THE MODIFIED ‘SWITCHING-MODULATOR’ FOR GENERATION OF AM AND DSB-SC: THEORY AND EXPERIMENT

B Kanmani

Department of Telecommunication Engineering,
BMS College of Engineering, Basavanagudi, Bangalore – 560 019 INDIA
Email: bkanmani.tce@bmsce.ac.in

ABSTRACT

The ‘switching-modulator’ or the ‘square-law’ modulator can be used for generating amplitude modulation (AM/DSB), while the ‘ring-modulator’ or the balanced modulator can be used to generate double-side-band-suppressed-carrier (DSB-SC) in the laboratory. For decades it has been accepted that different circuits are required for generating these two forms of AM, which differ only in the presence or absence of the independent carrier. In this work, we have modified the switching-modulator by introducing an additional active device. With this modification, the modulator becomes capable of generating AM with varying depths of modulation, including the DSB-SC. Thus a single circuit can be used to generate both the DSB and the DSB-SC. We give the theory and the experimental results of the modified ‘switching modulator’. The simplicity of the proposed method makes it ideally suited for laboratory implementation.

Index Terms— amplitude modulation, analog circuit, analog modulator, analog adder, analog filter

1. INTRODUCTION

Generation of various forms of amplitude modulation (AM), continues to find place in the present Undergraduate Engineering curriculum of the ‘Electrical Sciences’ stream. While the normal AM or the double-side-band (DSB) is generated using either the ‘switching-modulator’ or the ‘square-law’ modulator; the double-side-band-suppressed carrier (DSB-SC) is generated using the balanced modulator or the ‘ring-modulator’. It is known that generation of the DSB using the ‘switching modulator’, necessitates the amplitude of the carrier to be much higher than the message amplitude since the switching action needs to be dependent only on the carrier, while in the square-law modulator, the total amplitude of the message and carrier to be ‘low’ enough to operate the active device in the ‘square-law’ region [1-5]. Thus both the existing methods of discrete component realization of the AM have strict operating conditions. The ‘ring modulator’, used for the generation of the DSB-SC, does not have strict difficult to maintain operating conditions. The DSB-SC with the carrier becomes the DSB, while the DSB with the carrier removed results in the DSB-SC form of modulation. Yet, the ‘switching-modulator’ or the ‘square-law’ modulator cannot be used for the generation of the DSB-SC, nor can the ‘ring-modulator’ be used to generate the DSB. Independent transformer-less circuits for generating the AM and the DSB-SC have been developed [6,7], which are suitable for low power generations. In this work, we modify the ‘switching modulator’ to be able to generate both the DSB and the DSB-SC, along with the elimination of the difficult to maintain operating conditions present in existing methods.

The rest of the paper is as follows: Section 2 describes the ‘switching modulator’, along with a discussion of the ‘square-law’ modulator and the ‘ring modulator’. Although these methods are well described in any Under Graduate book on ‘Analog communication’, a brief discussion is included to help comprehend the modification and benefits of the proposed ‘modified switching modulator’. Section 3 gives the working of the developed ‘modified switching modulator’, while Section 4 gives the experimental implementation together with the results. Section 5 has the concluding remarks.

2 THE SWITCHING MODULATOR

The blocks in the ‘switching modulator’ used for low-power generation of the AM waveform are: (i) a means for summing the high frequency sinusoidal carrier $c(t)$ given by $A_C \cos(2\pi f_C t)$ and the low pass message signal $m(t)$, (ii) an active device and (iii) a band pass filter (BPF) tuned to the carrier frequency, as shown in figure 1.

978-1-4244-3677-4/09/$25.00 ©2009 IEEE

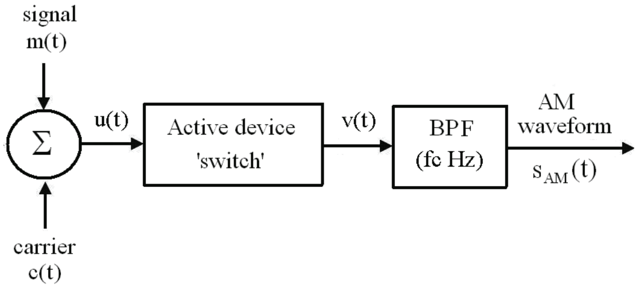


Figure 1: The switching modulator used for the generation of amplitude modulated waveform

