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MER-322: Dynamics of Physical Systems
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Approximating an Integrating Operational Amplifier System

Introduction

This exercise involved creating a numerical model to predict the voltage response of an integrating operational amplifier. This numerical approximation was confirmed accurate by comparison to the actual response, measured and plotted in an oscilloscope. A function generator and a power supply were used to create the input signal and power the op-amp, respectively.

Methods

The system comprised an operational amplifier with an input to the inverting input terminal separated from the output by a resistor($46.2k\Omega$) and a capacitor($0.1\mu F$) in parallel. There were additional resistors in between the non-inverting input terminal and ground ($4.58k\Omega$), and the input and the inverting input terminal ($4.61k\Omega$). The system parameters were measured with a multimeter directly from the supplied system components. A function generator produced the input for the circuit. Then, the voltage response and the input were measured and viewed with an oscilloscope. This was repeated with frequencies of 2kHz, 200Hz, and 100Hz to measure the voltage response with different input periods.

The analytical approximation used the transfer function of the system, calculated by converting the state equation into the Laplace domain to find the ratio between the system output and system input. The input square wave was adjusted from 2kHz to 200Hz, to 100Hz to match the measured cases of different frequencies. Simulink numerically solved for the system output with the Runge-Kutta method of state propagation, and 3 periods of both the input and output were selected for comparison to the physical system's measured output.

Results

Figures 1 to 4 display the comparison between the measured output and the numerical approximation with varying frequencies. Because we tested a range of frequencies, the smallest period was the 2kHz test, and the largest was from 100Hz test. The effect this had on the system is the difference between Figures 1 and 3; With a larger period, the system output is a curved triangle wave with a much higher amplitude compared to the higher frequency samples. The triangular wave produced at 100Hz shows characteristics of an exponential function, the slope slightly diminishing at the peaks to form a wave shape.

Discussion

From these plots, as the frequency of the input square wave decreases, the amplitude of the resulting triangle wave output increases. The reason for this relationship is the effect of the integrating operational amplifier circuit on any voltage input. Because the circuit's output is the negative integral of the input, the longer the input is non-zero, the longer the slope of the output is non-zero. When the frequency lowers the period increases, and the square wave input is a non-zero voltage value for more time, so the output has the same slope for a longer time and reaches a higher magnitude maximum. The area underneath the function (within every half-period) increases as the frequency decreases, so so the integral has higher magnitudes. This is also seen in figure 4, as the integral of a straight line is a polynomial function, and the output of the triangle wave is conjoined polynomial functions.

