First cycle distortion (FCD) - Graham, what is that?

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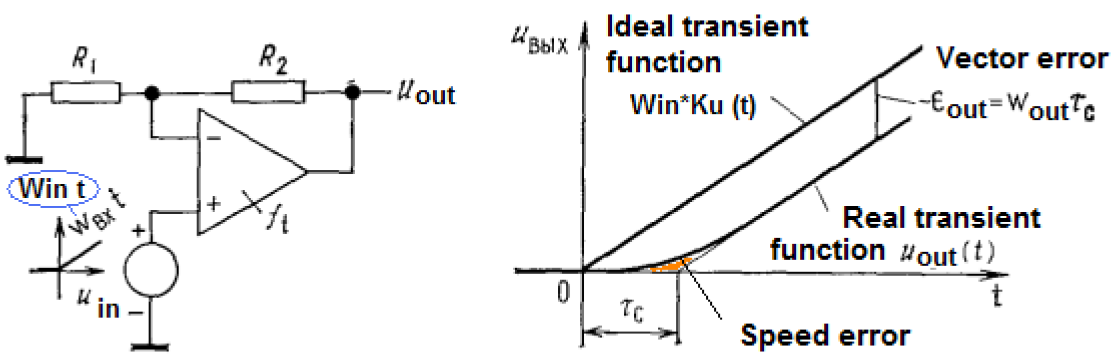
millwood

I had asked when Graham invented FCD that he provide clear definition of FCD. However, he was too busy branding my requests as attacks so we never got time to understand clearly what he meant by FCD.

Well, I certainly hope that he come back to finish this discussion....

And I think if proven true, FCD can be a revolutionary step forward in our understanding of audio and human hearing.

Back in 1982, I. Dostal [1] introduced the concepts of such distortions as vector and sped (velocity), Fig. 1



Speed error of a non-inverting amplifier when excited with a linearly increasing voltage

Fig. 1

Figure 1 on the right shows the ramp voltage reduced to the output voltage level by multiplying by Ku, as well as the actual output voltage.

The real output voltage is delayed at the amplifier output by the time the signal travels from input to output (τ_c).

The filled triangle represents speed distortion. Let's consider the manifestation of high-speed distortions on a specific example of a composite amplifier, Fig. 2