It can be seen that the input to the active device $u(t)$, is given by,

$$u(t) = \left[m(t) + A_C \cos(2\pi f_C t) \right] \tag{1}$$

Although the carrier and the message signal are available as the sum at the input to the active device, it is assumed that the magnitude of the message signal is far less than the carrier amplitude, i.e.,

$$|m(t)| << A_C \tag{2}$$

and hence, the switching of the active device depends only on the carrier. With this assumption, the signal $v(t)$, at the output of the active device can be represented as:

$$v(t) \cong \begin{cases} u(t) & c(t) > 0 \\ 0 & c(t) < 0 \end{cases} \tag{3}$$

or equivalently as,

$$v(t) = u(t) g(t) \tag{4}$$

where $g(t)$ is a rectangular pulse waveform, switching states between 0V and +1V, at a frequency equal to the carrier frequency f_C Hz. Using Fourier analysis, it can be shown that the output of the band pass filter (BPF), tuned to the carrier frequency f_C, and bandwidth $2f_m$, results in the desired AM waveform, given by:

$$s_{AM}(t) = \frac{A_C}{2} \left[1 + \frac{4}{\pi A_C} m(t) \right] \cos(2\pi f_C t) \tag{5}$$

For proper functioning of this switching modulator, the condition imposed by equation (2) has to be satisfied, which implies the modulation index of the generated AM waveform is very low. In addition, the assumption of an ideal switch for the active device may not be realistic. Hence, AM generated using the switching modulator being of low modulation depth, cannot be used to demonstrate ‘over-modulation’.

2.1 The square-law modulator

The blocks in the ‘switching modulator’ can be converted to the ‘square-law’ modulator, which is another method of low power AM generation, by changing the region of operation of the active device of figure 1. Here the active device is operated such that its output is related to its input through,

$$v(t) = a_1 u(t) + a_2 u^2(t) \tag{6}$$

with a_1 and a_2 being constants, and $u(t)$ remaining same as before (equation (2)). With signal $v(t)$ given to a BPF tuned to the carrier frequency f_C with bandwidth $2f_m$, produces the desired AM

$$s_{AM}(t) = a_1 A_C \left[1 + \frac{2a_2}{a_1} m(t) \right] \cos(2\pi f_C t) \tag{7}$$

The proper functioning of this modulator depends on operating the active device in the ‘square-law’ region, which necessitates the transfer characteristic, can be exactly represented by equation (6). This is a valid assumption for any active device, for a very small operating range. Moreover, maintaining the operating range within permitted levels is practically difficult, since the amplitude swing of the message signal is unknown. Hence, the square-law modulator generates AM, for limited operating range in the carrier and signal strengths. This is the main drawback of the square-law modulator.

To summarize the existing methods of low power AM generation: the square-law modulator has low operating amplitude range for the incoming message and carrier, as the active device needs to be operated only in the square-law region, while the switching modulator produces AM only for low modulation index. Moreover, both these methods cannot generate the DSB-SC waveform, which is the AM with the carrier suppressed.

2.2 Existing methods for DSB-SC generation

The DSB-SC can be generated using either the balanced modulator or the 'ring-modulator'. The balanced modulator uses two identical AM generators along with an adder. The two amplitude modulators have a common carrier with one of them modulating the input message $m(t)$, and the other modulating the inverted message $-m(t)$. Generation of AM is not simple, and to have two AM generators with identical operating conditions is extremely difficult. Hence, laboratory implementation of the DSB-SC is usually using the 'ring-modulator', shown in figure 2, having four blocks: (i) input transformer, (ii) four diodes arranged to form a ring, (iii) output transformer and (iv) the BPF. The modulator has two external inputs: (i) the message signal or the modulating signal $m(t)$, and (ii) the symmetric, zero-mean square wave carrier $p(t)$, switching between magnitudes $\pm A_{DC}V$, at the carrier frequency f_C Hz. When the carrier is positive, the outer diodes (D0) conduct, while for the other half cycle of the carrier, when it assumes a negative value, the inner diodes (D1) conduct (figure 2).

