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AM SIGNALS WITH RANDOM MODULATION PARAMETERS AND THEIR DETECTION

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In this article a method of generating AM signals with randomly changing parameters was discussed. This method involves a modulation process in which some selected parameters of the modulation waveform (amplitude or frequency) are subjected to random variation. The result of this process are random changes (independent or simultaneous) in the depth or frequency of the modulation of AM signals. Using this method, it is possible to study the detection and discrimination of signals with parameters varying in time. This paper also presents the results of preliminary psychoacoustic studies related to the random amplitude modulation.

1. Introduction

Sounds perceived by humans vary in their amplitude-frequency structure. This particularly applies to the sounds of speech and music. The main feature of this variability is the irregular (pseudorandom) character of the amplitude and frequency changes.

In literature much attention has been devoted to the description of the mechanisms of perception of simple sounds, such as pure tones, multitones or more complex sounds like band-noise [3, 4, 16, 17]. Pure sounds can be described using relatively simple analytic expressions. The band noises cannot be described using such simple analytic relations, however the basic statistical moments describing the waveforms of these signals remain constant with time. Most complex to perceive are the real sounds of speech and music for which those moments may change with time. A first approximation of those sounds might be modulated signals with randomly changing parameters.

The hitherto studies on the perception of modulated sounds have focused on different aspects of the modulation process. For example, the similarity of the perception of AM and FM signals has been investigated [1, 3, 17]. The modulation transfer function MTF has been related to the perception of modulated signals [16]. Some masking effects, characteristics of the modulated sounds, have also been examined, e.g. the MDI effect [8]. In all these studies, however, the signals were usually subjected to a sinusoidal amplitude modulation (SAM).

It is worth noticing that random waveforms have very rarely been used so far as modulation sounds [8, 12, 15]. The results of psychoacoustic studies are not always univocal. For example, Sęk has proved that there is no significant difference in the AM detection thresholds between the regular and random modulation signals. MENDOZA *et al.* [8] showed that the AM detection thresholds for the random modulation signals are greater than those for the regular ones. It would be interesting to study the influence of random changes in signal parameters on the specific synchronous effect, i.e. the "phase locking" which clearly takes place in a simple tone [2]. One can expect that a complex envelope of the modulation waveform should cause a slightly different perception of the modulated signals than that of signals modulated with a tone parameters of constant.

The perception of AM signals can be affected if the frequency of the modulation tone changes with time. This effect may be also responsible for the differences in the ability to perceive modulation depending on the shape of the modulation waveform envelope.

Much attention has also been devoted to the psychophysiological aspect of these studies [2, 6, 7, 10, 14]. Some of the neurophysiological studies [6] have indicated the possibility to reproduce (provided the signal parameters have been properly selected) on the peripheral level a component of frequency equal to the modulation frequency. This effect might be responsible for the fact that the perception of modulation improves with the increase of the signal intensity [17].

JAVEL [6] proved the sensitivity of neurons to the temporal form of the waveforms of the signals stimulating them. He studied, among others, the dependence of the neurons' response on the level of the modulated signal intensity as well as on the depth and frequency of modulation. REES and PALMER [14] continued these studies and showed that the distributions of neuron firings in response to the amplitude-modulated stimuli depend on the modulation frequency.

For further studies concerning this problem it is necessary to develop a methodology of generating signals for which it would be possible to control the following features: random variation of their basic parameters, the independence or coherence of this variation for particular parameters, and the degree of their mutual correlation. This condition is not fulfilled by the narrowband noise applied so far as a modulation signal. With the above in mind, a study was undertaken aimed at the development of a method of generating random signals which would satisfy the above conditions. Moreover, a preliminary investigation of the detection thresholds of AM signals generated by this method was conducted.

2. Algorithm of the generating a modulation signal with parameters randomly changing in time

To generate a random AM signal, a modulation of a sinusoidal carrier by waveforms with discrete random changes in amplitude and frequency was applied. In the duration corresponding to the half-period of the modulation signal the amplitude and frequency. However, at the transition from one half-period to another, those parameters were subjected to random changes. Such a generating procedure required a drawing of the "n" random numbers of a given distribution, where "n" is the number of half-periods of the modulation tone (dependent both on the frequency of this tone and its duration). These numbers were then used for the change in either the amplitude or frequency of the modulation waveform. This yielded random changes in the modulation or frequency of the AM signal. When only the amplitude was subjected to a random change, the zero-crossings of the modulation signal remained constant.