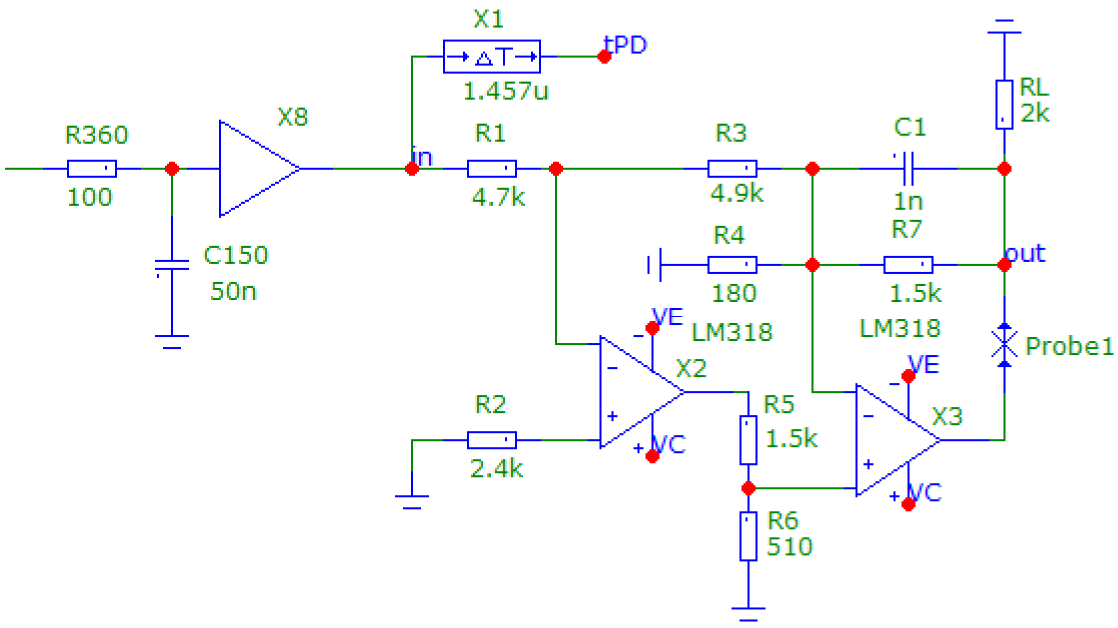


Fig. 2

Let's check the loop gain and stability margins, Fig. 3

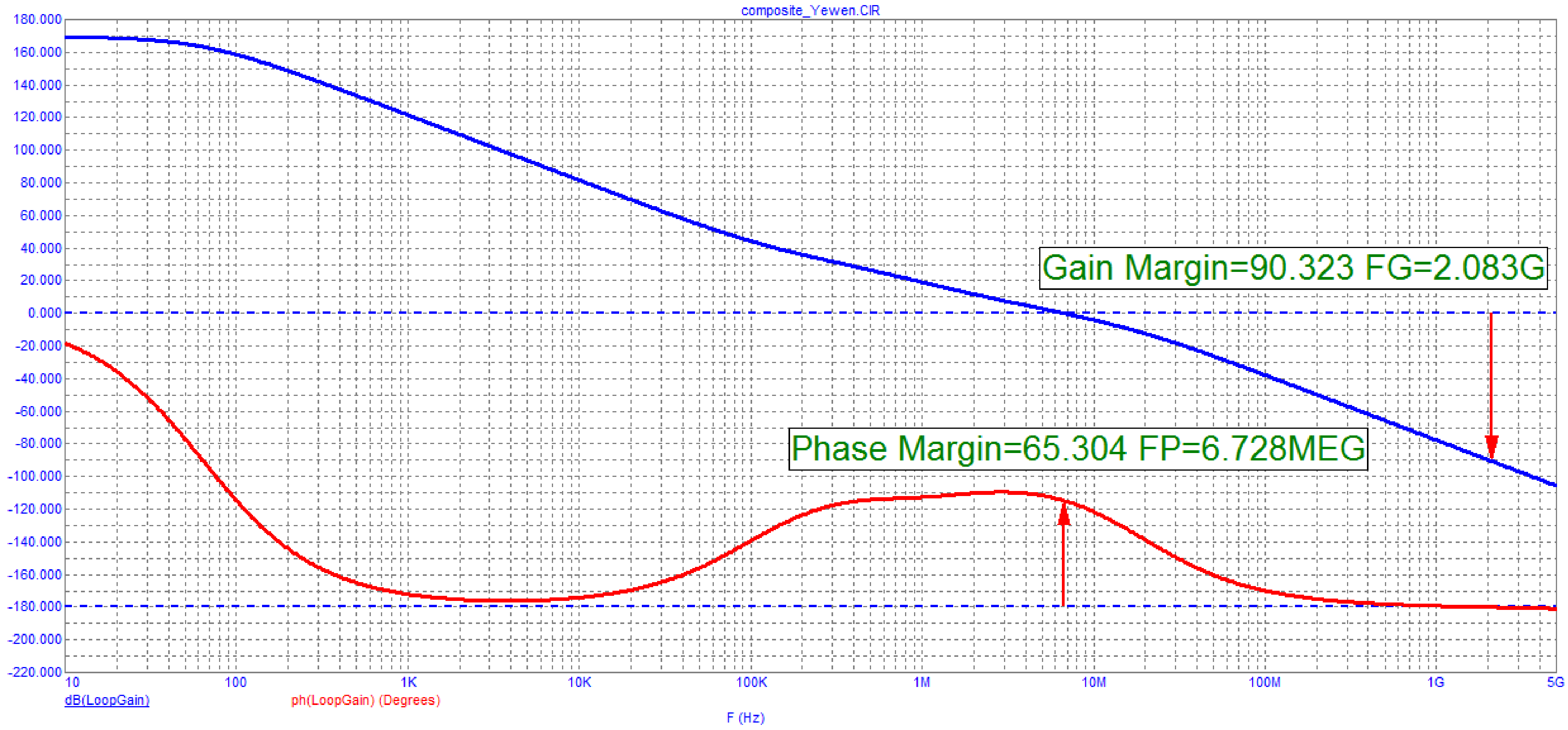


Fig. 3

The amplifier has a phase margin of 65 degrees, which is close to optimal. The loop gain at 20 kHz is 70 dB, and at low frequencies it reaches 170 dB.