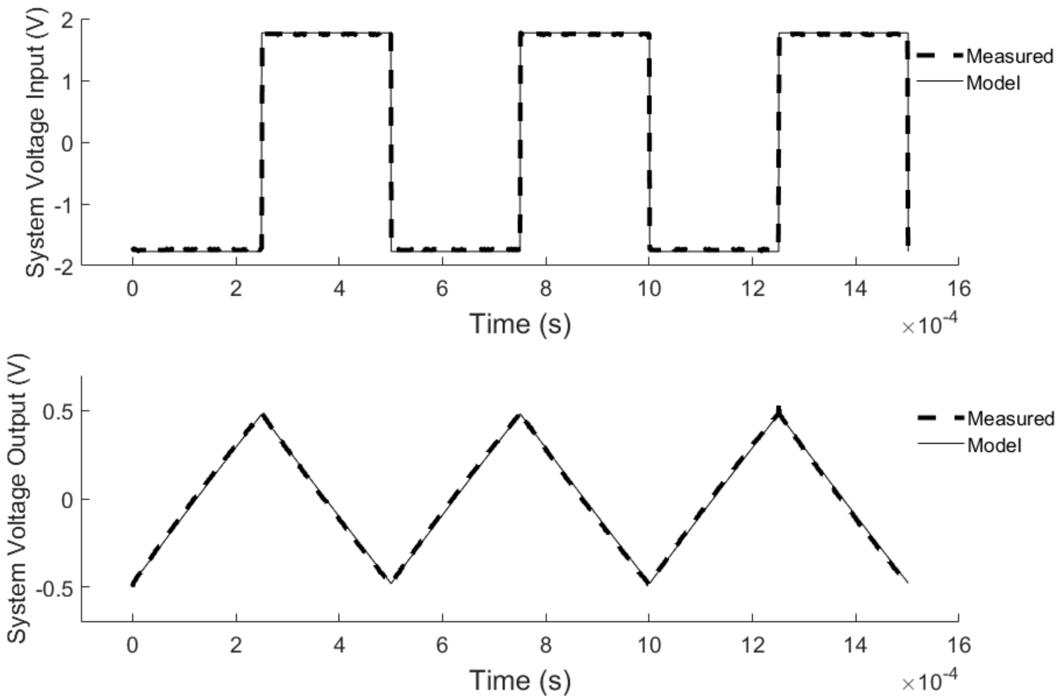

Figure 1: 2000Hz square wave with a peak to peak amplitude of 3.54V (top) producing a triangle wave output (bottom). The measured and simulated input and voltage responses are plotted over each other, confirming the simulation's accuracy.

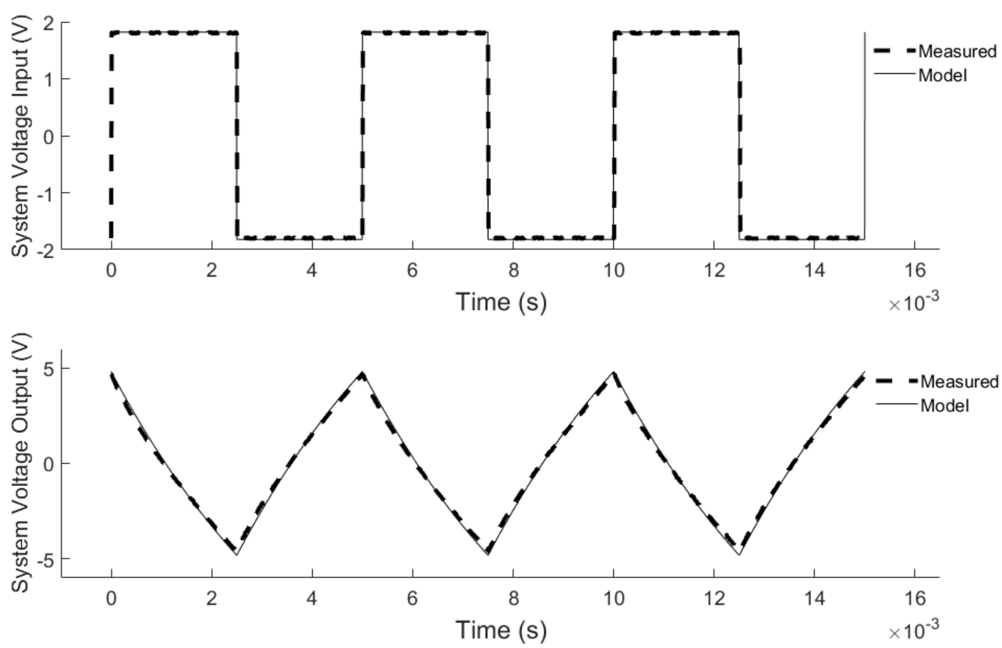

Figure 2: 200Hz square wave with a peak to peak amplitude of 3.64V (top) producing a triangle wave output (bottom). The measured and simulated input and voltage responses are plotted over each other, confirming the simulation's accuracy.

