Modeling a Single-sideband Transmitter in SIMETRIX for Instructional Purposes

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ABSTRACT
Theoretical block diagrams of single-sideband transmitters are well documented in many Electronic Communication textbooks. However, senior engineering students often experience difficulty in understanding and evaluating the principle of operation of this versatile transmitter. It must be noted that single-sideband is the preferred modulation format in analogue voice transmission for two-way radio communications and furthermore forms the basis of many frequency-division multiplexing systems. This theory therefore needs to be conveyed to senior engineering students in a simple, practical and understandable way. This paper aims to present such a method which was developed in the Electronic Communication laboratory at Vaal University of Technology. Basic fundamental models are adapted in a software simulation package called SIMTERIX (free student version), to provide a complete single-sideband transmitter. Key parameters of this completed model are then manipulated by engineering students to produce different waveforms and signals at various test points. This enhanced visual presentation enables the student to grasp the fundamental operating principles of single-sideband transmitters, obtaining a printed copy of the resulting spectrum showing all corresponding frequency signals. Students are further encouraged to engage actively in the practical work, thereby providing an opportunity for them to develop problem-solving skills and critical thinking. Contrasting the sole use of theoretical block diagrams to the combined use of this simulation model reveals that engineering students are twice as likely to grasp the operating principles of single-sideband transmitters.

Keywords: Block diagram, SSB, simulation models, critical thinking

1.0 INTRODUCTION

"Universities are full of knowledge; the freshmen bring a little in and the seniors take none away, and knowledge accumulates"(Lowell 2008). Those words well convey the challenge facing many institutions of Higher Education (HE) around the world. This "knowledge", referred to in the opening quotation, does not signify course content (which students are very good at regurgitating), but rather implies the application of course content to new situations (thereby creating new understanding and new knowledge). However, many senior students graduate from university without being able to write well enough to satisfy their employers while others cannot reason clearly or perform competently in analyzing complex, non-technical problems (Bok 2006). Students subsequently struggle in applying course content to new situations, and therefore take very little practical skills away from the university.

Enhancing students perception of complex technical matters are fundamental requirements if students are to develop into critical-thinkers and creative problem-solvers, becoming valuable members of an industrialized society. A University of technology must therefore place particular value in its academic activities on the search for innovative applications of technology in all fields of human endeavor (Du Pré et al. 2001). One application of technology involves using simulation models to convey the fundamental operating principles of a single-sideband (SSB) transmitter to senior engineering students in telecommunications.

It must be noted that elaborate simulation tools (such as MATLAB and SIMULINK) currently exist which can be used to successfully model a SSB transmitter. However, these simulation tools are often financially beyond the grasp of African students, and may even sometimes appear more complex than simple. The purpose of this paper is therefore to present a relatively simple and free simulation package, called SIMETRIX, for the successful simulation of a SSB transmitter. Key parameters of this simulation model may then manipulated by engineering students to produce different waveforms and signals at various test points, thereby visually enhancing the instructional process.

Rationale for using simulation software in conveying fundamental principles to students is first substantiated. The theoretical block diagram of the SSB transmitter is then reviewed along with desired outcomes. Symbols (sub-circuits hidden within a square block with external connection points) which are created from existing simulation models available in SIMTERIX are introduced and explained. Simulation results of this SSB transmitter is then correlated to the theoretical expectations.

2.0 RATIONALE FOR USING SIMULATION MODELS

Computer-based learning facilitates consistent delivery, proof of completion and increased retention of information (Kruse and Keil 2000) while the use of simulation in education allows the users to learn relationships and principles for themselves (Robert 2003). Engineering students are subsequently exposed to the same simulation models with the same results, which may be printed out as proof of completion. Additional advantages to the students include self-pacing, interactivity and data storage via USB flash disk for future reference. Furthermore, using electronic equipment within the teaching and learning environment supports the development of high-level thinking in the following two ways (McCown et al. 1996):

- It provides students with opportunities to develop their problem-solving skills and
- It may serve as a tool for thinking and problem solving.

3.0 FUNDAMENTAL OPERATING PRINCIPLES OF A SSB TRANSMITTER

SSB modulation is the most efficient form of Amplitude Modulation (AM) where the carrier frequency and one of the sidebands are suppressed (Schweber 1996). This type of radio-frequency (RF) transmission is used for its outstanding power (power saving of over 83 %) and bandwidth efficiency (50 % reduction in bandwidth usage), when compared to full carrier AM systems (Young 2004). Early SSB transmitters used balance modulator circuits to eliminate the carrier signal and sideband filters to remove the unwanted sideband (Roddy and Coolen 1995). The block diagram of a basic SSB transmitter is shown in Figure 1 below together with four specific test points (TP), which will be discussed next.