A crucial aspect of this method was the definiton of a coefficient describing the range of randomness of the changes of the parameter under investigation.

In the case of a classical AM modulation, in which the carrier and modulation signals are sinusoidal, this coefficient should correspond to that of the modulation depth m reported in literature. To satisfy this condition, for the modulation and carrier signal the value of RMS was at first determined according to equation (2.1):

$$V_{\mathrm{RMS}}=\sqrt{\frac{1}{n}\sum_{1}^{n} V_i^2(t)}\,, \tag{2.1}$$

where $V_i(t)$ is the temporal value of the modulation signal.

The modulation depth coefficient was defined in the logarithm scale as a product of two RMS values, one for the modulation signal and another one for the carrier signal, according to (2.2):

$$m=20\log\frac{V_{\mathrm{RMS}}}{V_{\mathrm{RMS}}(\mathrm{car})} \tag{2.2}$$

where $V_{\mathrm{RMS}}(\mathrm{mod})$ — RMS of the modulation signal, while $V_{\mathrm{RMS}}(\mathrm{car})$ — RMS of the carrier signal.

In the literature [13] one can encounter another measure which has the meaning of the variance of the signal power or intensity:

$$v_p=\frac{1}{n}\sum_{1}^{n}(V_i^2(t)-V_s^2)^2, \tag{2.3}$$

where "v_p" stands for the variance of the signal power, $v_i^2(t)$ is the square of the temporal value, while V_s^2 is the power of a signal corresponding to the mean value of the acoustic pressure.

This value also characterizes in a way the degree of irregularity of a modulation signal. It can be proved that for a sinusoidal signal, i.e. when the discrete values $V_i(t)$ are assigned to successive half-periods, this measure should be equal to zero irrespective of the amplitude because the $V_{(i)}(t)$ values are equal to the mean value V_s.

To estimate the degree of irregularity, sometimes a coefficient called "crest factor" [5] is used that is defined as the ratio of the peak value to the rms value of the waveform:

$$\mathrm{cf}=\frac{X_p}{X_{\mathrm{RMS}}}, \tag{2.4}$$

where "cf" is the "crest factor" coefficient, while X_p means the maximum value of the waveform and X_{RMS} its rms value.

3. Hardware and software of the signal generating

The signals (the modulation, carrier, and random ones) were generated using a special card equipped with a DSP made by Tucker Davis Technology (Gainsville, USA). This card has its own operational memory.

The operation buffer of this card may be filled with samples via APOS library functions and procedures. Upon the generation of a random signal, the working buffer of the memory of the card was filled with Gaussian distribution samples collected from the APOS library. When the program was running, this buffer was treated as a program array of random numbers. Then from the file as many numbers as there were the half-periods of modulation oscillations (at a given frequency) were drawn out.

The process of preparation of a random amplitude signal is shown in Fig. 1.

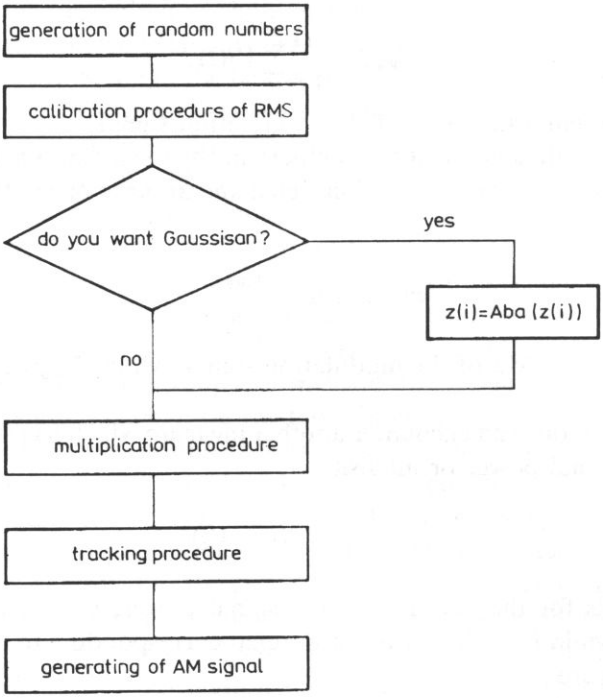

Fig. 1. Algorithm for preparation of a random amplitude signal.

