# Practical Analysis of Signals with Amplitude Modulation

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*Abstract* – **A practical exercise for presentation and analysis of signals with different kind of amplitude modulation is described in the paper. A new method for interactive simulation of processes is proposed. The method can be developed and the described exercise can be used for web based distance education.**

*Keywords* – **signal processing, amplitude modulation, computer simulation, distance education.**

## I. Introduction

Modulation is a Physical process, in which the spectrum of a low frequency signal i.e. the carrier of some information, is transferred in the high frequency domain. This is a method of long-distance signal transmitting, whose basics are going to be represented.

One of the parameters $(a_1, a_2, a_3, ..., a_n)$ of a high frequency signal $a(t) = f(a_1, a_2, a_3, ..., a_n)$, called 'Carrier', synchronized with a low frequency signal $s(t)$, that is the carrier of information, is varied in time. As a result a high frequency signal, called 'Modulated Signal' is outputted, which possesses a qualitatively new property. It gets the information that is previously carried by the signal $s(t)$. Usually as a Carrier is used harmonic tremble of this kind:

$$a(t) = A_0 \cos(\omega_0 t + \varphi_0) \ , \qquad (1)$$

If just its amplitude varies as time passes, an 'Amplitude-modulated signal' is got, whose mathematical model is as it follows

$$a(t) = A_m \cos(\Omega t + \varphi_\Omega) \ , \qquad (2)$$

where the quantity 'm' is called 'Coefficient of modulation'.

In case the low frequency signal (called 'Modulating signal', as well) is a harmonic tremble of this kind:

$$s(t) = A_m \cos(\Omega t + \varphi_\Omega) \ , \qquad (3)$$

monotone amplitude-modulated signal is got, described with the following expression:

$$a(t) = A_0[1 + m\cos(\omega_0 t + \varphi_0)]\cos(\omega_0 t + \varphi_0) \ , \qquad (4)$$

and the coefficient of amplitude modulation is

$$m = \frac{A_m}{A_0} = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}} \ . \qquad (5)$$

Generally this coefficient is taken separately for both positive and negative semi-waves. When the coefficient of amplitude modulation is a small value, the relative alternation of the wrapping curve is small $|ms(t)| << 1$. On condition that $|ms(t)| \approx 1$, the process is called 'Deep amplitude modulation'.

After appropriate mathematical transformations the signal presented with (4) could be represented as a sum of harmonic trembles.

$$a_{AM}(t) = A_0\cos(\omega_0 t + \varphi_0) + \frac{mA_0}{2}\cos[(\omega_0 - \Omega)t + \varphi_0 - \varphi_\Omega] + \frac{mA_0}{2}\cos[(\omega_0 + \Omega)t + \varphi_0 + \varphi_\Omega] \ . \qquad (6)$$

These trembles compose the spectrum of the amplitude-modulated signal, whose amplitude-frequency spectrum density diagram is shown on Fig. 1.

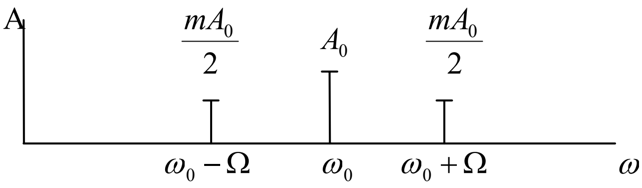


Fig. 1.

The spectrum contains a compound, which frequency equals this of the Carrier signal, and two side compounds with frequencies $(\omega_0 - \Omega)$ and$(\omega_0 + \Omega)$. When the modulating signal is a complex tremble, the spectrum contains as well as the harmonic, that equals the frequency of the Carrier, two side bands of spectrum compounds, as well. The relevant amplitude-frequency spectrum density diagram is shown on Fig. 2.

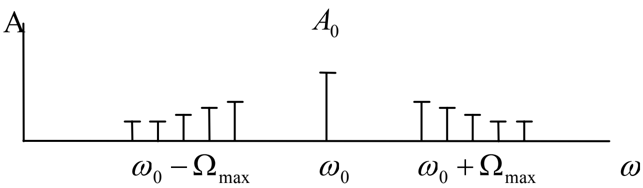


Fig. 2.

The average power of an amplitude-modulated tremble for one period of the Carrier signal is defined by the following expression

$$P_{T_\omega} = \frac{A_0^2}{2}[1 + \cos(\Omega t + \varphi_\Omega)]^2 = P_0[1 + \cos(\Omega t + \varphi_\Omega)]^2 . \qquad (7)$$

In case that a modulating signal is absent the power $P_0$ could be found through (7), when $m = 0$. When $m = 1$ and $\cos(\Omega t + \varphi_\Omega) = 1$ the power is maximal and if $m = 1$ and $\cos(\Omega t + \varphi_\Omega) = -1$, its value is minimal. The average

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power of the radio-signal for one period of the modulating signal is defined by the expression:

$$P_{T_\Omega} = \frac{A_0^2}{2}\left(1+\frac{m^2}{2}\right) = P_0\left(1+\frac{m^2}{2}\right) \ . \qquad (8)$$

The method of amplitude modulation has some serious disadvantages in respect of Energy. It is clear that even in a work-mode, when a modulating signal is absent, power is radiated, which is the main cause of the low efficiency of amplitude-modulating devices.