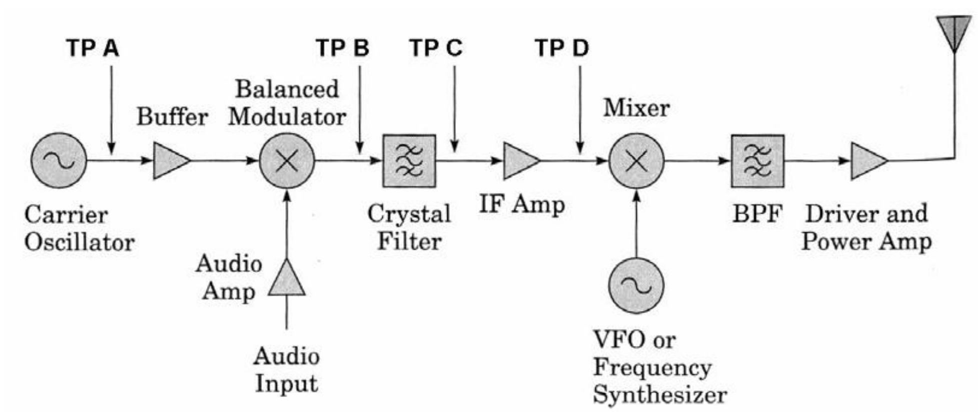


Figure 1: SSB-SC transmitter block diagram (Blake 2002).

Senior engineering students must be helped to grasp and interpret the frequency domain waveforms of the SSB system at selected test points. This will aid them in faultfinding RF transceivers and in understanding frequency division multiplexing (FDM), which is based on

SSB principles. The following desired outcomes, based on the selected TP noted above, are envisaged where students need to (Swart 2011):

- Determine the frequency and amplitude of the original carrier signal and verify that its frequency component is within the medium-frequency (MF) band (TP A);
- Analyze the amplitude of the suppressed carrier to ascertain if the balanced modulator's suppression specification adheres to the international standard (ITU-R Recommendation 326-5) (ITU 2009) of more than 40 dB (TP B);
- Distinguish between the two sidebands generated by the balanced modulator and calculate the modulating frequency, which must be within the voice-frequency (VF) or very-low-frequency (VLF) bands (TP B);
- Evaluate the operation of the crystal filter to establish which sideband (upper or lower) is passed to the next stage (TP C);
- Calculate the gain of the Intermediate Amplifier (IF) by determining the amplitude of the sideband that is passed (TP D).

These desired outcomes may be achieved when students make use of a spectrum analyzer to measure the frequency domain waveforms at the selected TP shown in Figure 1. Unfortunately in the Republic of South Africa (RSA), one spectrum analyzer may cost as much as $5000 and would not suffice to train above 14 engineering students in a laboratory at any given time. Simply buying more spectrum analyzers to ensure greater student exposure is not a viable option. Using a free simulation software package along with appropriately designed models to create the block diagram of the SSB transmitter is a welcome alternative that provides additional benefits to engineering students within the Telecommunications laboratory.

4.0 ADAPTING CURRENT MODELS TO SUIT THE SSB TRANSMITTER

The fundamental building block of any SSB transmitter is the balanced modulator, a circuit which suppresses the carrier and produces two sidebands. The MC1496 is a well-known IC which may be used as either a balanced modulator or product detector. The datasheet for this IC includes typical application circuits, including a balanced modulator circuit for 12 V operations giving exact component values and connections. This application circuit was incorporated into SIMETRIX, which includes a basic simulation model for the MC1496. This circuit is hidden within a singular symbol termed the BalancedModulator, which features nine connection points (known as Module Ports within the simulation package) as shown in Figure 2.

