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Precisely Measuring Using Behavioural Blocks in PSpice

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Abstract – We created specialized behavioral blocks that compute fast and accurately the power, the rms and average values of a signal. The signals can be seen through an adjustable "examination window". The method was tested on some filters and illustrated on some DC-DC converters, where the switch period is of μseconds and it is hard to obtain accurate data. The signals can be seen through an adjustable window.

Keywords: behavioural blocks, VIP, VIMED

I. INTRODUCTION

Generally, the problem of the system analysis is to find a system's response at given excitations. Therefore establishing necessary and sufficient parameters is necessary for obtaining the response's signals. In this measuring method we are interested in obtaining the response's signals through numerical simulation, using Pspice.

A no harmonic but periodic excitation can be developed in Fourier series as a sum of harmonic components and one can apply the superposition principle. The analysis can be reduced to find the response of each harmonic excitation component that actually means determining the magnitudes and initial phases for the harmonic components. The principle of superposition cannot be applied on nonlinear systems. The response of a nonlinear system to a harmonic excitation is not harmonic, but periodic so that, even if the excitation has only one harmonic component, the response will have more components with different frequencies [3]. One defines a harmonic signal equivalent to the given signal (no harmonic but periodic) setting the condition that both signals must have the same rms value. The rms value for a periodic signal x(t) with period T is [3]:

$$X_{rms} = \sqrt{\frac{1}{T}\int_T x^2(t)dt} \qquad (1)$$

The instantaneous power of the energy transfer between two uniports is:

$$p(t) = v(t)\cdot i(t) \qquad (2)$$

Even if the circuits are nonlinear, phenomena are periodical and one can define the average power:

$$P_{avg} = \frac{1}{T}\int_T v(t)\cdot i(t)dt \qquad (3)$$

During a Pspice simulation one can measure instantaneous values, time domains or one can use Pspice offered functions. Such an example is RMS() [2]. The root mean square value is computed using specific Pspice techniques (products, filters) and not by applying an integral relation and thus, the function response is oscillatory damped. Experimental studies we made showed that the RMS() function response's damping in Pspice was slower than the computing time used by the techniques described here. For obtaining a convenient precision, the time for a regular Pspice simulation is very long.

Because of these reasons, we created some specialised behavioral blocks for measurement, VIP and VIMED, more faster and precise. For rigorously applying relation (1), the integral must be computed on an interval multiple of the signal's period and, for a higher precision, the computation is done after the transitory regime is finished. The signals can be seen through an adjustable „examination window"[6].

The blocks used for measuring the rms and average values perform mathematic relations between the corresponding input and output signals. This is why the blocks are created as macromodels containing controlled "mathematic expression" or "table" sources and predefined mathematic functions of the Pspice simulator.

The whole work is done during the periodic regime of the measured signals. By *transitory regime* we mean the simulation transitory time for each simulation running until the model reaches its

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permanent regime. Nonperiodical signals have not been studied.

II. MACROMODELS

A. *The Hanning window*

One defines an examination window by a function f(t) that gives the weights according to the signal inside the examination interval and is zero outside this interval. If the signal x(t) is examined during an interval θ, between the moments $t_1$and t_2, with t_2-t_1=θ, the active signal is:

$$x_1(t) = f(t)\cdot x(t) = \begin{cases} f(t)\cdot x(t), t_1 < t < t_2 \\ 0 \qquad , \quad \text{otherwise} \end{cases} \tag{4}$$

The window is used to control an *integration process* and must not affect the integral value, so the following normalization relation has to be assessed:

$$\int_{t_1}^{t_2} f(t)dt = 1 \tag{5}$$

The rectangular window gives the same weight along all points of the examination interval of the signal.
The macromodel of the Hanning window is obtained by developing the rectangular window by adding a cos(2πt/θ) block, thus the mathematic expression of the Hanning window is:

$$\text{hann}(t) = \begin{cases} \frac{1}{\theta}\cdot\left[1+\cos\left(2\pi\cdot\frac{t-\tau}{\theta}\right)\right] & , |t-\tau|<\frac{\theta}{2} \\ 0 & , |t-\tau|>\frac{\theta}{2} \end{cases} \tag{6}$$

where θ is the examination time, $\theta = t_2 - t_1$, and τ is the middle of the examination interval, $\tau = \frac{t_2+t_1}{2}$.

