

2006-814: VIRTUAL TOOLKIT FOR COMMUNICATION SYSTEMS AS A TOOL FOR INNOVATION

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Communication Systems Toolkit As a Tool for Innovation

Abstract

In previous publications, we have discussed the preparation¹, the utilization² and the effectiveness³ of a Virtual Toolkit for Communication Systems, which takes advantage of LabVIEW's graphical user interface. This paper describes the use of the same toolkit in a class project that demonstrates a novel idea for envelope detection of amplitude modulated (AM) signals. It first proposes a new technique of envelope detection using sampling. It then presents a mathematical model and analysis to show the feasibility of this new technique. Finally, the results of a simulation of the proposed technique using the toolkit will be presented followed by a discussion of the evolution of the toolkit from a demo package to a research tool.

I. Introduction

This paper is a follow-up on recent papers that describe a simulation toolkit for communication systems based on LabVIEW^{1,2} and its reception by students at two different institutions³. In those papers we stated that in the absence of hardware that would reinforce the theoretical presentation, computer simulations of the systems described in class are the next available tools to bring these concepts to life. Those papers also describe the particular class environment and the process in which the software development tool, namely LabVIEW, was chosen. Although MATLAB is the standard software tool employed in the areas of signals and systems, as evidenced by the proliferation of books⁴⁻⁶ devoted to MATLAB based exercises in those subjects, the choice of the software tool is justified in other publications^{1, 7, 8}.

This paper will describe the use of the toolkit in the demonstration of a novel idea for envelope detection of AM signals. Section II will provide a summary of amplitude modulation and envelope detection of AM signals as well as recent developments in envelope detection and related fields. Section III will present the method of sampling the AM signal for envelope detection, present a mathematical analysis of the proposed process and demonstrate the feasibility of this method with the toolkit. Section IV will conclude with a discussion of the toolkit as well as comments on hardware implementation.

II. Envelope Detection of AM Signals

An AM signal, $s(t)$, is given by

$$s(t) = A_c [1 + m(t)] \cos \omega_c t \quad (1)$$

where $m(t)$ is the modulating (or message) signal, A_c and ω_c are amplitude and frequency of the carrier (modulated) signal respectively⁹. Figure 1 shows the front panel of the virtual instrument that demonstrates AM with the toolkit. The upper left graph is that of a square wave message signal and the upper right graph depicts its magnitude spectrum. The lower left graph is that of

the AM signal when this message signal modulates a 32 Hz carrier signal. The lower right graph depicts the magnitude spectrum of the AM signal.

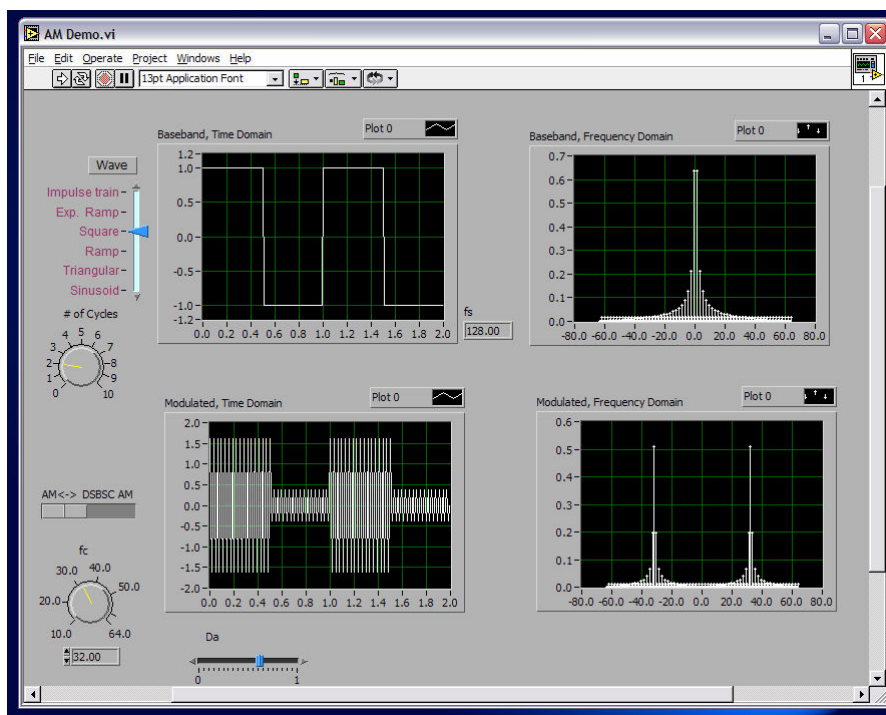


Figure 1: Demonstration of Amplitude Modulation (AM) using the toolkit.