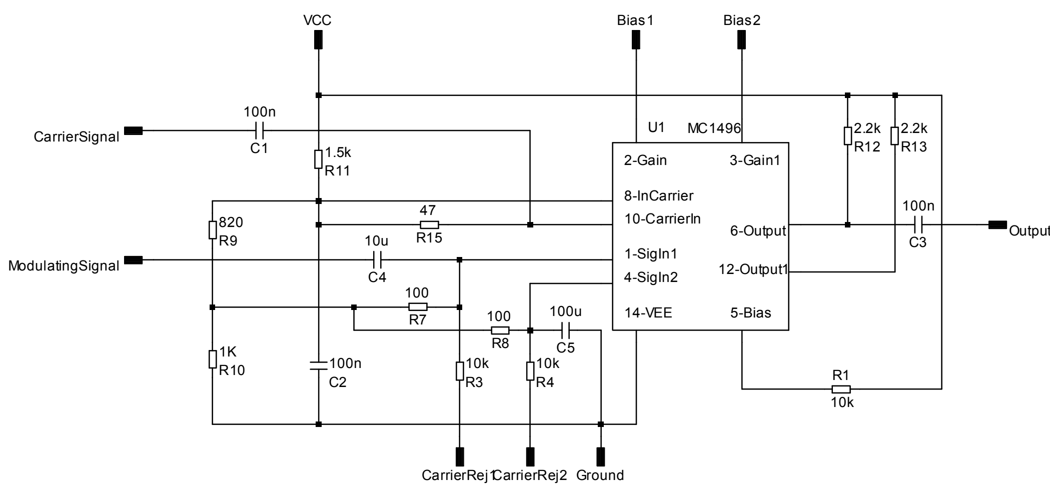


Figure 2: A sub-circuit created to function as the BalancedModulator

The Bias connections (Bias 1 and 2) set the gain of the internal transistors used in the MC1496 (and subsequently the output level of the two sidebands), while CarrierRej1 and 2 sets the level of carrier suppression. These symbols may be created in SIMTERIX (using the Symbol Editor on the File menu) by exploiting existing simulation models.

The complete block diagram of the SSB transmitter used in SIMTERIX is shown in Figure 3, where the BalancedModulator symbol forms the heart of the system. The CarrierSignal input originates from a BufferCircuit, which is another symbol created in SIMTERIX using two transistors in a complimentary-emitter follower configuration. The CarrierOscillator symbol encompasses a two inverter-oscillator, where the resonating frequency is determined by an external capacitor (C1). The ModulatingSignal input is fed from a Voltage Source available in the simulation package (V2). The output of the BalancedModulator is fed to a FilterCircuit, which is the fourth symbol created in SIMETRIX using cascaded Class A RF amplifiers tuned in the collector. These tuned circuits (resonating frequency set by two external capacitors, C2 and C3) allow either the upper or lower sideband to pass to the AmplifierCircuit. This is the final symbol created in SIMTERIX using an operational amplifier with an adjustable gain set by an external resistor (R1). The 47k load resistor (R3) functions as a dummy load, absorbing the RF power from the AmplifierCircuit.

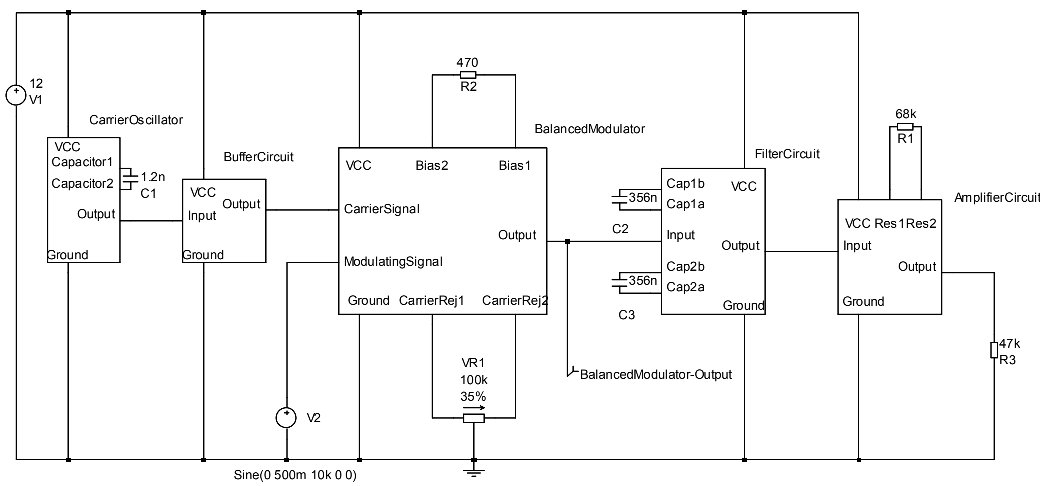


Figure 3: SSB transmitter block diagram created in SIMETRIX

5.0 ANALYSING THE RESULTS OF THE SIMULATION MODEL

A complete SSB transmitter training board (DL2514) was purchased from the Delorenzo Group (2009) to obtain the exact frequency domain sketches at the various test points. This training board is shown in Figure 4, and is currently being used in the Radio Engineering III laboratory for experimental purposes. Frequency domain sketches are obtained for the four test points (TP A, TP B, TP C and TP D) via a computer based spectrum analyzer (a PICO-SCOPE) and are depicted sequentially in Figure 5 on the left hand side (Swart 2011).