B. *The VIP Block*

The VIP block has been created for measuring the rms values of the voltage (V) and current (I) and the power (P). This block is used in a section of a conveyor chain and also for measuring the active power sent to a load impedance. There are inputs used for voltages and also "current-controlled voltage sources" inputs, that means of "const*i" type. The block becomes active after a number of N_0 signal periods, after the transitory regime is over, and is measuring the signals over N signal periods.
The "fer" input, connected at the "fer" entrance of every integrator, does control the integration interval. These integrators have been developed from the INTEG integrator of the abm.olb library. The integrator INTEG3 has been modified to have three inputs, accomplishing the function:

$$v_{out}(t) = \text{GAIN}\cdot\int v_{fer}(t)\cdot v_{x1}(t)\cdot v_{x2}(t)dt \tag{7}$$

This integrator will accomplish the function (3), choosing GAIN=1/T=frequency, $v_{x1}(t)=v(t)$, controlled by the window $v_{fer}(t)=fer(t)$. At the output of this block a voltage is obtained, computationally equal to the transferred power. The VALEF integrators have been developed from INTEG of the Pspice library, which have added a new input and do extract the square root. Thus, they calculate the function:

$$v_{out}(t) = \sqrt{\text{GAIN}\cdot\int v_{fer}(t)\cdot v_x^2(t)dt} \tag{8}$$

Choosing GAIN=1/T=frequency, $v_x(t)=v(t)$, controlled by the window $v_{fer}(t)=fer(t)$, the first integrator will compute the rms value of the voltage and the second integrator has the input X connected to a voltage with the same value to that of the current and will generate, after the active window time interval, the rms value of the current $v_2[V] = k[\Omega]\cdot i[A]$ where k=+1 is the gain of H1, measured in Ohms. H1 is a current controlled voltage source. The VIP block has only one transparent parameter, called "frecv", set at the default value of 50Hz [1].

C. *The VIMED Block*

The VIMED block has been created for measuring the average values (MED comes from medium) of the current (I) and voltage (V) in a section of a conveyor chain. The block becomes active after a number of N_0 signal periods, after passing the transitory regime, and is measuring the signals over N signal periods. The signal transmitted from the input to the output of the circuit is not influenced by the VIMED block. The "fer" input of the window block, connected at the "fer" entrance of every integrator, does control the integration interval, that means it opens the window at $t_1=N_0T$ and closes it at $t_2=(N_0+N)T$.
The VALMED integrators have been obtained from INTEG of the Pspice library, which extracts the square root. These blocks must accomplish the function:

$$v_{med}(t) = \sqrt{\text{GAIN}\cdot\int v_{fer}(t)v_x(t)dt} \tag{9}$$

Setting GAIN=1/T=frequency, $v_{x1}(t)=v(t)$, $v_{fer}(t)=fer(t)$ the integrator will compute the average value of the voltage, for the first integrator and the average value of the current for the second integrator. The VIMED block has only one transparent parameter, called “frecv”, set at the default value of 50Hz[1].

stable and the transitory regime is finished so the values can be measured.

