Developing Behavioural Macromodels for Calculating PSpice Functions

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Abstract – Instantaneous signal values in regular PSpice simulations can be obtained with PSpice functions using specific PSpice techniques (products, filters) and not by an integral relation and thus the results have significant errors. For a good precision the simulation time should be long. To overcome this problem we created some specialized behavioral blocks. They compute fast and accurately the rms and average values of a signal. Integrals are computed on an interval multiple of the signal period and the computation is done after the transitory regime. The signals can be seen through an adjustable "examination window".

Keywords: VIP and VIMED Blocks, Examination Window

I. INTRODUCTION

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

In case of a liniar system with a harmonic excitation, the response will be harmonic as well, of same frequency but having the magnitude and the initial phase of different values as those of the excitation[3]. The linear system is characterised by a magnitude and a phase delay depending usually on frequency, then the analysis is reduced in this case to the determination of the amplitude and initial phase of the response harmonic signal.

A nonharmonic but periodic excitation can be developed in Fourier series as sum of harmonic components and we can apply the principle of superposition. The analysis can be reduced to finding the response for every harmonic component of the excitation, that means actually 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 at 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].

II. THE EQUIVALENT HARMONIC SIGNAL

Into a section of a diport chain, with periodic signals, appear a voltage v(t) and a current i(t), values which are usually nonharmonic.
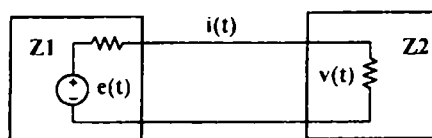

Fig.1 Section into a diport chain

$$i(t) = \frac{e(t)}{Z_1 + Z_2} \quad (1) \qquad v(t) = \frac{Z_2}{Z_1 + Z_2} \quad (2)$$

If the diports are liniar, the equivalent impedances Z_1 and Z_2 depend on frequency, not on current or voltage. If the diports are nonlinear, one cannot apply the clasical characterisation through impedances and constants.

One defines a harmonic signal equivalent to the given signal (nonharmonic but periodic) setting the condition that both signals should have the same rms value. The rms value for a periodic signal x(t) with T period is [3]:

$$X_{ef} = \sqrt{\frac{1}{T} \int_T x^2(t) dt} \qquad (3)$$

The instantaneous power of the energy transfer from the first diport to the second is:

$$p(t) = v(t) \cdot i(t) \qquad (4)$$

Even if the circuits are nonlinear, phaenomena are periodical and one can define a medium power:

$$P = \frac{1}{T} \int_T v(t) \cdot i(t) dt \qquad (5)$$

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Using the elements above one can define an equivalent impedance Z_E as the harmonic equivalent signal:

$$\underline{Z}_E = Z_E \cdot e^{j\varphi_E} \quad (6), \text{ where } Z_E = \frac{V_{ef}}{I_{ef}} \quad (6') \text{ and}$$

$$\cos\varphi_E = \frac{P}{V_{ef}I_{ef}} \quad (6'')$$

Because the diports are nonlinear, the magnitude Z_E and the argument φ_E will depend on the currents and voltages, but also on their waveforms.

III. MEASUREMENTS IN SIMULATION REGIME. MACROMODELS

A Pspsice simulation of electric waves propagation along a diport chain makes possible viewing the voltage and current waves in every section between two consecutive diports. One can measure instantaneous values, time domains or one can use Pspsice offered functions. A such example is RMS() offered by PSpice[2]. The root mean square value is computed using specific Pspice techniques (products, filters) and not by applying an integral relation and, as it follows, the function response is oscillatory damped, with a weak damping. For a convenient precision, the simulation time will be very long. The same problems appear when computing the transmitted power.

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

The blocks used for measuring the rms and average values must be able to do some mathematic relations between the corresponding inputs and outputs. That's why the blocks are created as macromodels containing controlled sources of the types "mathematic expression" or "table" and predefined mathematic functions of the Pspice simulator.