Let's remove the Bode graph, Fig. 4

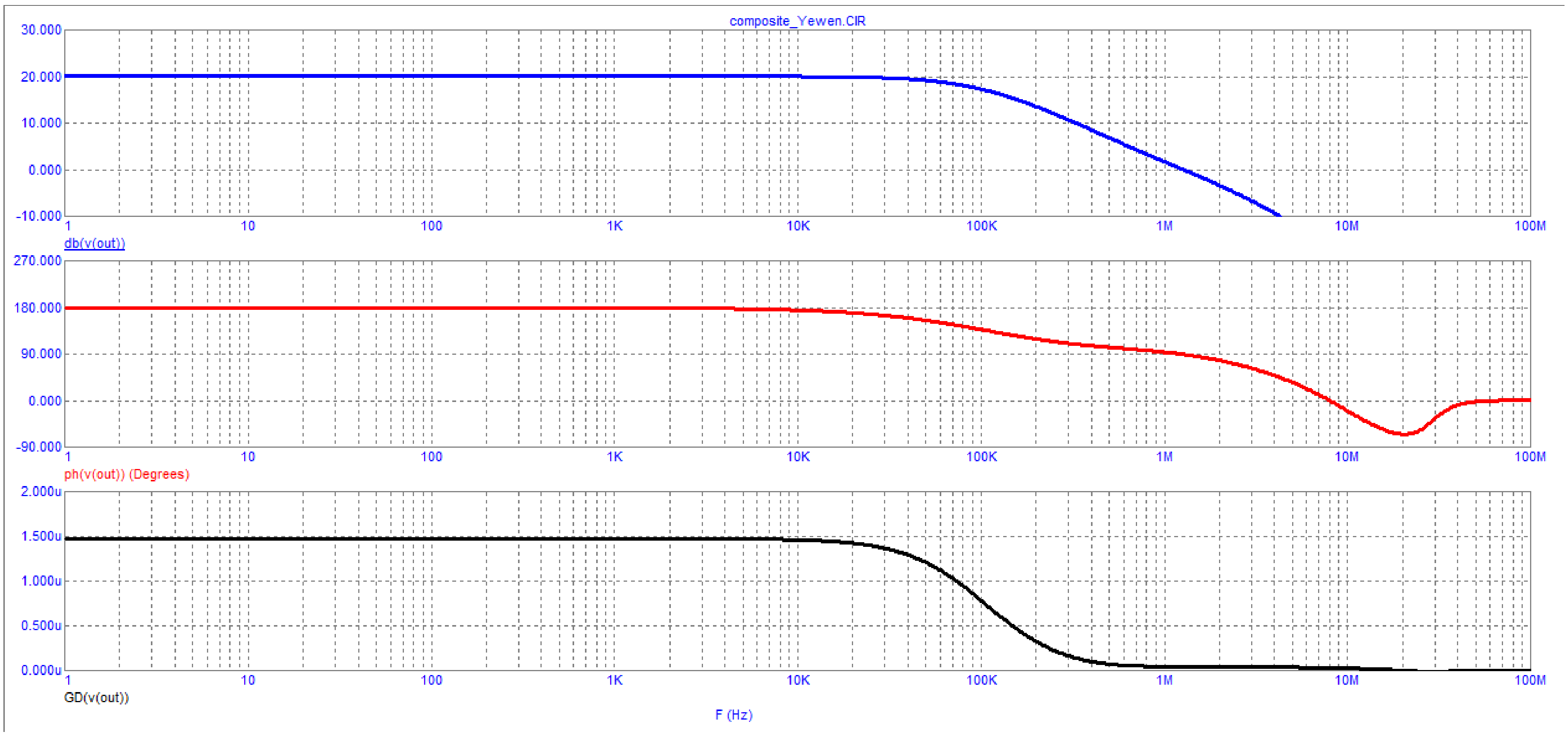


Fig. 4

DC amplifier, therefore, the group delay is constantly from infra-low frequencies and has a horizontal section almost up to 10 kHz, higher in frequency, a smooth decline of the group delay begins. As practice shows, in order for the amplifier to have a minimum of transient distortion, its GDT must be constantly in the sound band and have a margin in both directions at least 10 times, i.e. from 2 Hz to 200 kHz.

For example, the following parameters are given for the reference amplifier Goldmund Telos 5000

Goldmund Telos 5000
http://www.goldmund.com
Circuit Speed
• Slew rate : > 200 V/us.
• Rise time : < 200 ns.
Group Delay
Time Propagation delay < 100 ns stable with frequency from DC to 200 kHz.

Let's measure the spectrum of nonlinear distortions at a frequency of 20 kHz with an output voltage of 10 V (peak), Fig. 5

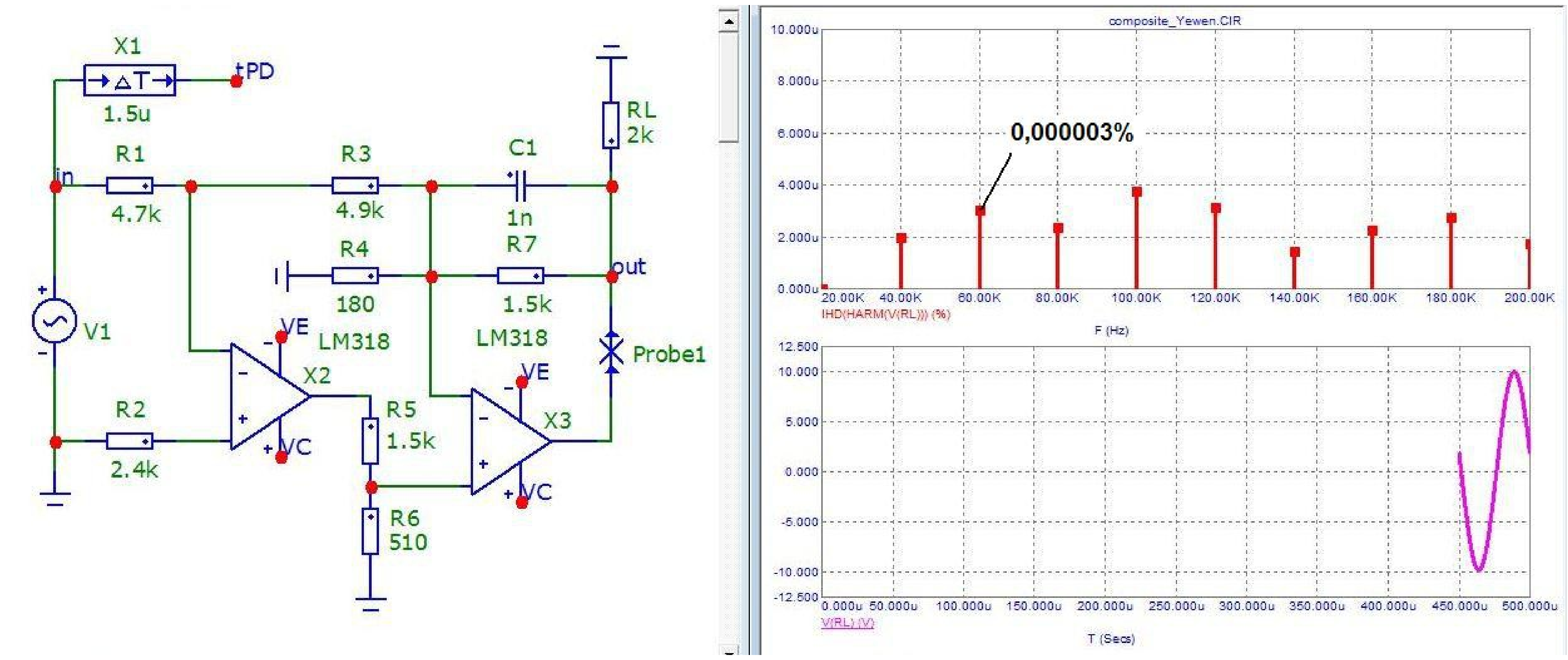


Fig. 5

Due to the deep feedback, the level of nonlinear distortion in the steady-state mode in the 80 kHz band does not exceed 0.000004%. At lower frequencies, the level of distortion is even lower. There are practically no transient distortions in amplifiers with more than 10-fold linearity margin of the group delay and they are stable already from the first to the second period. The amplifier was simulated in the 11-th version of the program Microcap, where it is not possible to check the distortion spectrum in the first periods, therefore, we will check in the 4-th period (program limitation), Fig. 6