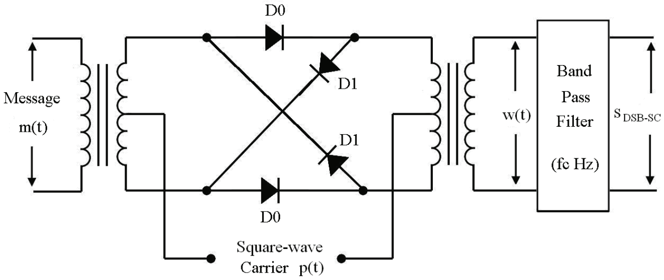


Figure 2: The ring modulator used for the generation of the double-side-band-suppressed-carrier (DSB-SC)

Hence, it can be seen that the input $w(t)$ to the band pass filter (BPF) of figure 2, can be represented as:

$$w(t) = \begin{cases} m(t) & p(t) > 0 \\ -m(t) & p(t) < 0 \end{cases} \qquad (8)$$

which is equivalent to

$$w(t) = m(t)p(t) \qquad (9)$$

With $w(t)$ applied to BPF, tuned to the carrier frequency f_C and bandwidth $2f_m$, we have the filter output as the desired DSB-SC waveform:

$$s_{DSB-SC}(t) = \frac{4A_{DC}}{\pi} m(t) \cos(2\pi f_C t) \qquad (10)$$

This standard form of DSB-SC generation is the most preferred method of laboratory implementation. However, it cannot be used for the generation of the AM waveform.

2.3 A comment

The DSB-SC and the DSB forms of AM are closely related as; the DSB-SC with the addition of the carrier becomes the DSB, while the DSB with the carrier removed results in the DSB-SC form of modulation. Yet, existing methods of DSB cannot be used for the generation of the DSB-SC. Similarly the ring modulator cannot be used for the generation of the DSB. These two forms of modulation are generated using different methods. Our attempt in this work is to propose a single circuit capable of generating both the DSB-SC and the DSB forms of AM.

3 THE MODIFIED SWITCHING MODULATOR

The block diagram of the 'modified switching modulator' given in figure 2, has all the blocks of the switching modulator (figure 1), but with an additional active device. In this case, the active device has to be of three terminals to enable it being used as a 'controlled switch'. Another significant change is that of the 'adder' being shifted after the active device. These changes in the 'switching-modulator' enable the carrier to independently control the switching action of the active device, and thus eliminate the restriction existing in the usual 'switching-modulator' (equation (2)). In addition, the same circuit can generate the DSB-SC waveform. Thus the task of modulators given in figures 1 and 2 is accomplished by the single modulator of figure 3.

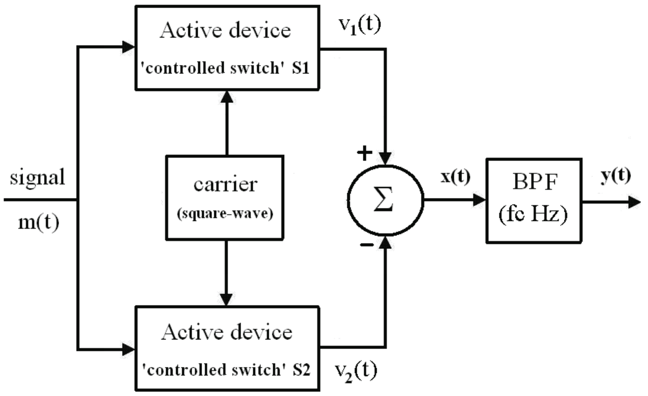


Figure 3: The modified 'switching modulator'

As in the ring modulator, the carrier $p(t)$, is a symmetric, periodic, zero-mean, square wave, of frequency f_C Hz, (equal to that of the sinusoidal carrier $c(t)$), switching between voltage levels $\pm A_{DC}$ V. Switch S1 is such that it conducts when the carrier is 'high', and produces an output voltage $v_1(t)$ given by,

$$v_1(t) = \begin{cases} \left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right) & p(t) > 0 \\ 0 & p(t) < 0 \end{cases} \tag{11}$$

with α, β and γ being constants. On the other hand, switch S2 conducts when the carrier is 'low', and produces an output voltage $v_2(t)$ given by,

$$v_2(t) = \begin{cases} 0 & p(t) > 0 \\ \left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right) & p(t) < 0 \end{cases} \tag{12}$$

One possible implementation of the controlled complementary switches S1 and S2 is given in figure 4. In this case, the constants α, β and γ, depend on the numerical value of the resistors R_B, R_C, R_E, and the characteristics of the transistor.