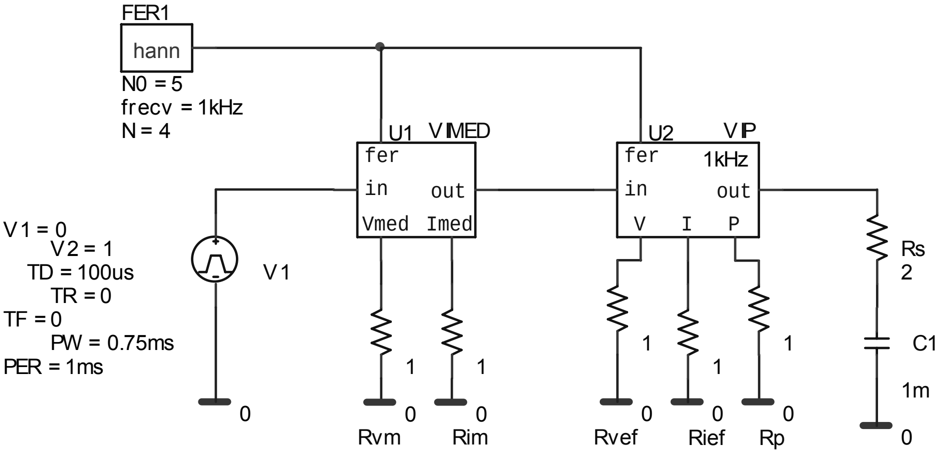

Fig. 1 Low pass filter circuit for testing the method for rms, average values and power

III. RESULTS OBTAINED IN PSPICE SIMULATIONS

A. *Filters*

An example is shown in the circuit in fig.1, where the blocks VIP and VIMED are set between the voltage source V_1 and the load resistance R_s. There were made a lot of tests using a high pass (RL) filter and respectively a low pass (RC) filter. After we obtained good results while testing, we used the method for CC-CC converters [4]. When testing we used a pulse voltage source because in CC-CC converters we need this kind of voltage source.

VIMED and VIP blocks are serial with the inductance L1 in first case and serial with the capacitor C1 in the second case. At the resistance terminals R_{vm} is measuring the average value (Vmed) of the filter voltage, R_{im} the average value of the current, R_{vef} the rms value of the voltage (V), R_{ief} the rms value of the current (I) and R_p the load power (P). These resistances have an unitary value for simplifying the reading results: the signal values at the measurement terminals are equal to the current values through the unitary resistances. There were made measurements for different values of the delay time, in every decade from 0μs to 100μs, one has used different values of the duty factor of 0.25ms, 0.5ms and 0.75ms and different values for the integration step, like 0.1, 0.5, 1, 1.5μs. For all these cases, the errors between the simulated and computed values were measured, the validity and utility of the blocks have been checked.

The Hanning window has its parameters set: the frequency to 1kHz, N_0=5, N=4 because one considered that after the fifth period, the LPF signal is

In case of the low pass filter circuit, the duty factor is given, by:

$$f_u = \frac{\theta}{T} \tag{10}$$

The average value of the voltage is calculated using the expression

$$V_{med} = V\frac{\theta}{T} = 1V\cdot\frac{\theta}{T} \tag{11}$$

and the rms voltage

$$V_{ef} = \sqrt{\frac{1}{T}\int_0^{\theta} v^2 dt} = 1V\cdot\sqrt{\frac{\theta}{T}} = 1V\cdot\sqrt{f_u} \tag{12}$$

all that because one consideres the voltage unitary at the circuit input [4].

One write the current described by the equations [4]

$$i(t) = \begin{cases} \dfrac{V}{R}\dfrac{1-e^{-(T-\theta)/\tau}}{1-e^{-T/\tau}}\cdot e^{-t/\tau} = i_1(t), & 0 < t < \theta \\ \dfrac{V}{R}\dfrac{e^{-\theta/\tau}-1}{1-e^{-T/\tau}}\cdot e^{-(t-\theta)/\tau} = i_2(t), & \theta < t < T \end{cases} \tag{13}$$

with the expressions for the average current

$$I_{med} = \frac{1}{T}\int_T I(t)dt = \frac{1}{T}\int_0^{\theta} i_1(t)dt + \frac{1}{T}\int_{\theta}^{T} i_2(t)dt \tag{14}$$

and the rms value:

$$I_{ef} = \sqrt{\frac{1}{T}\int_0^{\theta} i_1^2(t)dt + \frac{1}{T}\int_{\theta}^{T} i_1^2(t)dt} \qquad (15)$$

Under these circumstances, measurements were done obtaining smaller errors than with Pspice techinques.