The Rectangular 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 $t_2-t_1=\theta$, the operating signal is:

$$x_1(t) = f(t) \cdot x(t) = \begin{cases} f(t) \cdot x(t), t_1 < t < t_2 \\ 0 \quad , \quad \text{otherwise} \end{cases} \quad (7)$$

Because we use these windows for controlling an integration process and we do not want to affect the integral value, we assess the normalization relation:

$$\int_{t_1}^{t_2} f(t)dt = 1 \quad (8)$$

The rectangular window gives the same weight along all points of the examination interval of the signal. Considering (8) the rectangular window expression is:

$$f_1(t) = \begin{cases} \dfrac{1}{t_2 - t_1} \quad , t_1 < t < t_2 \\ 0 \quad , \quad \text{otherwise} \end{cases} \quad (9)$$

The time intervals that define the window can be expressed depending on the fundamental frequency ($\upsilon = 1/T$) of the examined signal:

$$t_1 = N_0 \cdot T = \frac{N_0}{\upsilon}; \quad t_2 - t_1 = N \cdot T = \frac{N}{\upsilon} = \theta \quad (10)$$

where N_0 is the number of periods from the beginning of the simulation while the window is not active and N is the number of periods while the window is active. The internal structure of the block that generates the window is described in fig.2. The resistances that appear are used only for respecting the Pspice requirements that every circuit node should have a finite resistance to the ground and they have the value $1G\Omega$, theoretically infinite. The measuring principle consists in integrating an unitary pulse current on an capacitor with a reference level.

The group $I_1 - C_1$ starts the integration at the initial moment. Capacitor C_1 is choosen so that its voltage should reach the reference level fixed by the comparator E_1 after N periods, when the output of the comparator jumps from 0 to 1V. This has two consequences: (1) the current through R_4 jumps from 0A to $1/R_4$A and thus the window is opening and (2) the group G_1-C_2-E_2 begins the integration for measuring the time interval while the window is opened. At the end of this time, comparator's E_2 output jumps from 0V to -1V and the current through R_4 becomes 0 again and the window is closing. The resistance value of R_4 makes sure that the norming relation is kept[1].
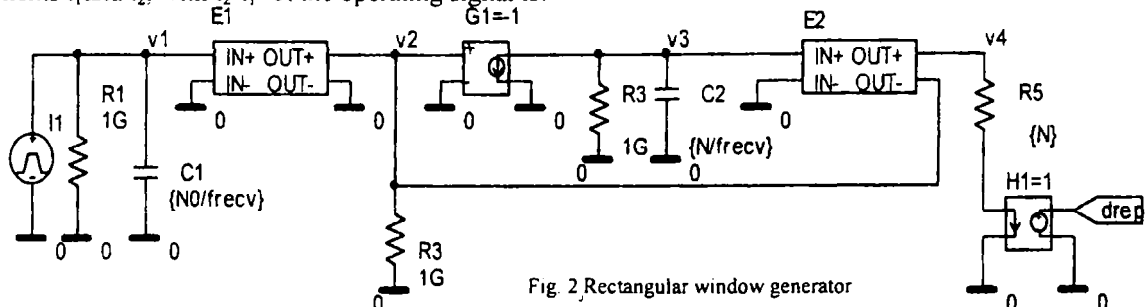

Fig. 2 Rectangular window generator

: The matematic expression of the Hanning window is:

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

$$(11)$$

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

For $t_1=0$; $t_2=\theta$; $\tau = \theta/2$ the Hanning window is defined by the relation[3]:

$$f_2 = \frac{1}{\theta}\left[1 - \cos\frac{2\pi t}{\theta} - \pi\right] = \frac{1}{\theta}\left[1 - \cos\frac{2\pi t}{\theta}\right] \text{ cu } 0 < t < \theta$$

$$(12)$$

For $\tau = \frac{t_1 + t_2}{2}$; $\theta = t_2 - t_1$, if we apply the integral over the Hanning function hann(t) we obtain:

$$\int_{t_1}^{t_2} hann(t)dt = \int_{t_1}^{t_2}\frac{1}{\theta}\left[1 + \cos\left(2\pi\frac{t - \frac{t_2+t_1}{2}}{t_2-t_1}\right)\right]dt =$$

$$= \frac{1}{\theta}\left[\theta + \frac{\theta}{\pi}\sin\frac{-\tau\pi}{\theta}\cos\frac{\pi}{2}\right] = \frac{\theta}{\theta} = 1$$
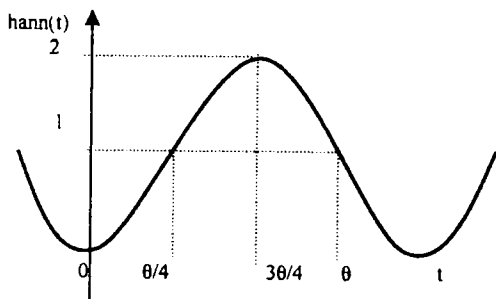

Fig. 3 Wave form of the Hanning window

The window is created in two steps:
→ the rectangular window is generated $f_1(t)$
→ the periodical function $f_2(t)$ is generated using the formula (12); $\theta=NT$

The VIP block has been created for measuring the rms values of the current and voltage in a section of a conveyor chain and also for measuring the active power sent to a load impedance. The X inputs are used for voltages, but there are also inputs which are of "current-controlled voltage sources" type, that means in form "const*i". 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.