An AM signal described by Equation (1) can be demodulated by an envelope detector, which is a simple circuit composed of a diode followed by a low-pass filter (Figure 2).

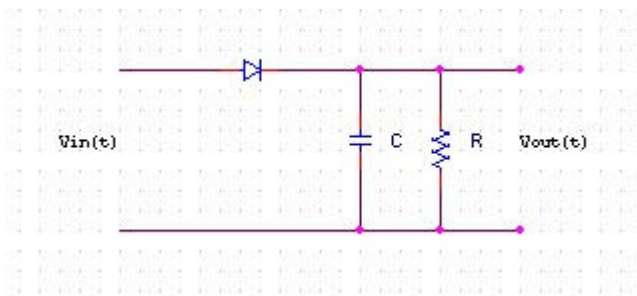


Figure 2: A diode envelope detector. $v_{in}(t)$ is the AM signal and $v_{out}(t)$ is the demodulated signal.

Supposing $m(t)$ is normalized, i.e., $|m(t)| < 1$, then the output voltage in Figure 2 is:

$$v_{out}(t) = KA_c [1 + m(t)] = KA_c + KA_c m(t) \quad (2).$$

KA_c is a DC voltage which may be used to provide automatic gain control for the AM receiver, $KA_c m(t)$ is the detected message. For audio signals, typical values for the envelope detector

components are $R = 10 \text{ k}\Omega$ and $C = 0.001 \text{ }\mu\text{F}$, yielding a low-pass filter with cut-off frequency of 15.9 kHz ⁹. Other methods of detection of AM signals exist, such as synchronous detection and square-law detection^{9, 10} but the method presented here implements envelope detection through sampling of the AM signal.

The sampling method of envelope detection should not be confused with digital radio such as Digital Radio Mondiale¹¹ or the Australian system described by Campbell *et al*¹² which employ QAM (quadrature amplitude modulated) digital signals. In fact, the method we present here is purely analog.

Envelope detection technology is rather mature. In 1964 Wade described an improvement of the envelope detector performance which involves sampling of the demodulated signal followed by a nonlinear transformation¹³. In 1998, Sangpisit *et al* proposed a novel envelope detector that approximates Hilbert transformation through differentiation¹⁰.

More recent developments in envelope detection have gone in the direction of a purely digital architecture¹⁴. In the digital domain, techniques that extract the analytical signal magnitude through the computation of the Hilbert Transform are rather slow¹⁵. In 1999, Fritsch *et al* proposed a nonlinear digital envelope detection filter (EDF) to speed up the process¹⁵, which was used by Lee *et al* for blood pressure measurement resulting in error reduction by 30-40%¹⁶.

III. Envelope Detection through Sampling (EDS)

EDS originated in our discussions in ELE 402 Digital and Analog Communication Systems. This technique uses a high speed sampler to detect the envelope of the carrier signal. The sampling frequency is set to the carrier frequency, preferably with a phase angle so the sampler picks the peak value. Fig. 3 summarizes the steps taken in EDS in the form of a flow chart.

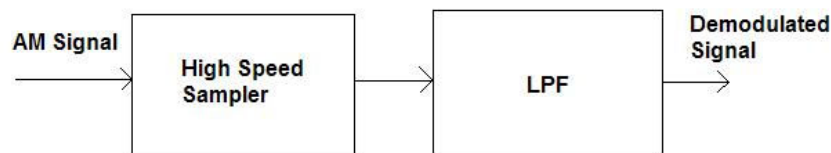


Figure 3: EDS process.