TABLE 1. Results for HPF

Quantity	F_{duty}=0.25		F_{duty}=0.5		F_{duty}=0.75	
	Val.	*Err %*	*Val.*	*Err %*	*Val.*	*Err %*
Vavg [mV]	250	0.2	500	0.2	750	0.2
Vrms [mV]	500	0.2	707.1	0.2	866	0.19
Iavg [mA]	125	0.06	250	0.06	375	0.06
Irms [mA]	135.3	0.07	259.2	0.19	378	0.18
P [mW]	366.2	0.15	134.4	0.3	286	0.3

There have been made a lot of comparison tables for the computed values (using formulas) and for the measured ones [4] in all situations described above. In tables 1 and 2 there is a short form of all error tables, it's something like the average value. The percentage-errors that have been obtained are very small, for voltages and currents percentage errors were less than 0.2% and for power less than 0.4 %[5].

TABLE 2. Results for LPF

Quantity	F_{duty}=0.25		F_{duty}=0.5		F_{duty}=0.75	
	Val.	*Err %*	*Val.*	*Err %*	*Val.*	*Err %*
Vavg [mV]	250	0.3	500	0.3	750	0.2
Vrms [mV]	500	0.12	707	0.16	866	0.14
Iavg [mA]	216	0.02	249	0.01	216	0.02
Irms [mA]	216	0.04	249	0.01	216	0.02
P [mW]	93.3	0.23	124	0.16	93.3	0.4

B. *CC-CC Converters (Boost)*

Another circuit over which tests were done, is the **Boost CC-CC** converter[3]. In figure 2 is shown the circuit of the step-up converter and, at input and output, set the measurement behavioural blocks controlled by the Hanning block. The frequency of the Hanning window was set to the switch frequency. The final scheme consists on three parts, at the input there is the behavioural block for the Hanning measuring window, the VIMED block that measures the average values of the signals (current and voltage) at the input of the converter, the VIP block used for measuring rms values of the voltage (V) and current (I) and the power (P) at the input of the converter. The second part of the circuit is given by the converter itself; the last part is represented by the VIP and VIMED blocks at the output of the converter, used to measure the average (VIMED) respectively the rms and power (VIP) values of the output signals (current and voltage).