One can see the direct virtual bond between input(IN) and output(OUT) for the signal transmission from the input to the output of the circuit, bond which is not influenced by the VIP block. The "fer" entrance connected at the "fer" entrance of every integrator, does control the integration interval.

These integrators have been developed by strating from the INTEG integrator of the abm.olb library. The integrator INTEG3 has been modified and thus it has three inputs, accomplishing the function:

$$v_{out}(t) = GAIN \cdot \int v_{fer}(t) \cdot v_{x1}(t) \cdot v_{x2}(t)dt \quad (13)$$

Choosing GAIN=1/T=frequency, $v_{x1}(t)=v(t)$, everyhing controlled by the window $v_{fer}(t)=fer(t)$, this integrator will accomplish the function (5), obtaining at the output, after passing the interval time while the window is active, a voltage computationally equal with the transferred power. The VALEF integrators have been obtained from INTEG of the Pspice library, which have added a new input and do extract, at output, the square root. Thus, they accomplish the function:

$$v_{out}(t) = \sqrt{GAIN \cdot \int v_{fer}(t) \cdot v_x^2(t)dt} \quad (14)$$

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, as it can be seen in (18) and the second integrator has the entrance X connected to a voltage with the value equal 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 is the gain of H, measured in Ohms. The VIP block has only one transparent parameter, called "frecv", fixed at the default value of 50Hz[1].

The VIMED block has been created for measuring the average values of the current and voltage 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. One can see, also for this block, the direct virtual bond between input(IN) and output(OUT) for the signal transmission from the input to the output of the circuit, bond which is not influenced by the VIMED block. The "fer" entrance 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 it closes the window at $t_2=(N_0+N)T$.

The VALMED integrators have been obtained from INTEG of the Pspice library, which also extract the square root. Thus, they accomplish the function:

$$v_{med}(t) = \sqrt{GAIN \cdot \int v_{fer}(t)v_x(t)dt} \quad (15)$$

Choosing GAIN=1/T=frequency, $v_{x1}(t)=v(t)$, everyhing controlled by the window $v_{fer}(t)=fer(t)$, this integrator will compute the average value of the voltage, for the first integrator and the average value of the current for the second integrator.