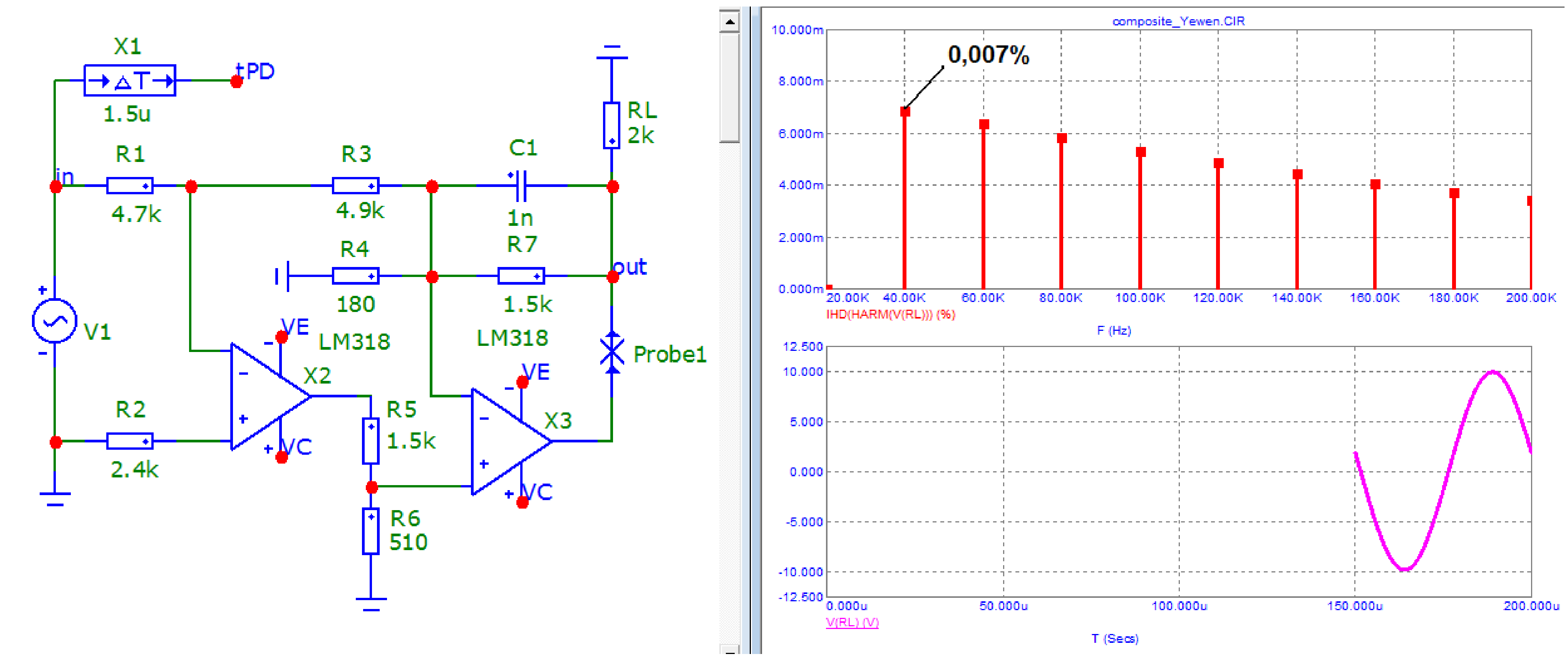


Fig. 6

Although the distortion is still small, it is more than 2000 times higher than in steady state.

Since the initial section of the sinusoid is close to a linearly increasing voltage, it is very convenient to see the speed distortions in the first period, Fig. 7