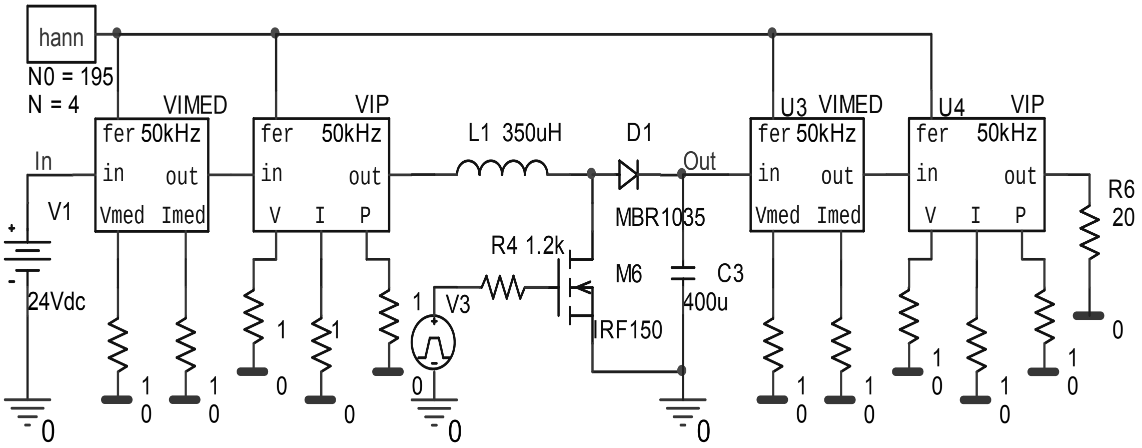

Fig.2. Testing the behavioural blocks for a Boost CC-CC converter

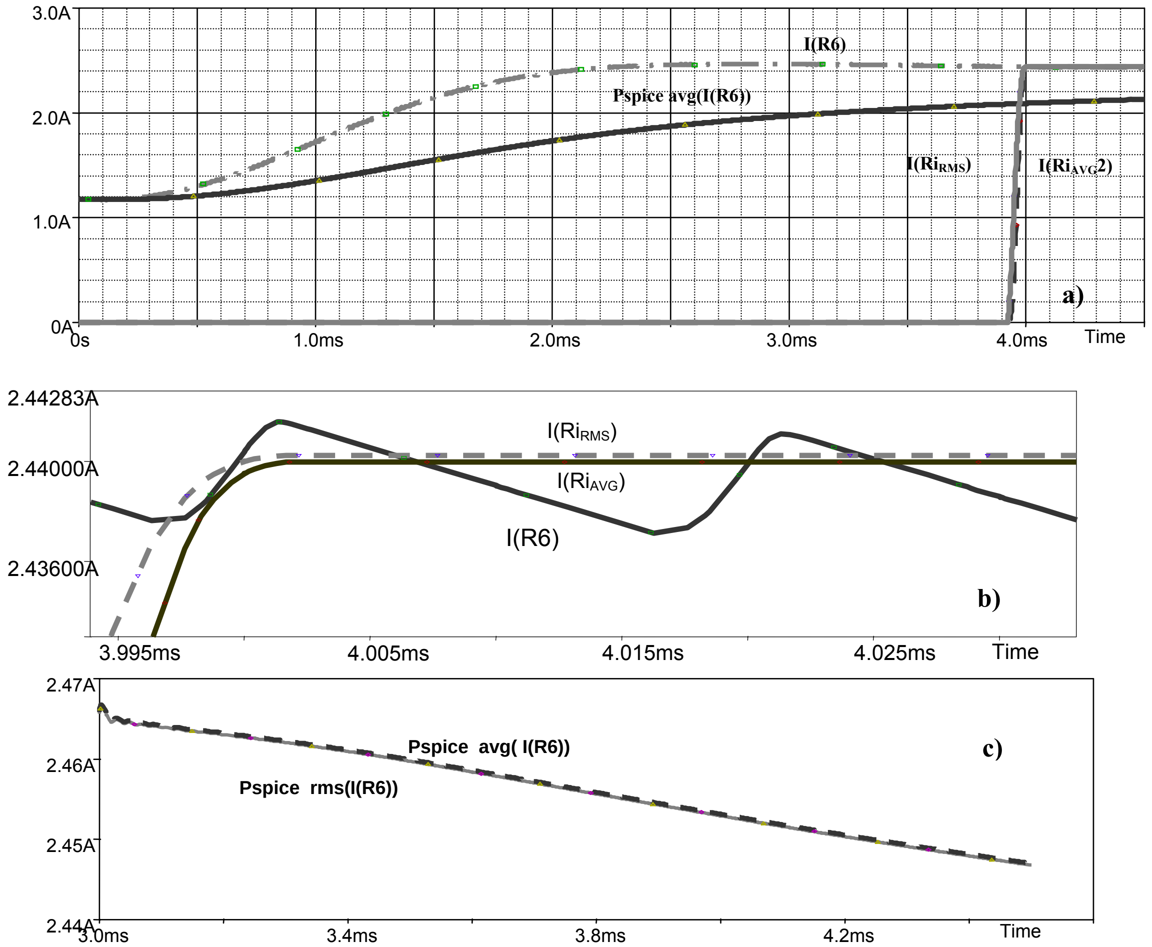

Fig. 3. Output current through the load resistance (ideal value=6A)
a) Comparison of the current, the AVG Pspice function and the AVG and RMS obtained with behavioural blocks b) detail c) zoom