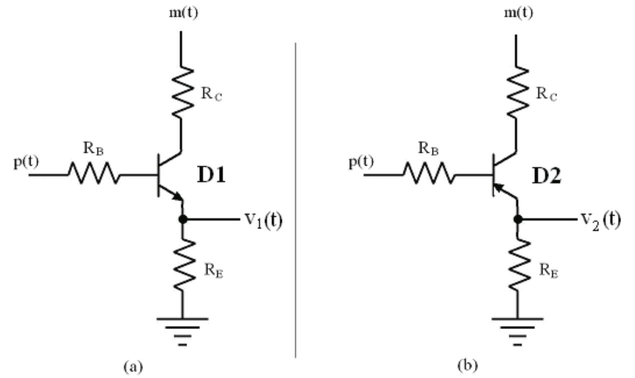


Figure 4: The 'controlled switches' used in the 'modified switching modulator'

The difference of $v_1(t)$ and $v_2(t)$ yields the signal $x(t)$, the input to the BPF:

$$x(t) = \begin{cases} \left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right) & p(t) > 0 \\ -\left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right) & p(t) < 0 \end{cases} \tag{13}$$

which is equivalent to,

$$x(t) = \left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right).\left(p(t)/A_{DC}\right) \tag{14}$$

Using the Fourier representation for $p(t)$, we obtain $x(t)$, the input to the BPF as,

$$x(t) = \left(\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right) . \left[\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)}\cos\left[2\pi f_C t(2n-1)\right]\right]$$

…..(15)

The frequency components in the spectrum of $x(t)$ are: (i) impulse at odd harmonics of the carrier frequency f_C Hz, and (ii) the message spectrum $M\left(f\right)$, scaled and frequency translated to odd harmonics of the carrier frequency f_C. Hence, with $x(t)$ applied to a band pass filter (BPF), tuned to the carrier frequency f_C, with bandwidth $2f_m$, we have the filter output $y(t)$, as,

$$y(t) = \frac{4}{\pi}\left[\alpha\left(A_{DC} - \gamma\right) + \beta\, m(t)\right]\cos\left(2\pi f_C t\right) \tag{16}$$

Equation (16) shows that an AM waveform is obtained when the amplitude of the carrier $p(t)$ satisfies: $\left(A_{DC} > \gamma\right)$, while a DSB-SC waveform is obtained when is equal to $\left(A_{DC} = \gamma\right)$. Thus, it is possible to obtain AM or the DSB-SC waveform from the 'modified switching-modulator' of figure 3, by just varying A_{DC}, the amplitude of the square wave carrier $p(t)$. It may be noted that the carrier performs two tasks: (i) control the switching action of the active devices and (ii) control the depth of modulation of the generated AM waveform. Thus, the proposed modification in the switching modulator, enables the generation of both the AM and the DSB-SC from a single circuit. Also, it may be noted that the method is devoid of any assumptions or stringent difficult to maintain operating conditions, as in existing low power generation of the AM. We now implement the 'modified switching modulator' and record the observed output in the next Section.

4. EXPERIMENTAL RESULTS

The complementary switches may be implemented using BJTs or the FETs or any two channel analog switch. The adder can be implemented using operational amplifiers or using transformers. The BPF can be either an active or a passive filter. The circuit implemented for testing the proposed method is given in figure 5, which uses transistors CL-100 and CK-100 for controlled switches, two transformers for the adder, followed by a passive BPF. The square-wave carrier and the sinusoidal message are given from a function generator (6MHz Aplab FG6M). The waveforms are observed on the mixed signal oscilloscope (100MHz Agilent 54622D, capable of recording the output in '.tif' format).