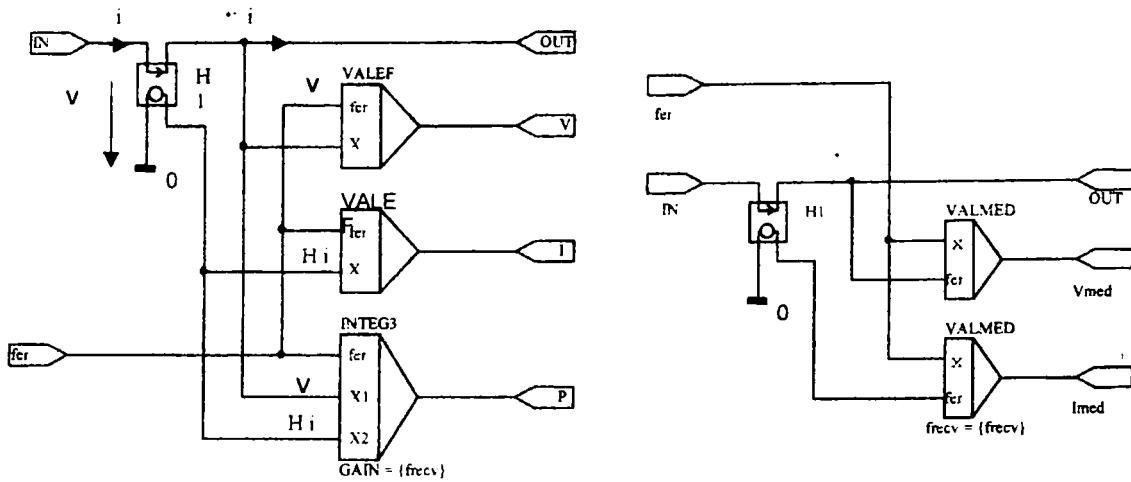The VIMED block has only one transparent parameter, called "frecv", fixed at the default value of 50Hz[1].
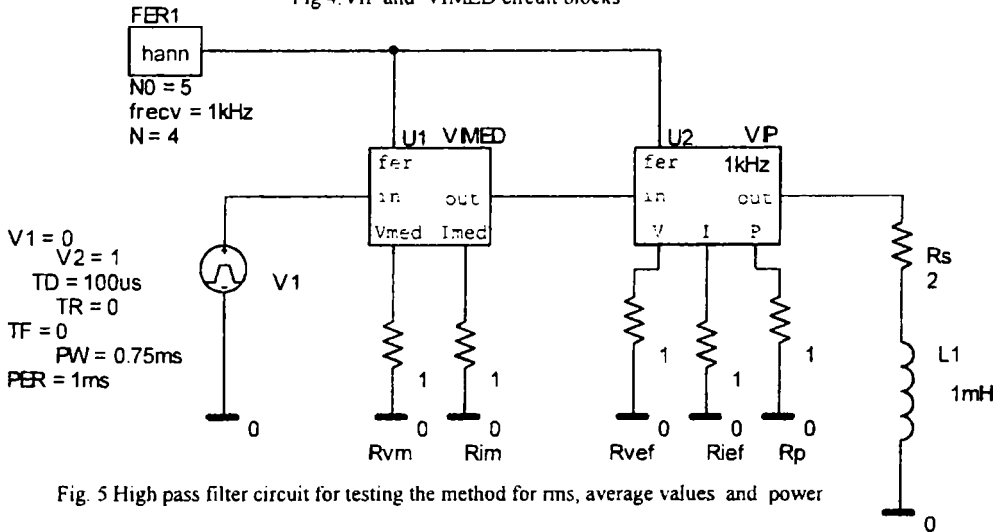
Fig 4. VIP and VIMED circuit blocks

Fig. 5 High pass filter circuit for testing the method for rms, average values and power

IV. EXAMPLE OF VALUES MEASURING USING VIMED AND VIP BLOCKS

An example is shown in the circuit in fig.5, where the blocks VIP and VIMED are arranged 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]. While 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 which are connected to the blocks outputs, we can measure: on R_{vm} the average value (Vmed) of the filter voltage, on R_{im} the average value of the current, on R_{vef} the rms value of the voltage (V), on R_{ief} the rms value of the current (I) and on 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. If these resistances are different from 1Ω (and different from zero), voltages must be

read. V1 source generates a rectangular signal of 1V magnitude (from 0V to 1V), of 1ms period (1KHz frequency). While testing this method using behavioural blocks, there were made measurements for different values of the delay time TD, in every decade from $0\mu s$ to $100\mu s$. When making the test simulations, one has used different values of the duty factor of 0.25ms, 0.5ms and 0.75ms. For all these cases, the errors between the simulated and computed values were measured, the validity and utility of the blocks have been checked. One has chosen simple circuits for testing, because one needed simple relations between voltages and currents, easy to be verified.

For the Hanning window, used in all these examples, one fixed the source V1 frequency of 1kHz, $N_0=5$, N=4 because one considered that after the fifth period, the signal in this case is stable and the transitory regime is finished so the values can be measured.

For the circuit of the high pass filter, the duty factor is given, generally, by the formula $f_u = \dfrac{\theta}{T}$ (16). The average value of the voltage has the expression

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$$V'_{med} = V\frac{\theta}{T} = 1V \cdot \frac{\theta}{T} \quad (17) \text{ and the rms voltage}$$

$$V_{ef} = \sqrt{\frac{1}{T}\int_0^\theta v^2 dt} = 1V \cdot \sqrt{\frac{\theta}{T}} = 1V \cdot \sqrt{f_u} \quad (18),$$