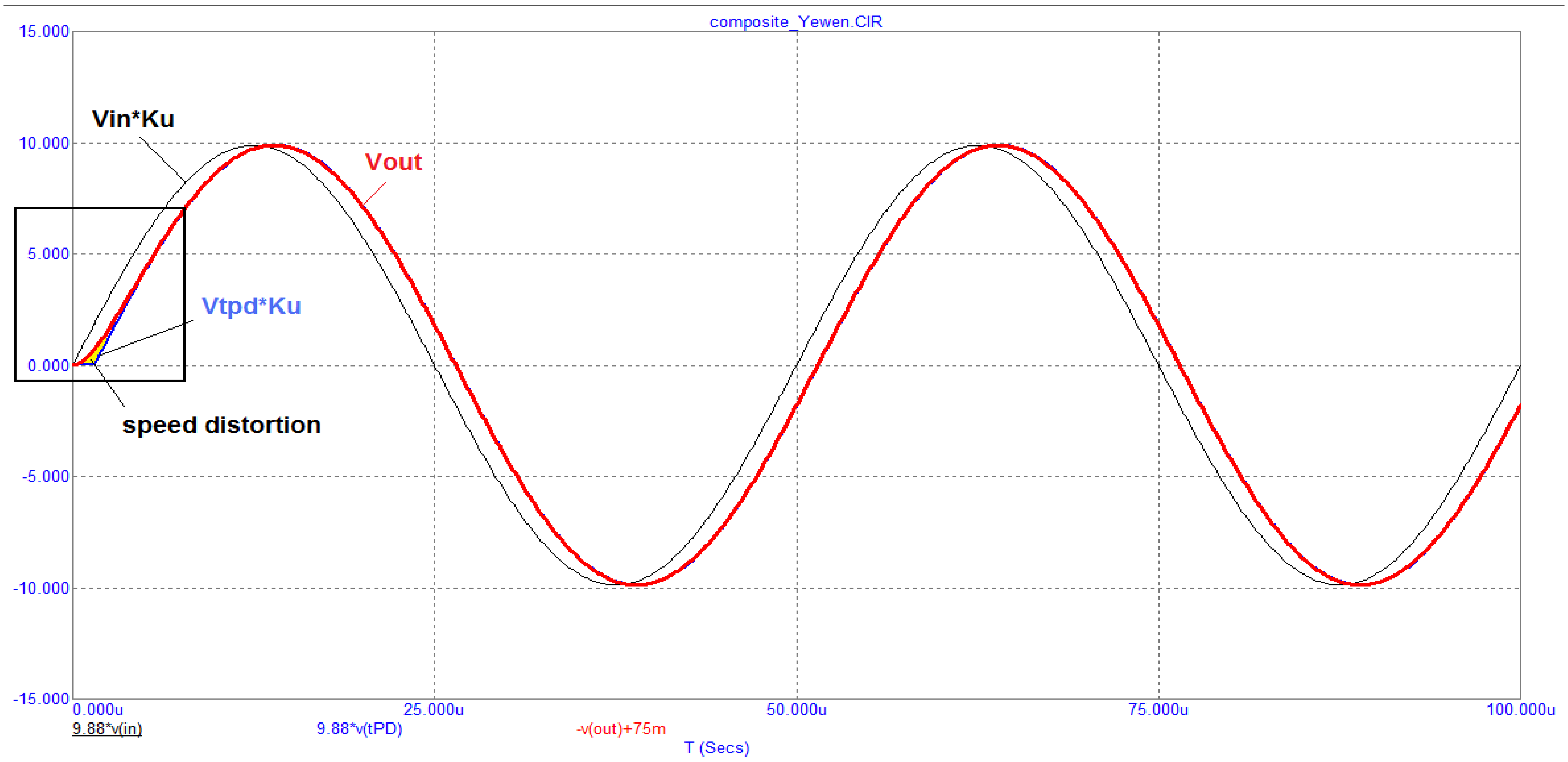


Fig. 7

The time propagation delay is quite large - 1.5 μs (see Fig. 4). We see the deviation of the output voltage from the sinusoid only at the beginning of the first period, Apparently it was this type of distortion that Graham had in mind. Starting from the second period and on subsequent ones, there are no speed distortions associated with transient distortions and the magnitude of the delay time. That is why they are not detected on standard measurements of distortions! The initial section of the sinusoid is marked with a square, let's see it in more detail in a stretched form, Fig. 8