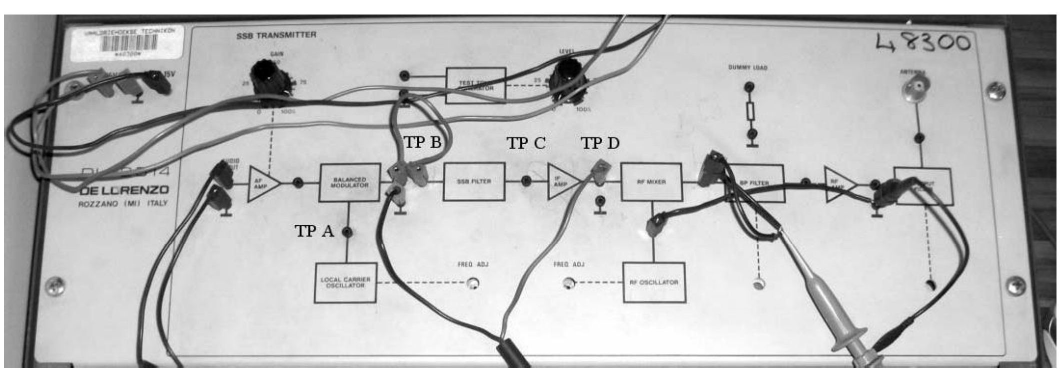
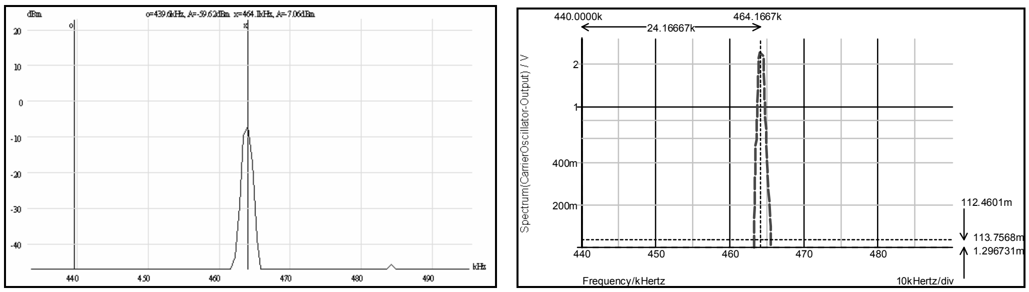
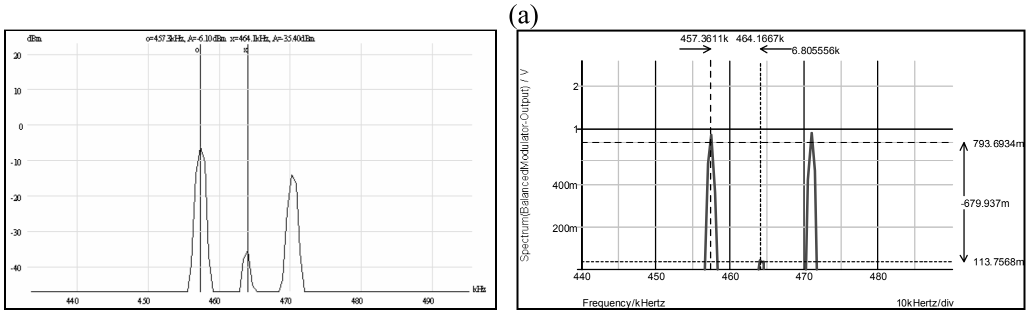


Figure 4: A complete SSB transmitter training board from the Delorenzo Group (2009)