A mathematical model for the high speed sampler would be the multiplication of the AM signal by an impulse train with a frequency of f_s . Figure 4(a) depicts the spectrum of the sampler when $f_s = f_c (= \omega_c/2\pi)$. Figure 4(b) depicts the spectrum of the AM signal, $S(f)$. Multiplication in time domain results in convolution in frequency domain. So the spectrum of the output of the EDS process may be obtained by convolving 4(a) with 4(b). The result of the convolution will yield

an infinite spectrum. We can estimate this spectrum as follows: Convolution of the impulse at DC in 4(a) with $S(f)$ will yield $\hat{M}(f)$. Convolution of the impulses at $\pm f_c$ will yield the spectrum depicted in 4(c). We note that this convolution will replicate $S(f)$ at $\pm 2f_c$ and at DC. Convolution with the impulses at $\pm 3f_c$ will replicate $S(f)$ at $\pm 4f_c$ and $\pm 2f_c$. Convolution with the impulses at $\pm 4f_c$ will replicate $S(f)$ at $\pm 5f_c$ and $\pm 3f_c$ and so on. The resulting spectrum will be the addition of all these replicas.

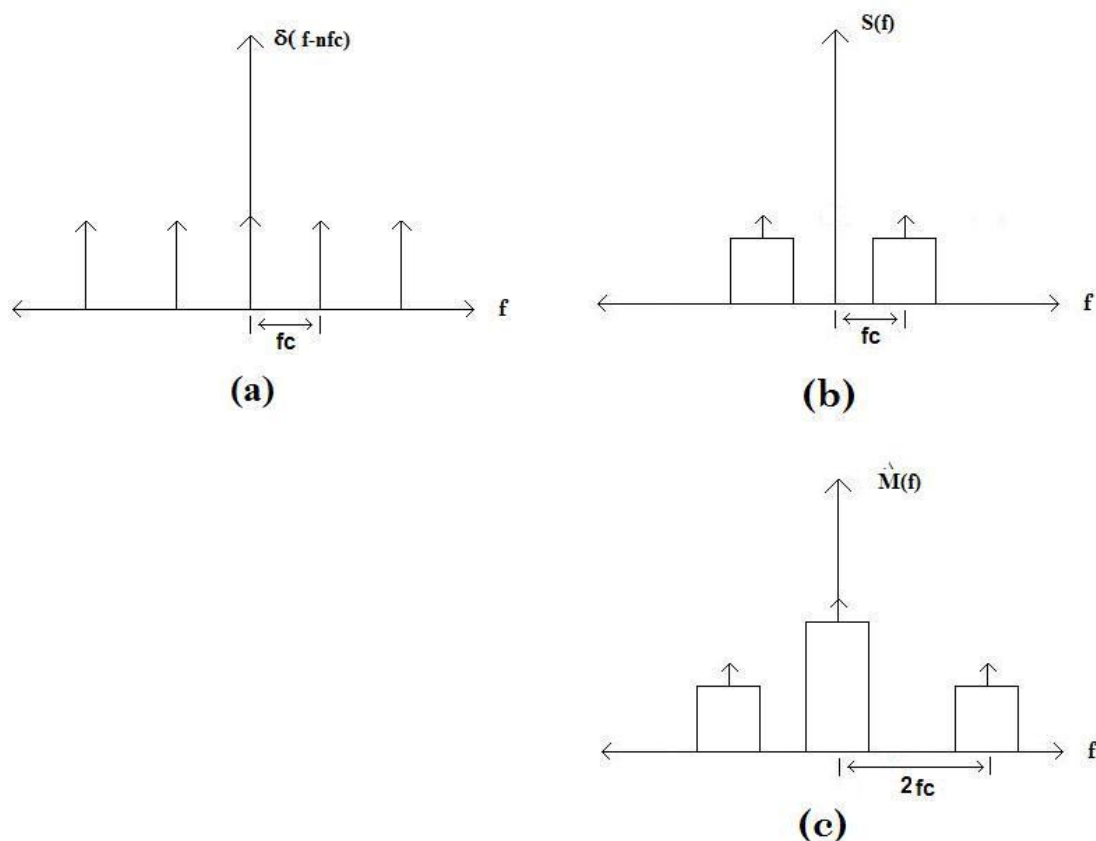


Figure 4: Toward a mathematical model: Spectra of various components.

