt{(\frac{R}{2L})^2 + \frac{1}{w^2}}$$

This in turn reduces the bandwidth which is given by the following equation

$$BW = w_H - w_L$$

Another thing that can be identified from Figure10 is the real input impedance is 50Ω which is the resistance value of the RLC bandpass filter. The values for L and C will be derived from the imaginary input impedance since they are complex and vary with frequency.

$$X_L = jwL \quad X_C = \frac{1}{jwC}$$

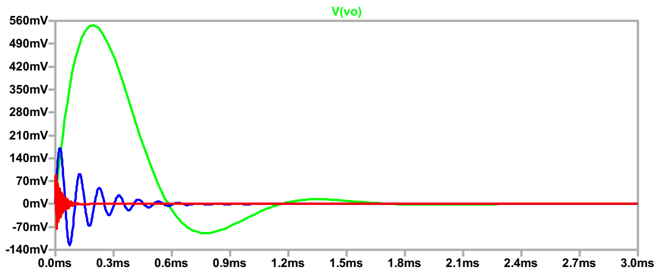

Fig 11 Step Response of Bandpass filter

In conclusion, the band pass filter can be used to pass only a certain band of frequencies, and can be easily programmed to have a specific centre frequency and quality factor. This is done by varying the values of R, L and C. The output plots show us the desired characteristics of the filter and we can infer the values of R, L and C from the real and imaginary parts of the input impedance.

Section 2 – Design Overview of Complex Impedance Meter

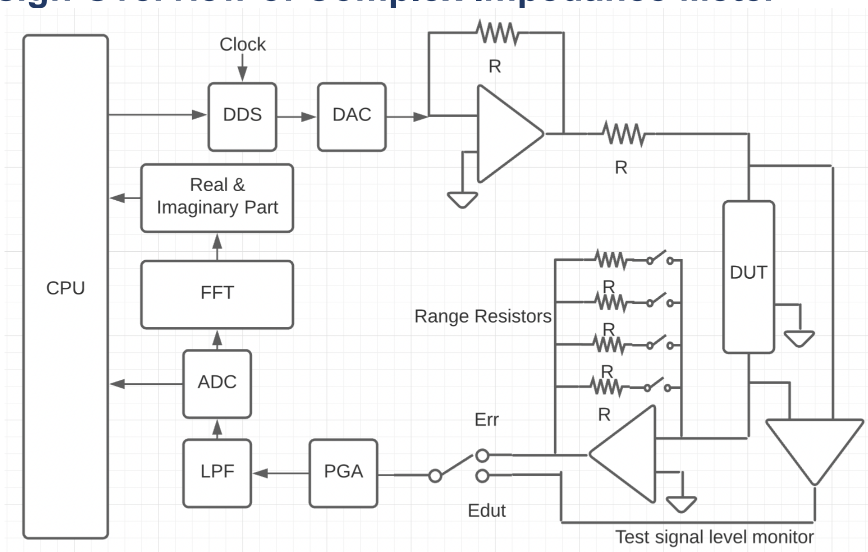

Fig 12 Block Design of Impedance Meter

This part provides the design overview and the designed system block design to implement an instrument used to measure the complex impedance. The basic principle used in the instrument is that of an auto-balancing bridge. The auto-balancing bridge has an applicable frequency range from 20Hz to 110MHz, which is within the desired measurement range from 100Hz to 100KHz. The general architecture of the auto-balancing bridge is shown in Figure 13

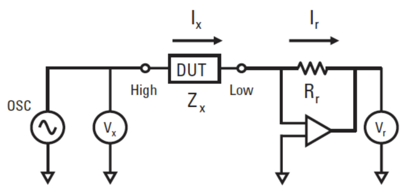

Fig 13 Auto-balancing bridge

The auto-balancing bridge has a high accuracy over a wide impedance measurement range and provides a grounded device measurement. The operation of the auto-balancing bridge is that the current 'Ix' balances with the current 'Ir' which flows through the range resistor. The potential at the low point is maintained at zero volts. The impedance of the DUT is calculated by using the voltage at 'Vx' and across the range resistor. The proposed design makes use of the auto-balancing bridge at its core in a modified version. The various parts of the proposed design are discussed below.

2.1 Signal Source

The proposed model makes use of Direct Digital Synthesis (DDS) for the generation of the signal to the DUT. DDS is a method of producing an analogue waveform which is usually a sine wave by generating a time-varying signal in digital form and then performing digital to analogue conversion. It can offer fast switching for the output frequencies, fine frequency resolution, and operation over a broad spectrum of frequencies. The DDS gets the instructions from the CPU on the frequency requirement of the input and then varies the input signal to the DUT as required for testing at various spot frequencies. The DDS can also make use of the Chirp functionality which is a pulsed frequency modulation scheme in which a carrier is swept over a wide frequency band during a given pulse interval. Frequency chirp is a method of transitioning between two different output frequencies over a specified time interval and the simplest one is a linear sweep. The microcontroller used to implement the design will perform the required DDS and ADC steps.

