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DESC9115 – Digital Audio Systems
Written Review 2

FACULTY OF ARCHITECTURE, DESIGN & PLANNING
ASSIGNMENT COVER SHEET

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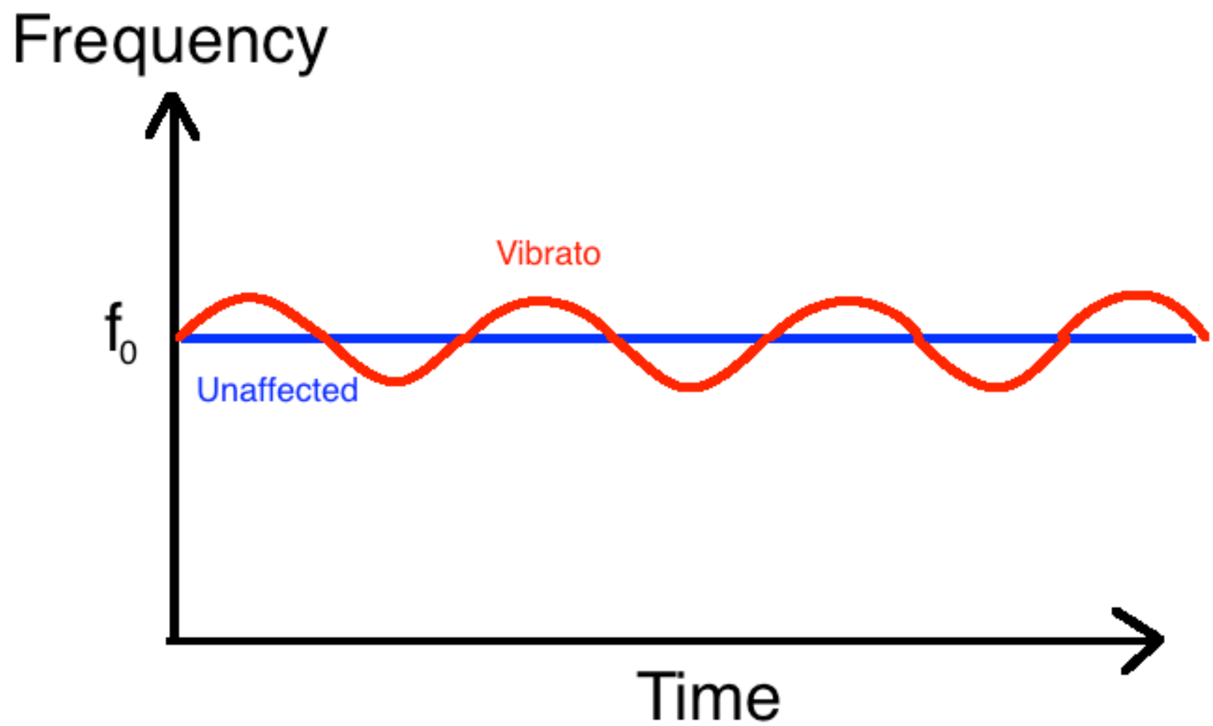
Vibrato (AKA Frequency Modulation)

Vibrato is a long-standing technique used within musical performance to create a small variation in the pitch of a musical signal to add timbre qualities that create musical interest to the listener. Listeners are drawn to sounds with dynamic spectral characteristics, and vibrato makes a sustained note sound much more interesting than a constant frequency. Vibrato has been used throughout musical history and can be demonstrated as far back as the baroque period, an era musical historians define as the years between 1600 and 1750. Vibrato is the name given to a musical phenomenon where the produced pitch is varied slightly and periodically in rapid succession, creating an oscillating "wobble" sound, this is also very often referred to as frequency modulation.



[Figure 1]: demonstrating the vibrato effect on frequency.

Typically a correctly executed vibrato should not reach a full semitone in width but fall short of that limit, typically a variation of 4-16%[1]. If the variation reaches the size of a semitone it is considered a to be a trill, in a musical context a trill is a fast alternation between two precise neighbouring scale notes.