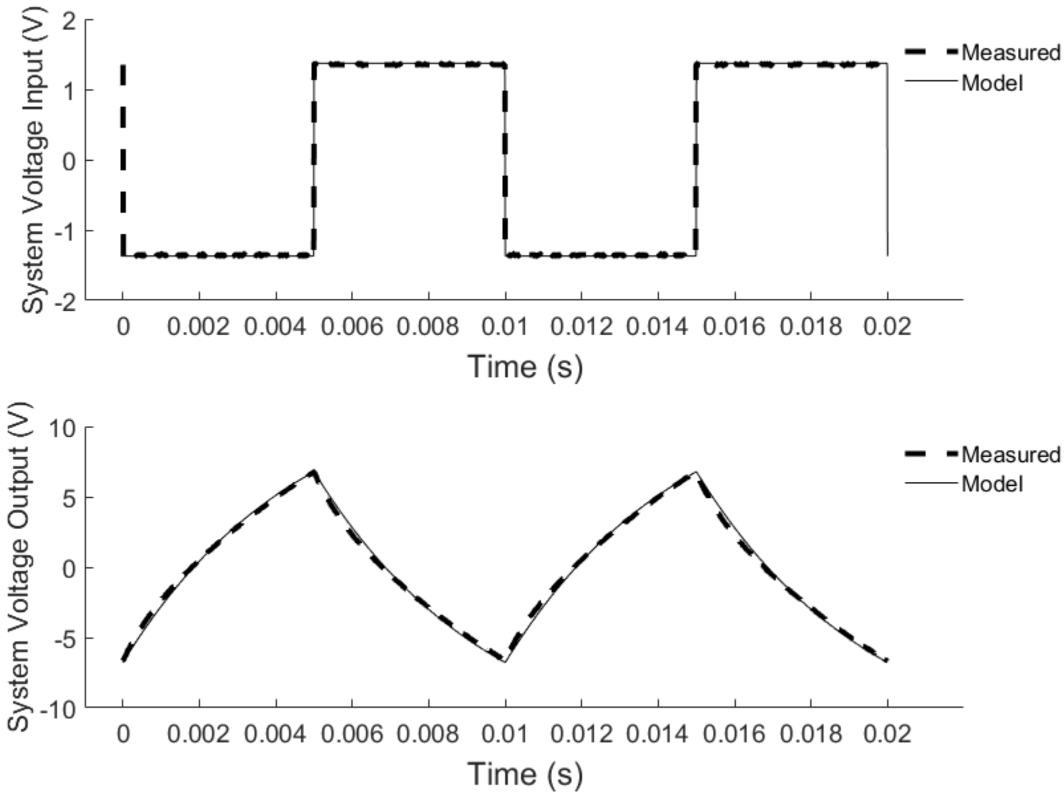

Figure 3: 100Hz square wave with a peak to peak amplitude of 2.74V (top) producing a triangle wave output (bottom). The measured and simulated input and voltage responses are plotted over each other, confirming the simulation's accuracy.

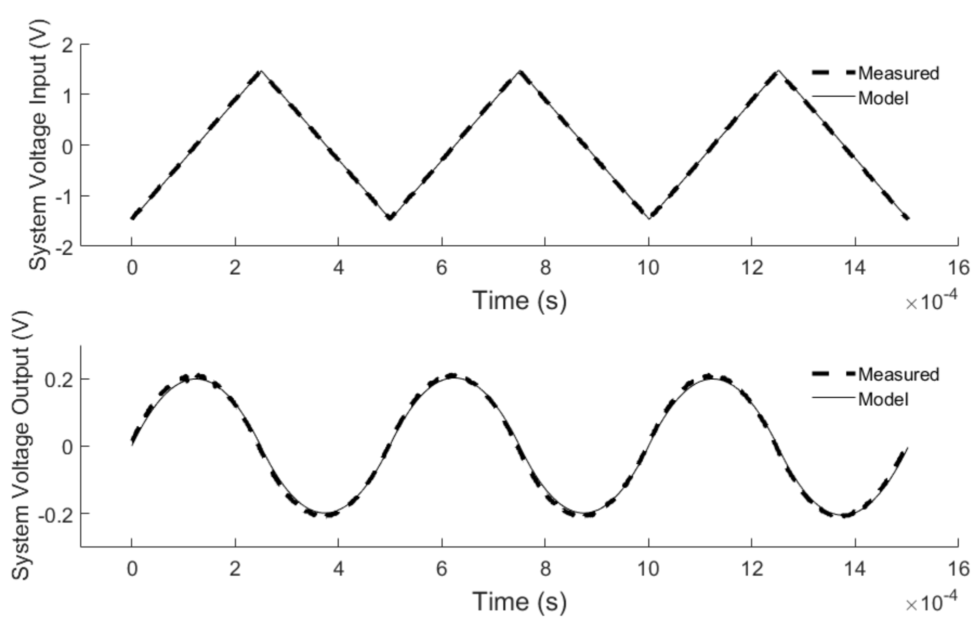

Figure 4: 2000Hz triangle wave with a peak to peak amplitude of 2.94V (top) producing a parabolic wave output (bottom). The measured and simulated input and voltage responses are plotted over each other, confirming the simulation's accuracy.