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

One write the current described by the equations[4]

$$i(t) = \begin{cases} \dfrac{V}{R} - \left(\dfrac{V}{R} - I_1\right)e^{-t/\tau} = i_1(t), & 0 < t < \theta \\ I_2 e^{-(t-\theta)/\tau} = i_2(t), & \theta < t < T \end{cases} \quad (19)$$

where the expressions of $I_{1,2}$ will be [4]

$$\begin{cases} I_2 = \dfrac{V}{R} - \left(\dfrac{V}{R} - I_1\right)e^{-t/\tau} \\ I_1 = I_2 e^{-(t-\theta)/\tau} \end{cases} \quad (20)$$

The current average value is given by

$$I_{med} = \frac{1}{T}\int_T I(t)dt = \frac{1}{T}\int_0^\theta i_1(t)dt + \frac{1}{T}\int_\theta^T i_2(t)dt \quad (21)$$

and the rms value

$$I_{ef} = \sqrt{\frac{1}{T}\int_0^\theta i_1^2(t)dt + \frac{1}{T}\int_\theta^T i_1^2(t)dt} \quad (22)$$

Under these circumstances, measurements were made obtaining smaller errors than with Pspice techinques. There have been made a lot of comparison tables for the computed values (using formulas) and for the measured ones[4]. Below we have a synthesis of all error tables. 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]. Simulating the circuit, we obtained waveforms as in fig.6.

Table 1   **I.** Simulation results for high pass filter   **II.** Simulation results for low pass filter

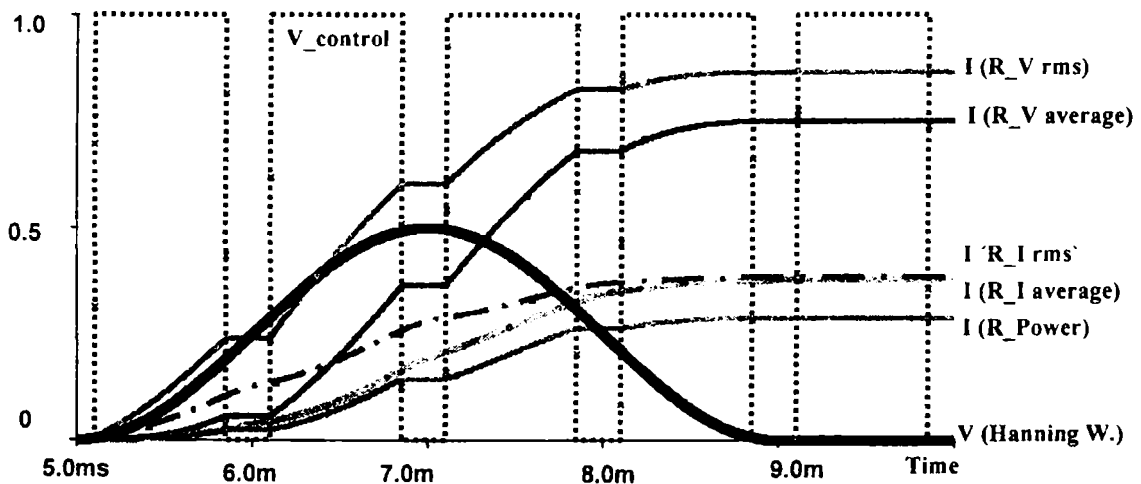| Quantity	F_{duty}=0.25		F_{duty}=0.5		F_{duty}=0.75		F_{duty}=0.25		F_{duty}=0.5		F_{duty}=0.75	
	Val.	Err %	Val.	Err %	Val.	Err %	Val.	Err %	Val.	Err %	Val.	Err %
Vm [mV]	250	0.2	500	0.2	750	0.2	250	0.3	500	0 3	750	0.2
Vef [mV]	500	0.2	707.1	0.2	866	0.19	500	0.12	707	0.16	866	0.14
Im [mA]	125	0.06	250	0.06	375	0.06	216	0.02	249	0.01	216	0.02
Ief [mA]	135.	0.07	259.2	0.19	378	0.18	216	0.04	249	0.01	216	0.02
P [mW]	366.	0.15	134.4	0.3	286	0.3	93.3	0.23	124	0.16	93.3	0.4