The drawn out sequences of numbers were subjected to the so-called calibration procedure.

The first calibration stage consisted in the so-called centralization of the generated sequence of random numbers. The centralization procedure was carried out according to the following formula:

$$z(i) = x(i) - \frac{1}{n}\sum x(i), \tag{3.1}$$

where $x(i)$ denotes the primarily drawn out sequence of numbers, while $z(i)$ stands for a sequence of random numbers subjected to the centralization procedure. The centralization then consisted in the subtraction from the drawn out random variable its average value and it assured the clearing of the average value of realization $z(i)$. The subsequent calibration stage involved standardization, i.e. multiplication of the realization by such a scaling factor that the RMS of the resultant modulation waveform was equal to the RMS of the carrier waveform. Therefore, the initial modulation depth was always equal to 100%. During the detection or discrimination experiment, it was possible to reduce this value by rescaling the modulation waveform.

Further steps taken within this study depended on what kind of random variation was selected: the pseudorandom or Gaussian. In the case of the former one, the values of the amplitudes in each of the half-periods were multiplied by the drawn out, centralized and standardized numbers. Such an operation yielded a distribution of temporal values of the modulation signal which was a certain combination of the sinusoidal and Gaussian distribution. An important feature of this distribution values, further referred to as pseudorandom distribution, was the appearance of two characteristic maxima which made the distribution more similar to a bimodal distribution. The reason for the appearance of these two maxima is the multiplication of the positive and negative values of the amplitudes in the half-periods of the modulation signal by positive and negative random numbers of the prepared realization. Thus, to obtain a distribution with one maximum, which would be closer to the standard distribution, it was necessary to replace the negative numbers of equal value. This operation is illustrated by the right side branch of the algorithm presented in Fig. 1.

After that the values of the amplitudes for subsequent half-periods of the modulation tone were multiplied by the already drawn-out random numbers (just as in the case of the previously discussed distribution).

The prepared sequence of random numbers could be saved on a disc as the so-called "frozen realizations". This permitted a multiple application of this realization at different stages of the psychoacoustic studies.

Due to the options offered by a computer program it was possible to select the random changes either in the amplitude or the frequency of the modulation tone.

There was also a third option of combined (simultaneous) random changes in both amplitude and modulation frequency.

In the case when the option of combined random changes in amplitude and frequency was selected, it was also possible to choose the combination of the realization according to which these changes were to proceed, i.e.:

- to select simultaneous, random changes in amplitude and frequency taking place according to two different realizations;
- to select simultaneous, random changes in amplitude and frequency taking place according to the same realization.

Figures 2 and 5 present some modulation waveforms (first column), the probability distributions of the temporal values corresponding to them (second column), and the resultant modulated waveforms (third column) for different types of random changes of the modulation parameters (for the carrier frequency equal to 250 Hz and a modulation depth of 50%). Figures 2b and 2c illustrate pseudosinusoidal changes of the modulation signal amplitude. Figures 3b and 3c refer to the Gaussian changes of the amplitude of the same signal. Figure 4b and 4c show random changes in the modulation frequency, while Figs. 5b and 5c present a simultaneous random changes in both amplitude and frequency of the modulation signal. The first line in these figures, marked with the letter "a", shows oscillograms, histograms and modulated signals for a sinusoidal (the so-called regular) modulation with no elements of randomness. The second line in these figures, marked with letter "b", encompasses oscillograms, histograms and modulated signals corresponding to a random variation of the selected parameter according to realization R1. The third line in the discussed figures marked with letter C, presents oscillograms histograms and modulated signals histograms, for realization marked as R2.

Comparing the side-most columns (both the left and right ones) of Fig. 2, one can see that for the modulation of a pseudorandom distribution waveform the distance between subsequent zero-crossings of the signal is constant. The amplitude, on the other hand, oscillates within a limited range at the transfer from one half-period to the next one. A very different shape of oscillograms is obtained for the Gaussian distribution. For this distribution, few fluctuations with maximum values of amplitude and numerous temporal values closer to zero can be observed.

Those close-to-zero values correspond to the temporal segments presented in the right column of Fig. 3, in which the resultant signal is not modulated.