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Vibrato can be considered to be either 'coherent vibrato' or 'non coherent vibrato', this will define the harmonic components in the output signal as being modulated at the rate and depth in case of coherent, or conversely as a particular frequency standing out against the others in the case of non-coherent vibrato. Curtis Roads claims [2] the '*vibrato percent deviation' (V)* can be defined as;

*V=0.2 * Log(pitch)*

Therefore a pitch of 440 Hz holds a calculated vibrato percentage deviation of about 1.2 percent or 5.3 Hz in depth. The frequency of the vibrato ranges from 5.0 to 6.5 Hz according to the fundamental frequency range of the pitches F3 to F6.

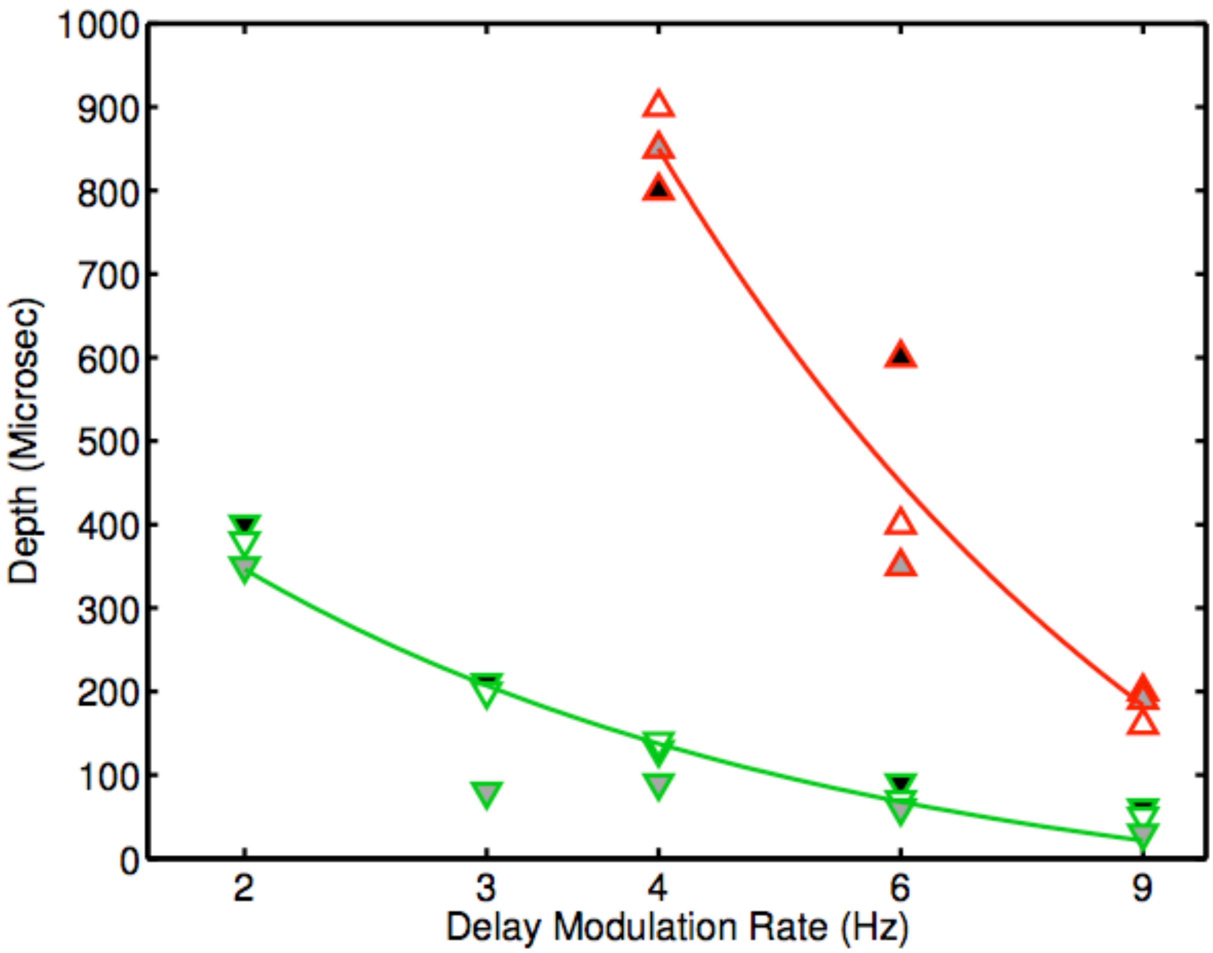
Vibrato is a technique that can be employed on the human voice through a tremor in the vocal chords or diaphragm, on a stringed instrument through an up and down motion of the finger on the string, on a brass instrument by physically shaking the instrument to move the mouthpiece away and closer to the players lips, or in woodwind by the player modulating their own airflow into the instrument. In the past century technology has been employed to create these effects electronically such as through a guitar pedal, or in the example of the now infamous Leslie speaker cabinet, mechanical motion.