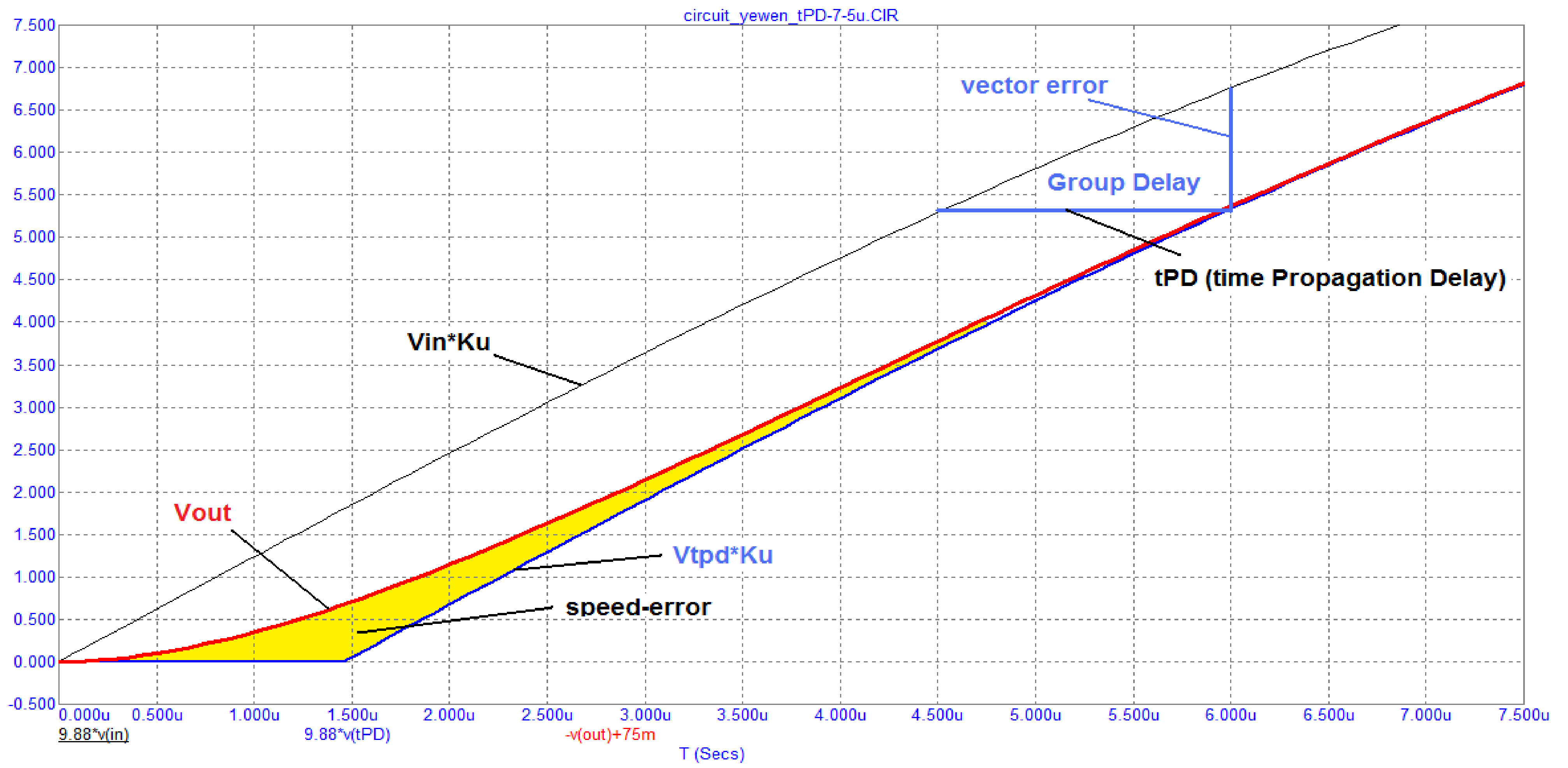


Fig. 8

It is clear that there is no repetitive high-speed distortion on a sinusoidal signal. For this, a triangular signal must be used as a test signal. Then, when changing the direction of the voltage (at the tops), speed distortions will appear every time. To isolate them, it is necessary to subtract the input voltage multiplied by Ku and delayed by the time propagation delay (GD) from the output voltage.

This procedure is very convenient to do virtually at the stage of amplifier design.

As practice shows, speed parameters are highly correlated with sound quality. The time propagation delay should not exceed 50 ... 70 ns. Most amplifiers in service have tPDs from 200 ... 300 ns to 1.5 μs.

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The problem with the signal that you describe in the .pdf is that again it is a start of a sinewave that starts infinitely fast. The reason that you only see it in the 1st cycle is because that 1st cycle is completely artificial and not a real life signal. The answer is staring you in the face there: after that 1st artificial start, there is no speed distortion anywhere else, only a pure delay.*

If you want to do it correctly, send the sine wave input signal through a low pass of say 30kHz (to stay with the DIM30). Then run your sim and use the output of the low pass as the input signal and check the distortion against that. You will not find 'speed distortion', because now you work with real life signals and the amp can handle that fine.*
The only thing you will see is a delay as you show in your .pdf after the 1st cycle.

We will measure the speed distortion of this amplifier at a frequency of 20 kHz according to the proposed method, Fig. 9