For the modulation signals that temporal values change randomly (Gaussian change) it was tested whether the distribution of probability was normal. For this purpose, a test consisting in calculating statistical moments of higher orders was used, i.e. moments of the third order, m_3, and the fourth order, m_4, were calculated. These moments were then used to determine the so-called asymmetry coefficient "asym" and a value of excess "exc" according to the following formulae:

$$\mathrm{asym} = m_3/s^3 , \tag{3.2}$$

where "s" is the standard deviation of a random variable contained in the generated sequence of random numbers,

$$\mathrm{exc} = m_4/v^2 - 3 , \tag{3.3}$$

where "v" is the variance of a random variable contained in the generated sequence of random numbers.

Results of the test are presented in Table 1.

The calculated values of the asymmetry coefficient and of the excess given in this Table are always lower than 3 that made us to consider the tested distributions as normal.

Both for the sinusoidal signal used as a modulation waveform and for the signal generated using the R1 or R2 realizations, the calculation of the "crest factor" coefficient gave the following values:

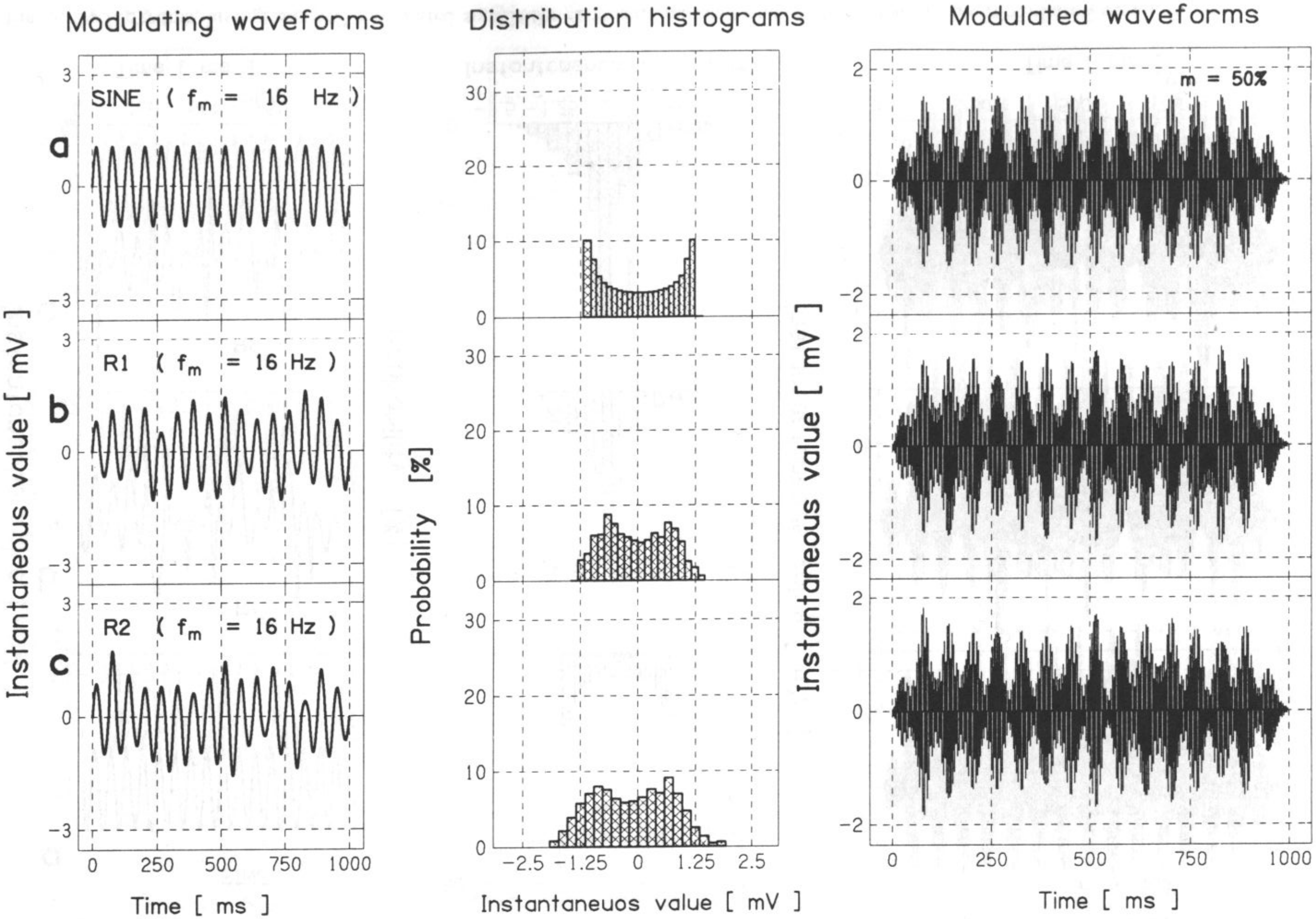

Fig. 2. Oscillograms, histograms and modulated signals for pseudorandom changes in the modulation signal (carrier frequency 250 Hz, modulation frequency — 16 Hz, modulation depth 50%).

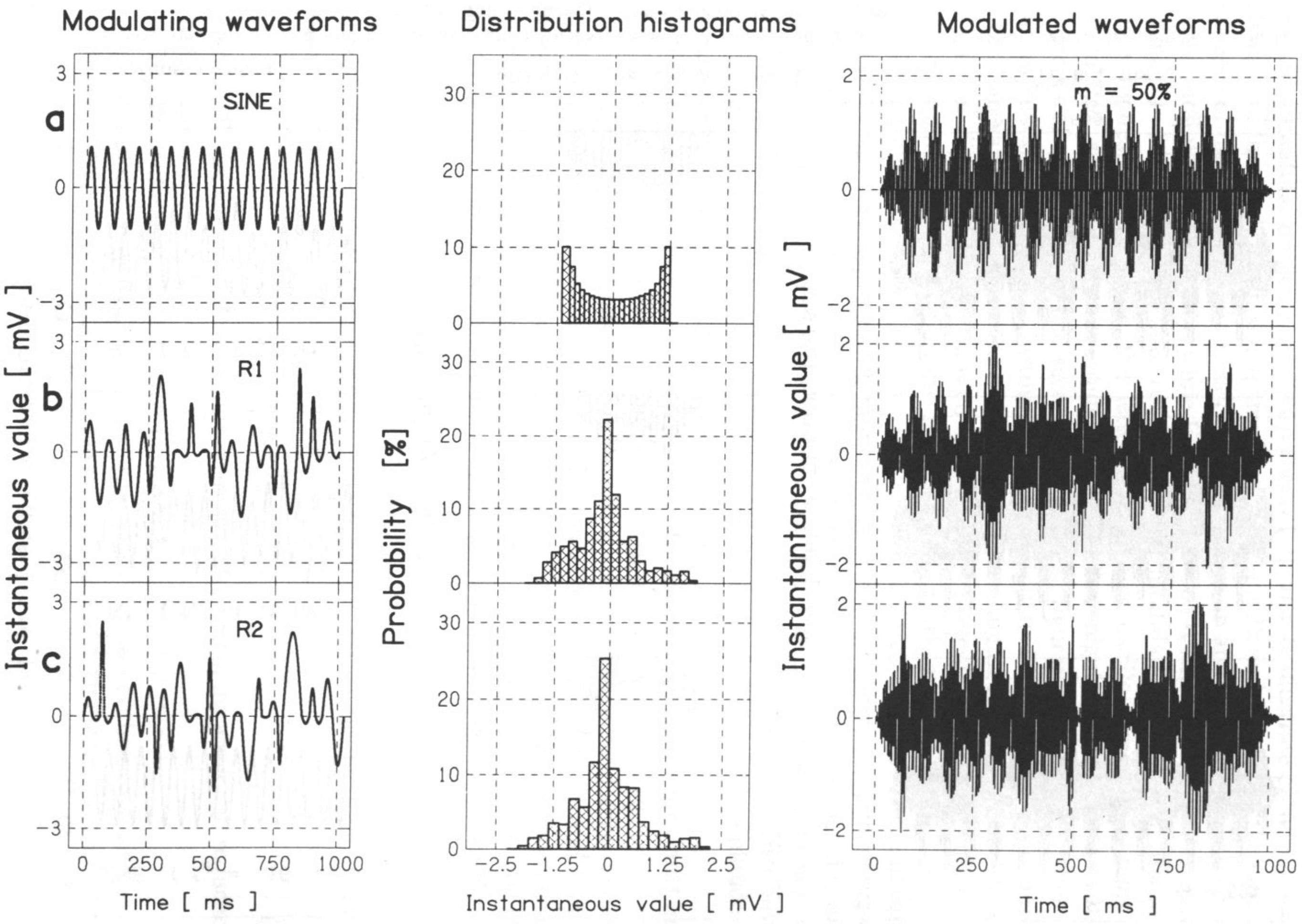

Fig. 3. Oscillograms, histograms and modulated signals for random, Gaussian amplitude changes in the modulation signal.