For reducing the energy losses of amplitude modulation, the so-called, 'Balance Amplitude Modulation' (BAM) is utilized. When BAM is used, as it is shown on Fig. 3, the compound, whose frequency equals this of the Carrier, is eliminated. This way 'Null Power' is ensured in a work-mode, when a modulating signal is absent. BAM is rarely used in practice, mainly because of complicated technical problems with receiving devices, as the Carrier has to be restored.

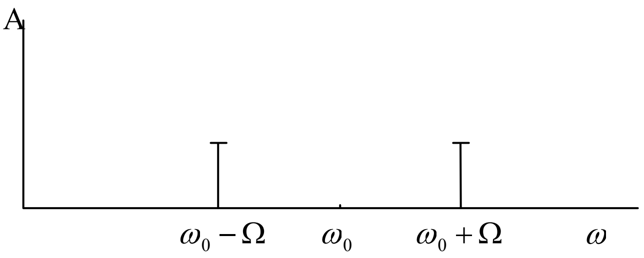



Fig. 3.

Based on the expression (4), the amplitude-modulated signal could be represented through BAM, where the modulating signal is a harmonic low frequency signal:

$$\begin{aligned} a_{BM}(t) &= mA_0\cos(\Omega t+\varphi_\Omega)\cos(\omega_0 t+\varphi_0) = \\ &= \frac{mA_0}{2}\cos[(\omega_0-\Omega)t+\varphi_0-\varphi_\Omega] \\ &\quad + \frac{mA_0}{2}\cos[(\omega_0+\Omega)t+\varphi_0+\varphi_\Omega] \ . \qquad (9)\end{aligned}$$

Another way of long-distance signal transmitting is the method of 'Amplitude manipulation' (AMn). Manipulated signals distinguish by the fact that their Carriers are continuous ones, but modulating signals are discrete, mainly square pulses. The amplitude of a Carrier varies curtly according to changes in the manipulating signal, so that the manipulated signal is better secured from noise and any kind of interference than amplitude-modulated ones. An amplitude-manipulated signal could be presented with the following expression:

$$a_{AMn}(t) = a_m(t)\cos\omega_0 t, \ a_m(t) = \begin{cases} A_0, & \text{binary } '1' \\ 0, & \text{binary } '0' \end{cases} \ . \qquad (10)$$

## II. Practical Analysis of AM, BAM and AMn signal

The results of AM, BAM and AMn could be observed and analyzed in details through the visual tool 'Simulink', which is a part of the programming environment of the 'Matlab' package. 'Simulink' is an outstanding application that implements lots of Matlab's built-in functions, so that their use is easy and powerful and, furthermore, models developed through it resemble real engineering solutions. This will become clear when the structure and the user-interface of the models of AM, BAM and AMn, are discussed. Each of the presented models uses strongly simplified and standard user-interface, which provides full control over the features of real-time simulations. One of the models is presented on Fig. 4.

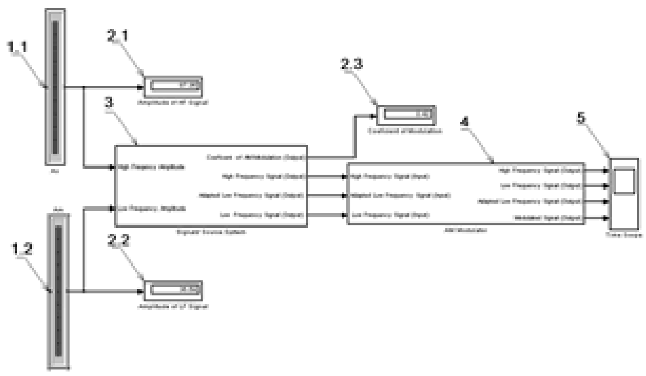



Fig. 4.

One could use such a model to thoroughly analyze Physical processes bonded with these sorts of modulation of continuous signals. An example list of some of the possible tasks of an exercise is presented and detailed explanations are available, as well.

## III. Task of the Exercise

1. The process of AM has to be simulated, as the parameters of the Carrier, the Modulating signals and the coefficient of modulation are properly selected. Observe and analyse the graphics of several cases, when $m < 1$.