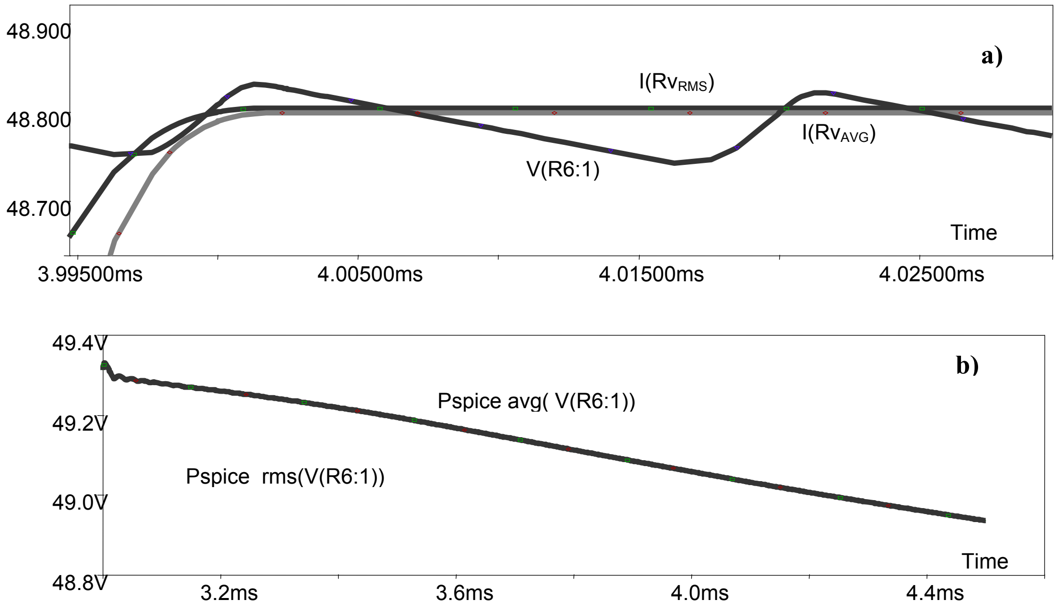

Fig.4. Output voltage (ideal value=48V)
a) Comparison of the current, the AVG Pspice function and the AVG and RMS obtained with behavioural blocks b) zoom

The simulation results of the circuit in fig.2 are shown in fig.3. In fig.3.a there is a comparison between the values obtain with the two methods, the classical Pspice and the one presented here. The advantage of the new method is it's accuracy and the fact that, after applying the observation window, the values are constant and easily to read. This detail is shown in fig.3b and also the behaviour of the RMS and AVG Pspice functions in fig.3c for the output current, behaviour which is everything else that constant. In fig.6 is also presented the output voltage, in fig.4a are shown the values obtained with VIP and VIMED blocks and in fig.4b the behaviour of the RMS and AVG Pspice functions of the same signal.

An important observation is that Pspice computes the values over the entire simulation interval, using all data collection. This means, if we want to obtain an accurate result we have to save the simulation data after the transitory regime is finished. A first conclusion can be drawn that the user must manually do a whole procedure that is avoided by using the measuring blocks. The use of the observation window eases the procedure. Pspice works on a history, meaning that the obtained values are calculated on a history so it is possible that, using exactly the same circuit, one can obtain different values for the same currents or voltages, depending on the history and of the moment in time when the simulation is done. The same phaenomenon happens with the transmitted power. This never happens using the behavioural blocks which work in the permanent regime, so another reason why this method is more accurate.

IV. CONCLUSIONS

This paper presented techniques of measuring power, rms and average values of the signals over a circuit, using some behavioural blocks developed with elements of the ABM library.

For a simple use of this method, all windows have an unitary area. To measure rms values and power the VIP block is used and to measure average values the VIMED block is used.

The "window" technique is very useful for setting the integration interval because the error does not depend on this window, neither on the window's position on the characteristic. The measurements can be done in permanent regime. It is not possible to use the FFT (Fast Fourier Transformation) instead, because FFT would obtain the component's magnitudes in a nonharmonic regime[6]. For the rms, average and power values, otherwise than using this method, some extra computations would be necessary. For the FFT precision, the simulation step should be very small and this would lead to a very long simulation time and huge simulations. This measuring method is original and one obtains very good results, percentual errors less than 1%, usually they are even smaller than 0.5%.

It was showed an example using a simple circuit and comparing the results obtained by computation and simulation [6]. Then the method was used over a more complicated circuit, illustrated here by a Boost-converter, where the switching times are also very small (μ-seconds) and thus the precision is very important[2].

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