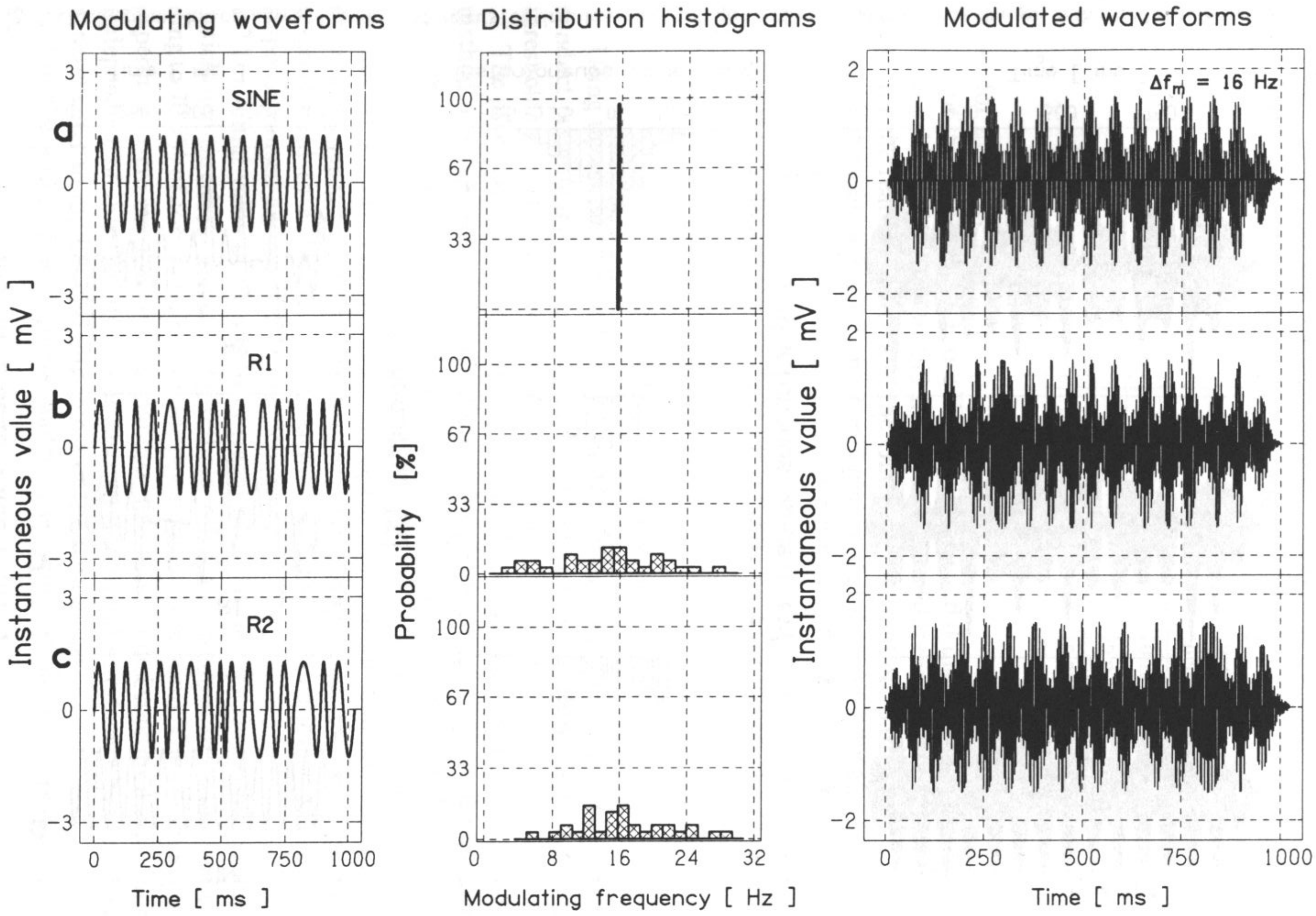

Fig. 4. Oscillograms, histograms and modulated signals for random frequency changes in the modulation signal.