Bandpass sampling theorem states that if a bandpass signal, $s(t)$, has a nonzero spectrum only over the frequency interval $f_1 < |f| < f_2$ where the transmission bandwidth, B_T , is taken to be the absolute bandwidth $B_T = f_2 - f_1$, then $s(t)$ may be reproduced from sample values as long as the sampling rate is $f_s \geq 2B_T$ ⁹. In the case for AM radio, f_c is much greater than the bandwidth of the baseband signal, B_{B_T} . The modulated signal, $s(t)$, is a bandpass signal centered around f_c with a bandwidth $B_T = 2B_{B_T} (\ll f_c)$. Therefore, $m(t)$ can be recovered from $s(t)$ if $s(t)$ is sampled at $f_s = f_c$. After lowpass filtering, the resulting spectrum would be identical to that of the signal obtained by diode-LPF method of envelope detection.

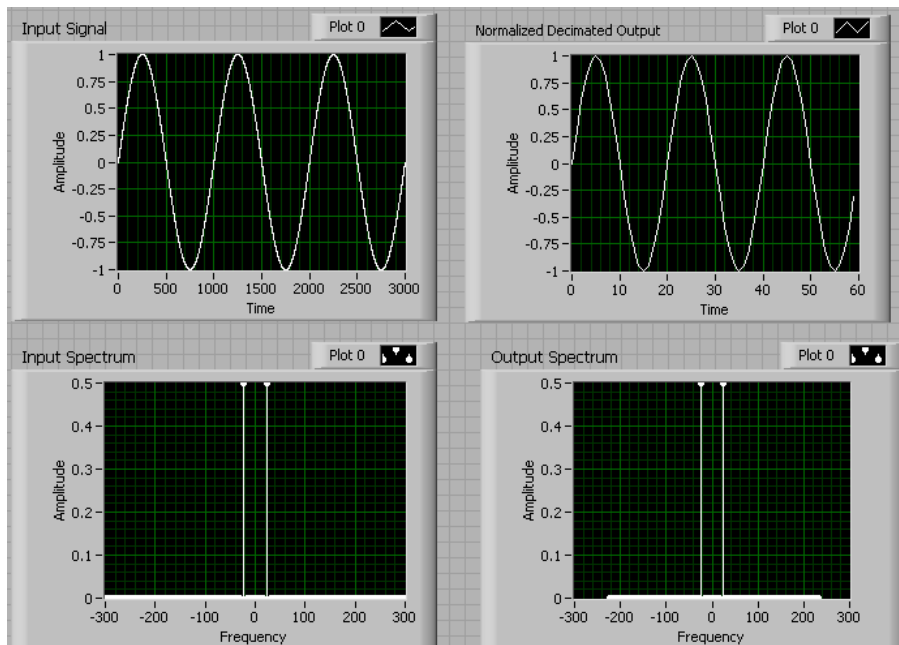


Figure 5: EDS with a sine wave message.

We tested this theory using our Virtual Toolkit for Communication Systems and Figures 5 and 6 depict a series of comparisons showing the time- and frequency-domain representations of the message and output signal with a message frequency of about 25Hz.