2.2 Auto-balancing bridge

The next part of the design is the auto-balancing bridge. To measure a wide range of impedance, the design is required to have several measurement ranges. In general, seven to ten measurement ranges are available, and the instrument should be able to automatically select the range depending on the impedance of the DUT. This is done so that the maximum signal level is fed to the ADC to give the highest SNR for maximum measurement accuracy. The maximum accuracy is obtained when the measured impedance of the DUT is close to the value of the range resistor being used. The instrument will measure the DUT impedance in the first try and then shift the range resisters to be closer to the measured impedance to improve accuracy as shown in Figure 14.

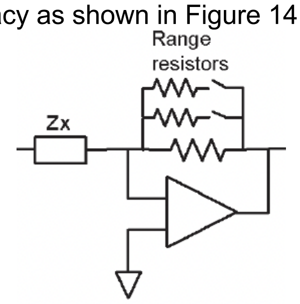

Fig 14 Range Resistors

The design also makes use of a level monitor function. This function helps monitor the test signal voltage or current that is applied to the DUT for maintaining accurate test conditions. The auto level control (ALC) can automatically maintain a constant test signal. The function adjusts the oscillator output until the monitored levels meets the setting value. The design makes use of a digital ALC, and the function is shown in Fig 15. The benefit of using digital ALC is due to its advantage over analogue in providing a stable ALC response for a wide range of DUT impedance.

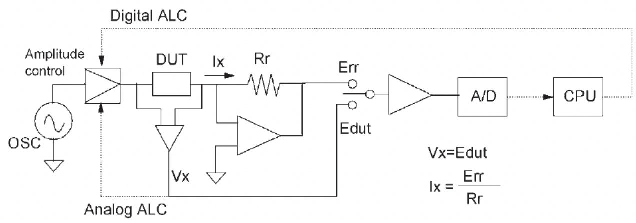

Figure 15 Auto Level Control (ALC) function

The best results are dependent on the measurement time as well. The trade-off to having a fast measurement conflict with the accuracy, resolution, and stability of measurement results. The measurement time is proportional to the number of sampling points taken to convert the analogue signals into digital values in each measurement cycle. Using a larger number of points which in turn increases measurement time can lead to improving measurement precision.

2.3 Phase Detection

The next part of the instrument is the calculation of the real and imaginary part of the impedance. The function used to perform this is the FFT function. A Fast Fourier Transform is a computationally efficient mathematical technique which converts the digital information from the time domain to the frequency domain for rapid spectral analysis. To get the best accuracy for the FFT, the signal is placed into a FFT bin. The example for a FFT bin of 100 in the equation where Fs is the sample rate.

$$Freq = 100 * \frac{Fs}{FFTSize}$$

The aim is having the FFT centred in its FFT bin. The FFT will provide the complex equations from the waveform. This can be compared with the signal and complex equation that was received from the output voltage (S1) and the output current after being converted into a corresponding voltage (S2) with the help of an ADC.

$$S1 = a1 + jb1 \quad S2 = a2 + jb2$$

$$Xr = conj(S1/S2)$$

$$magnitude(dB) = 20 * \log_{10} \mid Xr \mid$$

$$phase = ang(Xr) * (180/\Pi)$$

A negative phase value indicates that the current leading the voltage and a positive phase value indicates the voltage leading the current.

2.4 Operation of the impedance meter

After putting all the components together, the final block diagram is as shown in Figure 12. The working of the meter occurs in the following steps. The MCU sends a tuning word to the DDS block which sends the digital data to the DAC to output a sine wave of a specific frequency. This output is then passed through an amplifier and sent to the DUT. The DUT is placed in the R1 position as explained in Part 1) A) of the auto-balancing bridge hierarchy. The R2 part is replaced by range resistors. These range resistors will be selected to match the impedance measured during the first cycle of the DUT impedance calculation. The signal is then sent to the PGA and LPF and finally to the ADC to be converted to a digital value. This data is then sent into the FFT block to extract the complex values of the impedance and in turn to get the magnitude and phase difference between the current and voltage to determine the type of instrument in the DUT. This happens during the first cycle of the instrument. In the second cycle, the measured DUT impedance is used to select the range resistor values higher than the measured DUT impedance. This will allow us to attain a higher accuracy calculation during the second run of the measurement. In conclusion, this method of impedance measurement promises to provide high accuracy for a wide range of impedance measurements.

References

[1] Agilent Impedance Measurement Handbook 4th Edition

[2] P. Kanaka et al., Design and Development of Portable Digital LCR Meter by Auto Balancing Bridge Method

[3] Nina et al., Portable Arduino – Based LCR - Meter