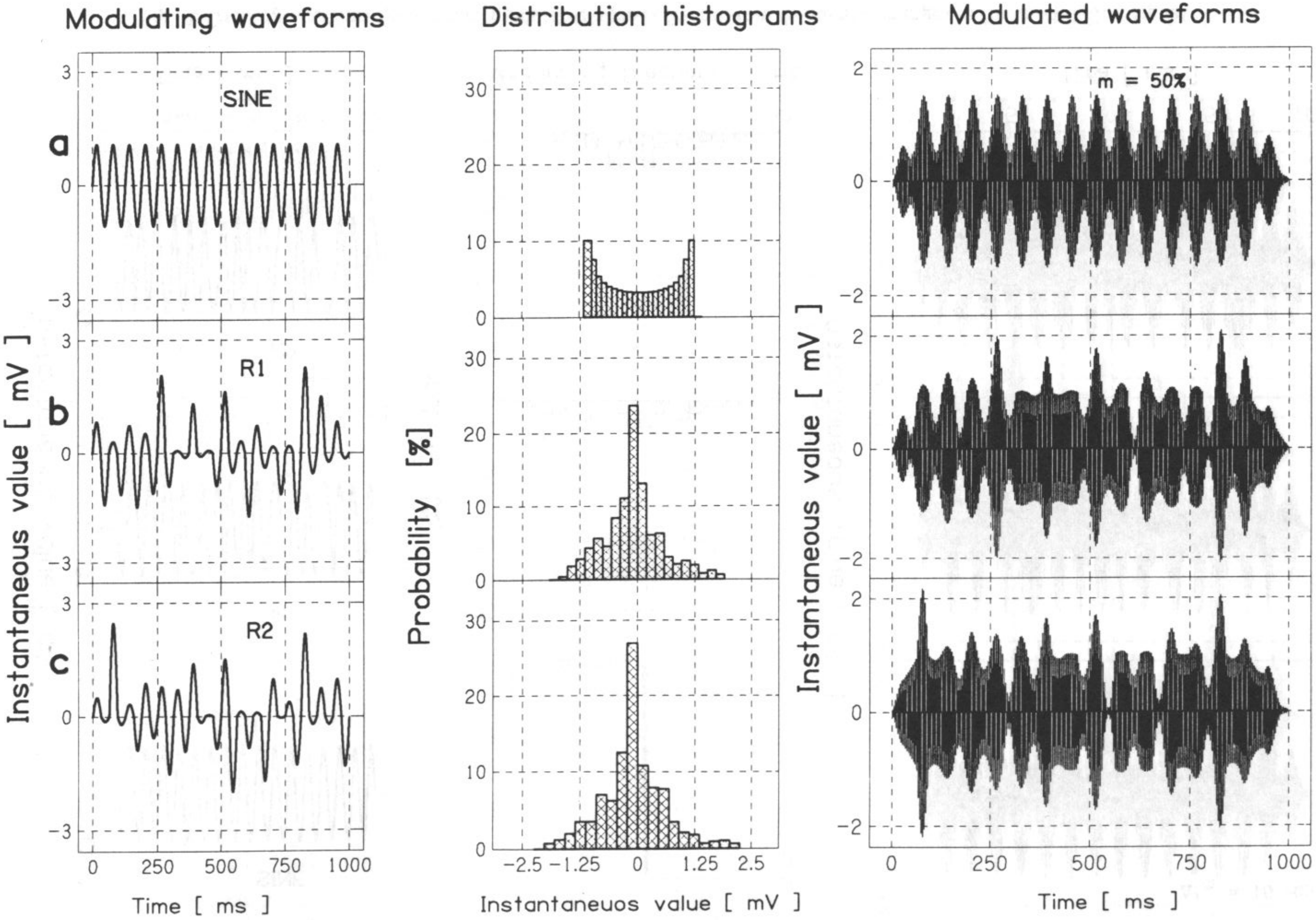

Fig. 5. Oscillograms, histograms and modulated signals for simultaneous, random amplitude and frequency changes in the modulation signal.

Table 1. Statistical coefficients of excess and skewness.