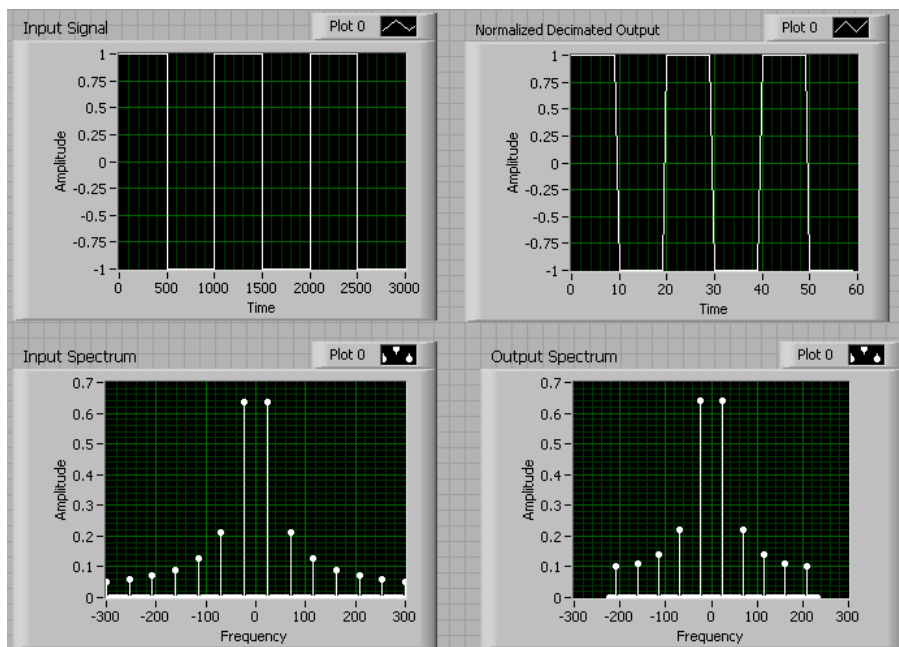


Figure 6: EDS with a square wave message.

As one can see in Figures 5 and 6, the original message is almost completely intact after the EDS process has been completed.

IV. Discussion

The utilization of the tools in this toolkit is understood better with a rudimentary understanding of discrete signals. Since these are computer simulations of analog processes, they are valid when the results of the processes all fall within the Nyquist rate determined by the original chosen sampling frequency. The concept of sampling frequency gets interesting when we simulate the sampling of analog signals where we can talk about two sampling frequencies: the sampling frequency of the entire simulation and the sampling frequency at which we retain samples from the simulated signal. We have decided to clarify this ambiguity by referring to the former as ‘simulation clock frequency’ and the latter as simply sampling frequency. In order to simulate analog processes with this toolkit, the simulation clock frequency should be sufficiently high in order to avoid aliasing modulated signals. In order to avoid memory problems, the carrier frequencies are kept artificially low.

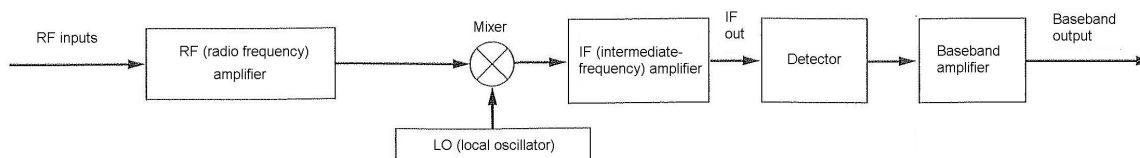


Figure 7: Superheterodyne receiver.

We have demonstrated the feasibility of the envelope detection through sampling (EDS) using a LabVIEW-based toolkit. However, this demonstration has been under ideal conditions. We have not dealt with the effect of noise. We have set the phase of the sampler such that it detects the peaks of the signal. However, deviations from this phase would result in the attenuation of the detected message. Furthermore, in the presence of additive noise, the S/N ratio would deteriorate. If EDS is to be implemented in hardware, we would suggest that it is incorporated into the detector of a superheterodyne receiver (Fig. 7), which most receivers employ⁹. Since the superheterodyne receiver utilizes a local oscillator to down-convert (or up-convert) the input signal to an intermediate frequency (IF) band, this oscillator may be employed to trigger the sampler to ensure proper phase.

The next logical step would be to test this theory in a laboratory using actual hardware. One could run tests at varying modulation frequencies (54-140kHz) and with different types of message signals. One could also try different methods of digital manipulation to answer questions like: Does linear interpolation sufficiently enhance the recovered signal? Would a more sophisticated interpolation method be needed?

We expect that commercial implementation of the EDS method would require hardware that is more complex (and hence more costly) than a simple diode. However, our main point is that the Communication Systems Toolkit, which was originally developed to demonstrate concepts in a

regular classroom with no special equipment other than a computer projection system, can also be utilized to test new ideas. Initially, it was developed for a course without any laboratory. It has also proven useful as a quick trial tool before committing oneself to a more costly hardware set-up.

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