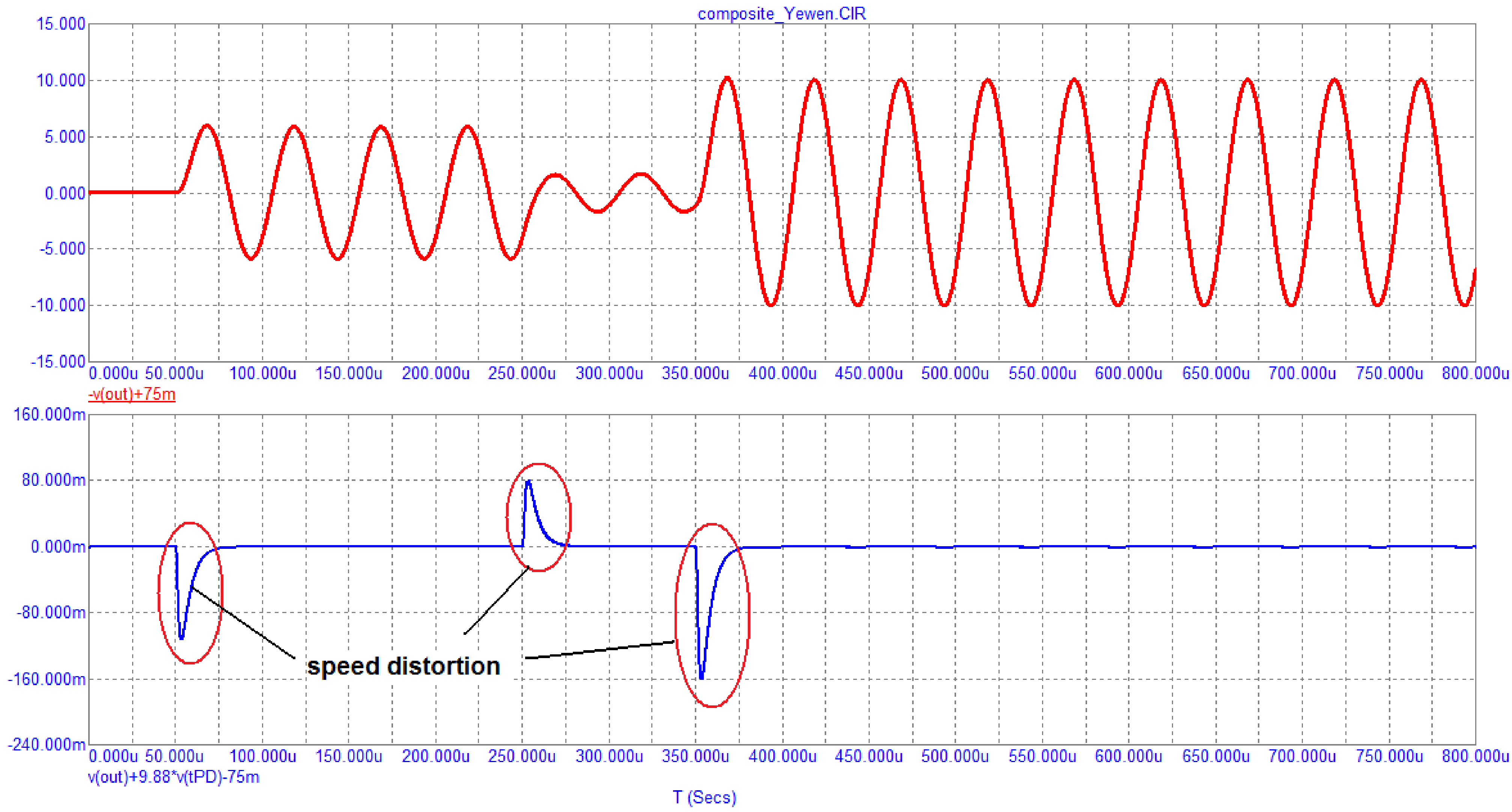

Fig. 9

As you can see from Figure 9, no filtering saves this amplifier with a long time propagation delay from speed distortion. The duration of speed distortions reaches half the period of the useful signal. Then we wonder why the amplifier does not convey the nuances of the microdynamics, “eats up” the after-sound, sounds “dead”.

Let us simplify the task to the amplifier and apply a signal with a frequency of 10 kHz to its input, and repeat the measurements, Fig. 10

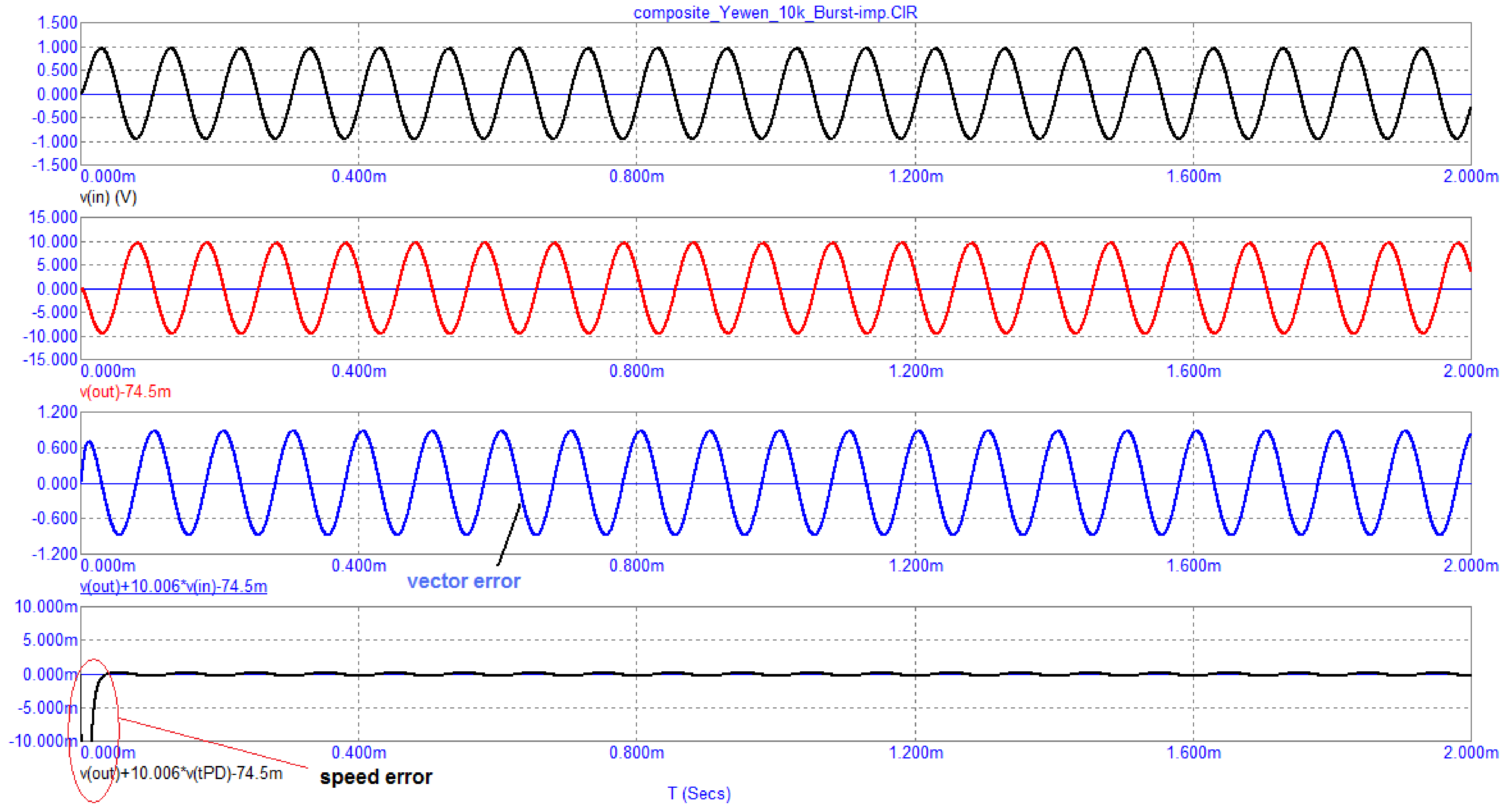

Fig. 10

Figure 10 shows that speed distortions are present only at the beginning of the first period (lower graph) - circled in red. In the steady state, there are only barely noticeable fluctuations - the result of measurement errors.