2. Simulate the processes of Deep modulation and Over modulation and observe the corresponding graphics.

3. Simulate the processes of Balance Amplitude Modulation (BAM) and Amplitude Manipulation (AMn).

4. Observe and analyse in details the Power Spectral Density Diagrams, provided by the PSDAs, for both the modulated/ manipulated and the input signals.

## IV. Practical Guide for the Exercize

At first a 'Simulation' has to be run through the 'Play' button, positioned on the main toolbar.

The values of amplitudes of the input signals are set, while a real-time simulation is running, through two ActiveX components (components 1.1 and 1.2 onto Fig. 4), i.e. sliders with discrete range from 0.01 to 100 and step of 0.01, which, practically, means that these amplitudes vary from 0.01 to 100.

Their values could be observed on the digital control displays 2.1 and 2.2 on Fig. 4. Thus both input signals and the coefficient of modulation (estimated in reference to equation (5)), whose value is displayed by the component 2.3 on the same figure, are precisely managed.

The 'Signals' Source System', i.e. component 3 on Fig. 4, generates both the Carrier and the Modulating signal, while doing some minor calculations. For example, it estimates the coefficient of modulation. Inspired by the Object-Oriented Programming (OOP), 'Simulink' makes it possible to create complex structures and hierarchies through its components as it is clear from Fig. 5, where the internal structure of the system 'Signal Source' is presented.

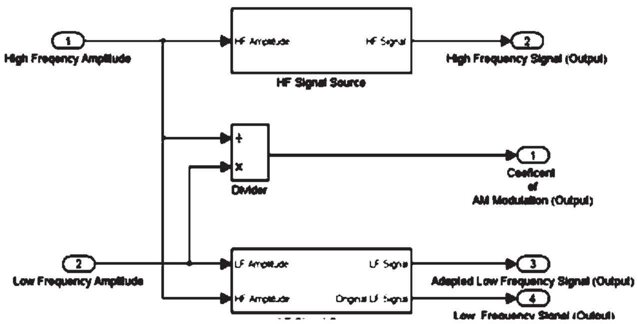



Fig. 5.

An option changing the sort of the continuous input signals (sine, square pulses, saw tooth and random signals are available) and their frequencies is easily found in the subsystems 'Source of the LF signal' and 'Source of the HF signal' (Fig. 6).

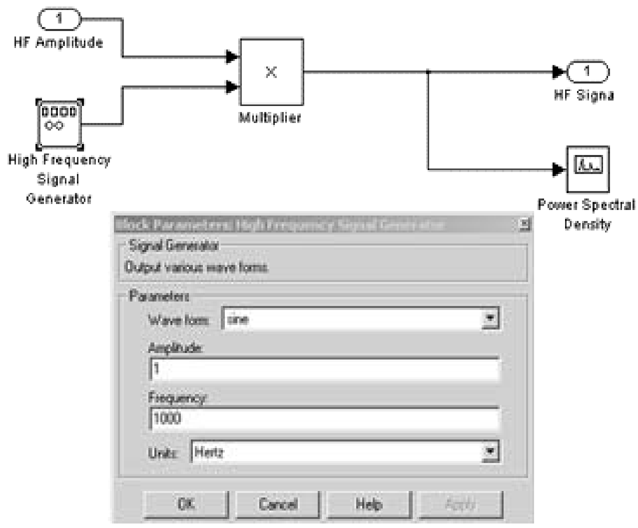
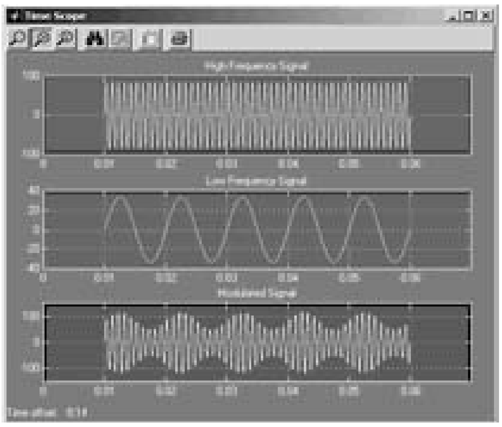



Fig. 6.

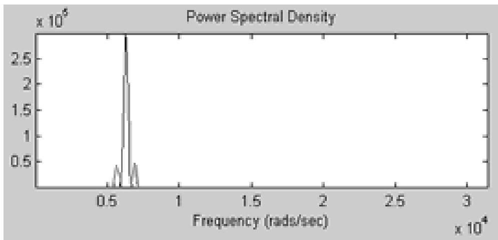
The 'Modulating System', which is component 4 on Fig. 4, modulates/manipulates input signals using the correspon- ing expressions for AM, BAM and AMn: (4), (9) and (1 It also passes input and modulated signals to the Time sco (component 5 on Fig. 4), through which they could be observed and analyzed in the time domain. Besides through the three Power Spectral Density Analyzers (PSDAs), positioned within the 'Signal Source' and the 'Modulating System', analyses about the properties of all the signals in the frequency domain could be worked out.