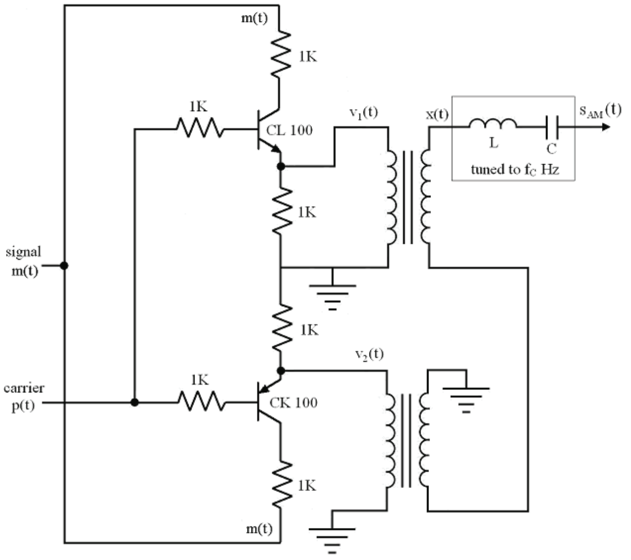
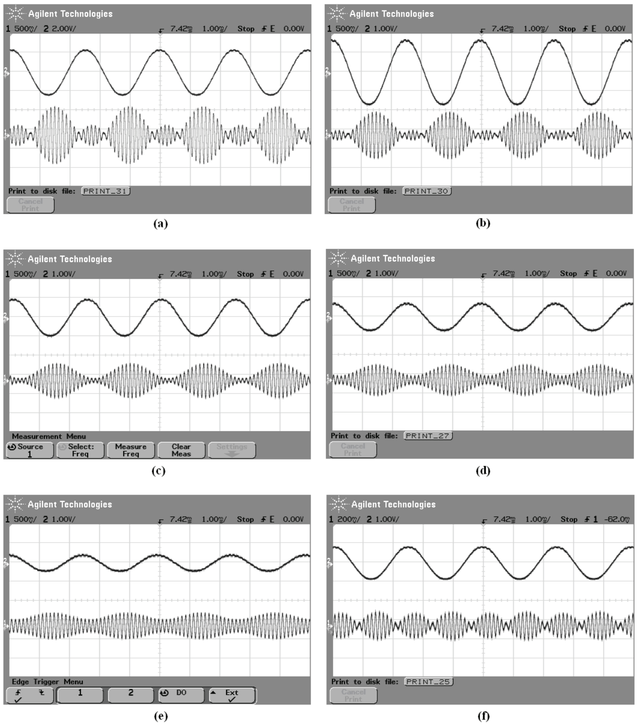


Figure 5: The implementation of the modified 'switching modulator' to generate the AM and the DSB-SC waveform

The modified switching modulator is tested using a single tone message of 706 Hz, with a square-wave carrier of frequency 7.78 KHz. The depth of modulation of the generated waveform can be varied either by varying the amplitude of the carrier or by varying the amplitude of the signal. Figure 6 has the results of the modulated waveforms obtained using the 'modified switching modulator'. It can be seen that the same circuit is able to generate AM for varying depths of modulation, including the over-modulation and the DSB-SC. The quality of the modulated waveforms is comparable to that obtained using industry standard communication modules (like the LabVolt for example).



(a) (b)

(c) (d)

(e) (f)

Figure 6: The message signal of 706 Hz along with the modulated waveforms obtained using the modified switching modulator, with a carrier of frequency 7.78 KHz : (a) to (e) AM for varying depths of modulation, and (f) the DSB-SC waveform

5. CONCLUSIONS

The existing methods for laboratory implementation of the DSB and the DSB-SC modulated waveforms require different circuits. We have demonstrated the generation of both the DSB and the DSB-SC using the modified 'switching modulator' for single tone modulation. The quality of the generated waveforms is comparable to those obtained using standard communication modules. The simplicity of the developed circuit makes it suitable for undergraduate laboratory implementation. Since the circuit generates AM using transistors and transformers, this method can be used for high power commercial broadcast of AM by replacing the semiconductor transistors with vacuum tubes.

Acknowledgements

The author would like to thank the Principal Dr K Mallikharjuna Babu and the Chairman Dr S Bislaiah, for providing an environment suitable to pursue research. Specific thanks are to Smt. Jayashubha, the laboratory Instructor, for patiently testing and recording the results of all the circuits.

REFERENCES

[1] S Haykin, 'Communication systems', Second Edition, Wiley Eastern Limited, 1983

[2] S Haykin, 'An Introduction to Analog and Digital Communications', John Wiley & Sons (Asia) Pte. Ltd, 2001

[3] G Kennedy, 'Electronic Communication Systems', third edition, Tata McGraw Hill, 1991

[4] B P Lathi, 'Communication systems', Wiley Eastern Limited, 1989

[5] S Haykin and B V Veen, 'Signals and Systems', Wiley Eastern Limited, 1999

[6] B Kanmani, 'The transformer-less double-side band suppressed carrier generation', The IET International conference on Wireless, Mobile and multimedia network, Mumbai, India, pp 121-124, 11-12, January 2008.

[7] B Kanmani, 'The transformer-less generation of amplitude modulation: Theory and Experiment', ICECS 2008, The 15th International conference on Electronics, Circuits and Systems, August 31st-September 3rd, Malta, 2008