The Leslie speaker cabinet was invented in the late 1940s by Don Leslie [3], the cabinet is comprised of a rotating horn attached to a midrange driver, and a woofer mounted over a rotating baffle, It has been widely used as an audio effect for musical performers, particularly in when used in conjunction with a Hammond organ, although it has also been employed with many other instruments. The characteristic vibrato sound of the Leslie is produced by the rotation of the horn and baffle system, which create a changing Doppler shift and filtering on the input signal. This Doppler shift creates a deviation in pitch because the distance between the sound source and the receivers ears is constantly being varied, in the case of the Leslie the variation is a sinusoidal cycle. Varying the distance is essentially equivalent to varying the time delay and will produce a cyclical variation in pitch. In this way we can create a vibrato effect using mechanical means where the rate and depth of pitch modulation directly translates into distance travelled. It is worth noting that sound is transmitted through only one side of the horn, the other side serving as a counter-weight. The rate of rotation of the horn can be altered between 0.672Hz and 6.920Hz, the baffle between 0.101Hz and 5.955Hz respectively.

[Figure 2]: The components inside a Leslie speaker cabinet. Sourced from Tumblr

In the realm of DSP we can achieve this Vibrato effect on a prerecorded audio track using a modulated variable delay driven by a low frequency oscillator and no feed-forward signal. The way a simple delay works is by creating a buffer with a length equal to the delay time, ensuring to initialize it to contain all zeroes, and then as the audio buffer is processed, transfer each sample from it into the delay buffer while extracting values from the delay buffer and mixing it with the original audio buffer. As the delay buffer is initialized to contain all zeroes, the first pass through it will do nothing to the original audio, but upon completion of the first pass the delay buffer will contain the samples from the audio that will then be mixed together, creating the delay. It is worth noting that in real-world applications of vibrato, frequency modulation is usually coupled with amplitude modulation, known as Tremelo. The nature of this tremolo can be highly complicated. However, under certain conditions it can be simplified as source-filter effect.
Studies have been conducted to determine the most optimal values for the two parameters of delay modulation rate (measured in Hz) and the depth of the modulation (measured in microseconds). One particular study used variable values for each of these paramters and asked participants to

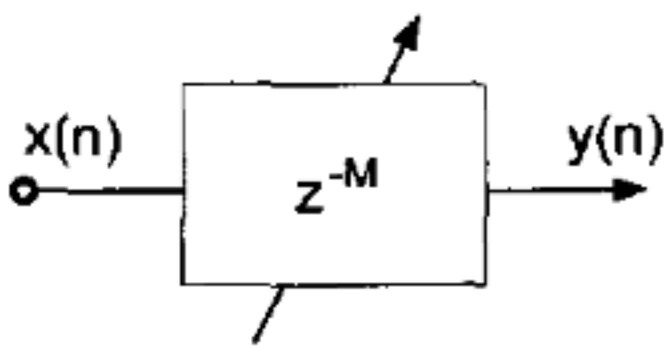
evaluate their preferences based on subjective analysis of how musically 'useful' the vibrato was perceived. The results of the study demonstrated a clear preference curve shown below with the limits of what was deemed to be "musically useful" by the participants;



[Figure 3] Results of Martens' experiment [4].