Fig.6 Simulation results of the high pass filter circuit

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The simulations of the circuit described in fig.5 have been made using OrCad. The resulting signals and the observation window are, as it can be seen in fig.6 [4][5]. One can see, that after applying the window, the signal value remains constant and easy to be

measured. Depending on the circuit we want to inspect, we have only to take care that the window is used only after the transitory regime is finished. Fig.7 describes the converter that uses the method above.
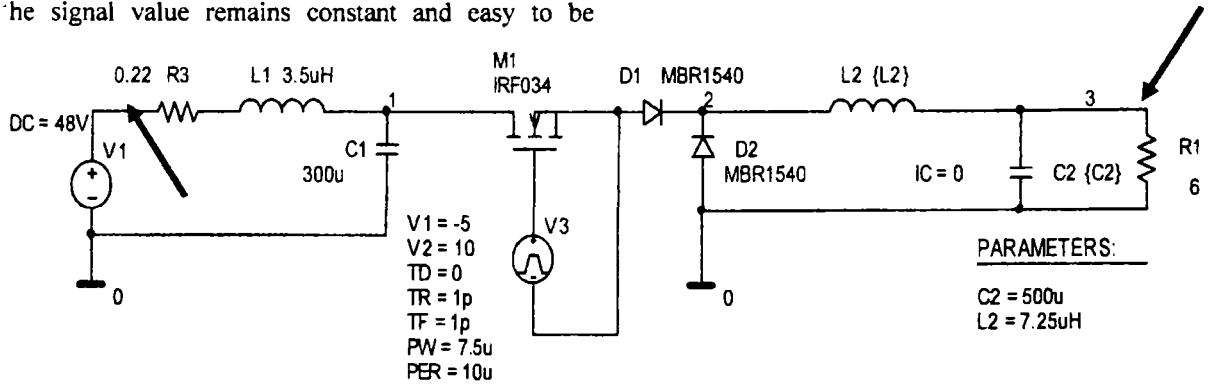

Fig.7 Buck Converter that used VIP and VIMED blocks for measuring average and rms values

In fig.7 the arrows show the place where the behavioural VIP and VIMED blocks were placed for the measurement. Because the period of the pulse voltage was 10μs, with a duty factor of 75%, the frequency of the Hanning window was chosen 100kHz=1/10μs. Performing the method, we obtained for this comverter an efficiency factor $\eta=(P_{meas}/P_{cal})100=(211.564/216.014)100=97.94\%$ (23) The difference between input and output values for rms of current and voltage were:

$I_{rms}=(I_{OUT}/I_{IN})100=(6.0075/4.6058)100=130.43\%$ (24)
$V_{rms}=(V_{OUT}/V_{IN})100=(36.045/48)100=75.09\%$ (25)
Relation (25) shows that the duty factor of the signal was 75% indeed, with a 0.09% measurement error which is inside the permitted limits of the presented method. The values obtained show that the efficiency factor was properly and correct calculated and that $P=I_{rms}V_{rms}$. Another result of applying the method over the Buck converter was that the average values of input/output currents and voltages are similar (see fig.8) and the conclusion is that these waveforms are almost continuous with no ripple or a very small one.
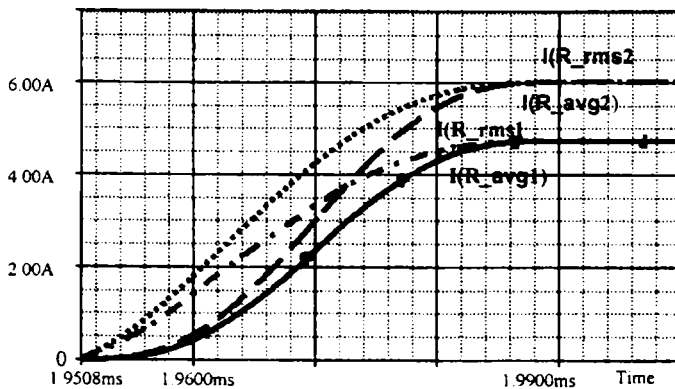
VI. CONCLUSION

In this paper, we presented some 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 measuring values in permanent regime, one uses the examination windows which have the role of convenient placing the ime interval over which measurements are done.

For a simple using of this method, all windows have an unitary area. For measuring rms values and power, one used the VIP block, for measuring average values, one used VIMED block, which have one signal input and one signal output virtually directly bond, an input for the examination window and three (V_{med}, I_{med}, P), respective two (V_{ef}, I_{ef}) outputs.

This measuring method is original and one obtains very good results. One showed an example using a simple circuit and comparing the results obtained by computation and simulation. Then we used the method over a more complicated circuit, illustrated here by a Buck-converter.

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Fig.8 Results of input/output waveforms obtained by applying the presented method over a Buck-converter