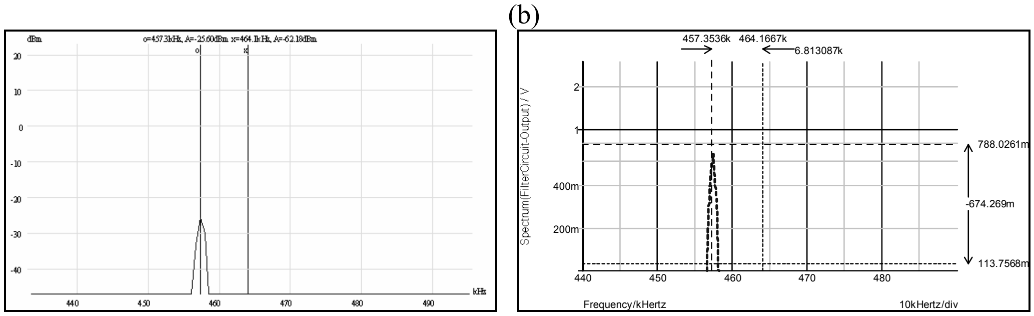
Figure 3 was used in SIMETRIX to simulate the various frequency domain sketches in order to compare them to the results obtained from the SSB training board. A transient analysis of the circuit was done for a total time period of 2 ms. This provides a good frequency resolution (500 Hz) in the frequency domain when selecting the Fourier plot which is set to display a frequency range of 440 – 490 kHz. The number of points is set to 65536 with an edited y-axis of 100 mV to 4 V. These results are shown on the right hand side of Figure 5.



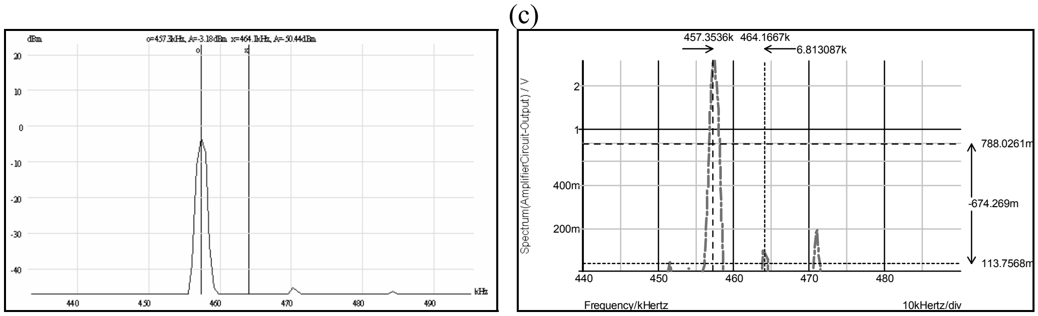
(a)



(b)



(c)



(d)

Figure 5: SSB Transmitter training board results shown on the left hand side with the results from the simulation model shown on the right hand side; (a) – Carrier frequency output; (b) Balanced modulator output; (c) Filter output; (d) Amplifier output

Figure 5 (a) illustrates the output carrier frequency (TP A = 464.1 kHz falling within the MF band) of the SSB Transmitter board while (b) shows the output of the balanced modulator indicating a suppressed carrier frequency (TP B = 28 dB of suppression which does not adhere to the international standard of 40 dB). The second input to the balanced modulator is the modulating signal, which is generated by an external signal generator (TP B = 6.8 kHz falling within the VLF band). The crystal filter has a bandwidth of 10 kHz (453.9 – 463.9 kHz) to allow the lower sideband to pass, being 457.3 kHz measured at TP C (see Figure 5 (c)). This 457.3 kHz is then amplified by the IF amplifier. These measured values are verified by the results of the simulation model which are shown on the right hand side.

6.0 CONCLUSIONS

From the foregoing discussion and analysis, it can be concluded that the results of the simulation model of the SSB transmitter closely resemble the results obtained from a hardware SSB transmitter training board. This justifies using the proposed simulation model in the training of senior engineering students to achieve the desired outcomes related to the operating principles of a SSB transmitter. This will aid students to better understand the operating principles of each section within the SSB transmitter, thereby facilitating synthesis as students logically combine the various elements into a fully operational system. Students can further evaluate the overall system according to international standards, determining the quality of carrier suppression. Students may also manipulate the main parameters (carrier and modulating frequencies, filter characteristics and amplifier gain) to observe the limits and thresholds of successful operation. The frequency domain sketches may also be stored and printed out for future reference or discussion. This all contributes to the promotion of higher-order cognitive thinking, as students are helped to develop their critical-thinking and creative problem-solving skills. The modeling of the SSB transmitter in the free simulation software, SIMTERIX, may very well assist senior engineering students to take “knowledge” away from the university in the form of understanding, synthesizing and evaluating a SSB transmitter.

7.0 ACKNOWLEDGEMENTS

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