The Plot shows curves fitting to the transition points between adjacent perceptual response regions, that of sub-useful and supra-useful defined by two delay-modulation parameters. Points representing the lower boundary of the musically useful region are plotted using downward-pointing triangles, and points associated with the upper boundary of the useful region are marked using upward-pointing triangles. For the purposes of this paper, only the black triangles shown are relevant as they denote the Vibrato results specifically, the other colours, white and gray, represent the response for processed effects of flange and chorus respectively. For the modulation depth data derived for all three types of effects, a simple linear regression was executed to fit a prediction equation for the lower boundary of the useful region using modulation period as the independent variable. It is worth noting the stimulus for the experiment was created using an input signal of a guitar performance of a single note, therefore the results are potentially not applicable to other performance methods, other musical instruments or the inclusion of several musical instruments together.

Adapting this delay to create a vibrato effect is not overly complicated and only takes a few steps. We need to create a variable delay and this requires two markers to our delay buffer, a writing marker that will proceed sample by sample as in the basic delay above, and a reading marker that will be calculated in relation to the writing marker and modulated by the LFO. The reading position will almost always fall between buffer positions, so interpolation is required to achieve more accurate output. The DAFX: Digital Audio Effects text book by Zolzer [4] gives the schematic for a vibrato function as follows;



[Figure 4] DAFX schematic of Vibrato process [5].

Zolzer also states that typically the values of the average delay time fall between 5 and 10ms and the low frequency oscillator rate falling between 5 and 14Hz and gives the following function as an implementation of Vibrato within matlab;

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```
function y=vibrato (y,SAMPLERATE,Modfreq,Width)
ya-alt=O;
Delay = Width; %basic delay of input sample in sec
DELAY = round (Delay*SAMPLERATE); % basic delay in
%samples
WIDTH = round (Width*SAMPLERATE); %modulation width in %
# %samples
if WIDTH>DELAY
    error ('de1ay greater than basic delay!!!');
    return;
end
MODFREQ = Modfreq/SAMPLERATE; %modulation frequency in #
%samples
LEN = length(x);  % # of samples in WAV-file
L = 2 + DELAY + WIDTH*2; % length of the entire delay
Delayline = zeros(L,l); % memory allocation for delay
Y = zeros(size(x)); % memory allocation for output
%vector
for n = l:(LEN-l)
    M = MODFREQ;
    MOD = sin(M*2*pi*n);
    ZEIGER = I + DELAY + WIDTH * MOD;
    I = floor(ZEIGER);
    Frac = ZEIGER-i;
    Delayline = [x(n) ;Delayline (l:L-l)];
    %---Linear Interpolation--------
    y(n,l) = Delayline(i+l)*frac + Delayline(i)*(i-frac);
    %---Allpass Interpolation-------
    y(n,i) = (Delayline(i+l)+(l-frac) * Delayline(i)-(l-
    frac)*ya~alt);
    ya-alt = ya(n,1);
    %---Spline Interpolation------
    y(n,I) = Delayline(i+l)*frac-3/6
    .... +Delayline(i)*((i+f rac) ^3-4*frace3)/6
    .... +Delayline(i-l)*((2-frac)-3-4*(i-frac)-3)/6
    .... +Delayline(i-2)*(l-frac)-3/6;
    % 3rd-order Spline Interpolation
    end
```

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[2] Roads, C. *"The Computer Music Tutorial"* 1995, MIT Press. Cambridge, Massachusetts, USA.
[3] Abel, J. Hanson, C. Herrera, J. *"Discrete Time Emulation of the Leslie Speaker"* Presented at the 2009 AES Convention, New York USA.
[4] Atsushi, M. Martens, W. *"Categories of Perception For Vibrato, Flange, and Stereo Chorus: Mapping Out The Musically Useful Ranges of Modulation Rate and Depth for Delay-Based Effects"* Presented at the 2006 Int. Conference on Digital Audio Effects, Montreal, Canada.
[5] Zolzer, U. *"DAFX – Digital Audio Effects"* 2002, John Wiley & Sons. NJ, USA.