Let's complicate the task, modulate the input signal and repeat the measurement without changing anything in the analysis settings, Fig. 11

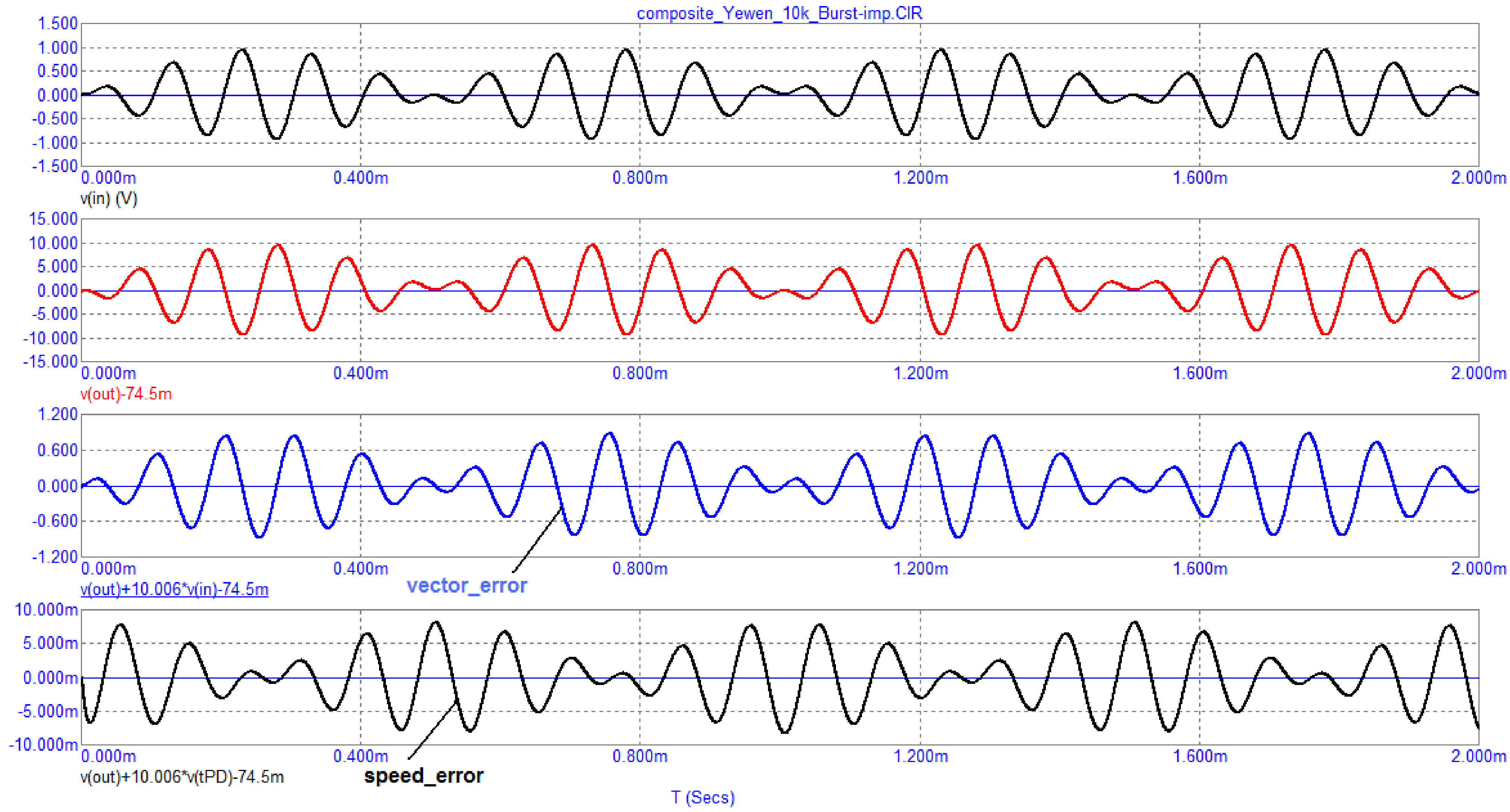

Fig. 11

As can be seen from Figure 11, the rate distortion reaches 7.5 mV. Moreover, their highest level occurs in areas where the amplitude of the output signal is minimal.

A significant influence on the determination of such parameters of sound as pitch, timbre, etc., is exerted by the temporal behavior of the first five to seven harmonics, as well as a number of "non-expanded" harmonics up to the 15th ... 18th. ... in real musical instruments, rather complex signals are created with a large number of overtones, a certain inharmony between them, a complex dynamic development in time of their spectral and temporal envelope, and a certain dynamics of changes in phase relationships, to which the hearing aid is quite sensitive. It was found that hearing responds primarily to the rate of phase change (ie, its frequency derivative), which is called the "group delay time" [2]. If we consider that the highest notes of musical instruments are at frequencies of about 8 kHz, then even the 5th harmonic will be at a frequency of 40 kHz.

Something about this issue is clarified by the article [3].

Literature:

1. I.Dostal, Operational Amplifiers, 1982
2. И.Алдошина, Тембр, часть 2, "Звукорежиссер", 2001, №3
3. James Boyk, There's Life Above 20 Kilohertz!
   A Survey of Musical Instrument Spectra to 102.4 Khz, http://www.cco.caltech.edu/~boyk/spectra/spectra.htm

best regargs
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