Fig. 7 demonstrates some results of AM, BAM and AMn in the time and frequency domains.

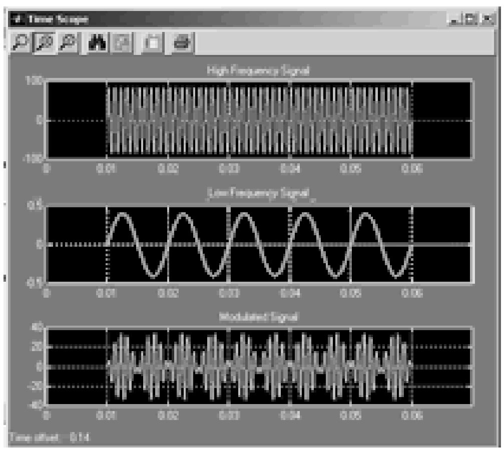
Apparently, having known all about input signals and the modulated signal, i.e. their form, spectrum and the influence of the coefficient of modulation, all the cases from the exam-



**AMPLITUDE MODULATION**
**(TIME DOMAIN, PRESENTED THROUGH A TIME SCOPE)**

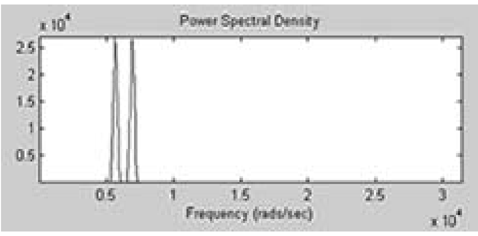



**AMPLITUDE MODULATION**
**(FREQUENCY DOMAIN, PRESENTED THROUGH A PSDA)**

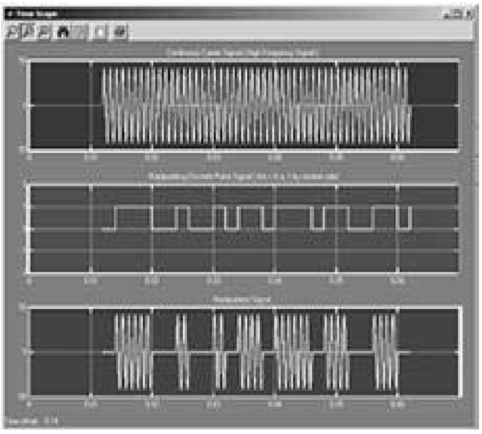


**BALANCE AMPLITUDE MODULATION**
**(TIME DOMAIN, PRESENTED THROUGH A TIME SCOPE)**

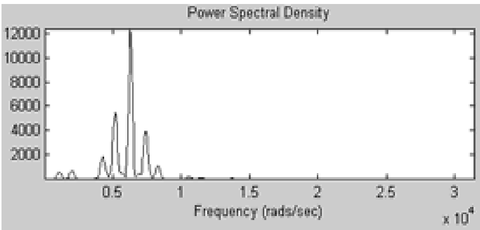
Fig. 7.




***BALANCE AMPLITUDE MODULATION***
***(FREQUENCY DOMAIN, PRESENTED THROUGH A PSDA)***



***AMPLITUDE MANIPULATION***
***(TIME DOMAIN PRESENTED, THROUGH A TIME SCOPE)***




***AMPLITUDE MANIPULATION***
***(FREQUENCY DOMAIN, PRESENTED THROUGH A PSDA)***

ple task list could be easily analyzed. Each of the models, developed through 'Simulink' for this exercise gives the same readiness in use, combined with powerful flexibility in managing with the signals used. To facilitate users all the typical cases, in which the Modulating signal might be sinusoidal, square impulses, saw tooth and even random, have been developed, as well, so that switching to different input signals is as easy as loading an ordinary file in an arbitrary Win32 application.

## V. Conclusion

- As the simulations are real-time, when some basic parameters of input signals are altered (the amplitude, the frequency or the form), while a simulation is running, the changes of signals in the time and frequency domain could be observed and analyzed indetails.
- The models are suitable both for the process of searching and developing better and easier to construct real engineering solutions and for education in the field of Signals (Telecommunications, DSP, LAN, WAN etc.).
- Like in the OOP one interface might implement different and complex actions, which means standardization.
- The 'user-friendly' interface, which is one and the same for all the built models, gives users the opportunity to do their job without any preceding training.
- The small size of the model files makes them easily publicized on remote servers and, consequently, they are suitable for distant educational purposes.

## References

[1] Dimitrov D., Kamenov C., Georgieva V., Signals and Systems Techniques Laboratory Work, 2001.
[2] Ferdinandov E., Signals and Systems, 2000.
[3] Nenov G., Signals and Systems, 1999.