Fmod	asym	exc
4 Hz	1.62018	0.00543
16 Hz	1.76279	0.56968
64 Hz	1.78148	0.75914
128 Hz	2.02359	2.02076
256 Hz	2.02359	2.02076

— for the sinus: 1.41438;
— for the realization R1 and the pseudosinusoidal distribution: 2.13066;
— for the realization R2 and the pseudosinusoidal distribution: 2.9866;
— for the realization R1 and the Gaussian distribution: 3.02418;
— for the realization R2 and the Gaussian distribution: 3.29662.

As one can see, the crest factor coefficient assumes the highest values for the Gaussian distribution and slightly smaller ones for the pseudosinusoidal distribution.

Thus the coefficient may account for the differences observed between Fig. 2 and Fig. 3.

4. Methodology of psychoacoustic studies

Using the method of random signals generation described in 3, it was possible to conduct preliminary psychoacoustic studies that aim was to determine the detection thresholds of AM signals with random changes in amplitude.

The psychoacoustic studies were performed according to the Levitt's "up-down" method following the 2AFC paradigm and at the feedback between the listener and the experimental program. On each trial a pair of stimuli was presented to the listener: a standard stimulus (as an unmodulated sound — sinusoidal) and signal (AM modulated sound). The depth of the signal modulation changed throughout the experiment depending on the manner the listener responded. Two successive correct responses led to a decrease in the depth of signal modulation, while one wrong response caused an increase of this depth.

The initial value of the depth of signal modulation was always higher than the anticipated threshold value. The threshold value was assumed to be that corresponding to 70.7% of correct points (on the psychometric function). The parameters of the experiment were recorded in a special text file, the so-called condition file (Annex 1). Independent of this file, there was also an additional interface which enabled the experimenter to modify currently most of the parameters.

For the series of experiments under discussion, the following parameters were selected:

- carrier frequencies: 250 Hz and 1000 Hz;
- modulation frequencies: 4, 16, 64 and 128 Hz;

- stimulus duration (either standard or signal): 1000 ms;
- intensity level: 70 dB SPL.

An appropriate quality of signals within the whole range of variation of the selected parameters was guaranteed by the cooperation of the software with the Tucker-Davis Technology hardware. The signal was generated by a 16-bit DA converter at a sampling rate of 44 kHz was low-pass filtered at 8 kHz.

A program-controlled PA4 attenuator was placed in the channel of the analogue signal. The generated analogue signal was supplied to a HB5 headphone amplifier (which was a component of the TDT set) with DT-48A Beyer headphones. Each trial consisted of 5 runs, each consisting of 40 pairs of stimuli: standard-signal.

The averaged results of five such runs, as well as the particular results, were written into the file (Annex 2). It was also possible to plot the curve of the listener's responses (Annex 3). Additionally, a preliminary statistical processing of the currently obtained results was done by calculating the basic statistical moments and performing a one factor variance analysis involving the calculation of the Snedecor F coefficient for the results of five runs.

Three subjects whose audiograms did not reveal any hearing loss took part in the experiment (the auditory sensitivity of each subject was within 0 – 5 dB).

Each subject went through a control stage where the so-called classical AM detection threshold for sinusoidal modulation was measured. Then, the AM detection thresholds were determined for the modulation waveform with pseudorandom changes in amplitude.

5. Discussion of the obtained results

The results for three subjects plotted in Figs. 6 and 7 show the AM detection thresholds as function of the modulation frequency at the carrier frequencies of 250 Hz and 1000 Hz, respectively. The dashed-line curve illustrates the detection thresholds for sinusoidal changes in amplitude, while the solid one those for random changes.

As follows from the results presented, detection thresholds for the sinusoidal and pseudorandom changes in amplitude nearly overlap within the limits of SD. For the modulation frequency below f_m, the detection thresholds are almost constant and then, above that frequency, they clearly decrease in the function of f_m.

The above regularity was observed for the detection threshold both for the sinusoidal and pseudosinusoidal modulation which is particularly apparent for the carrier frequency of 100 Hz.

The results obtained for the carrier of 250 Hz seem to imply that there is a slight difference between the two types of thresholds for the modulation frequencies of 4 Hz and 128 Hz. In order to resolve this problem an additional testing for these data was performed applying the t-Student test. The calculated value of the t-Student coefficient were equal to 1.606 and 2.421 at the modulation frequencies of 4 Hz and 128 Hz, respectively. The critical value of the t-Student coefficient amounted to 2.775 at four degrees of freedom and at the level of significance equal to 0.75. The results of

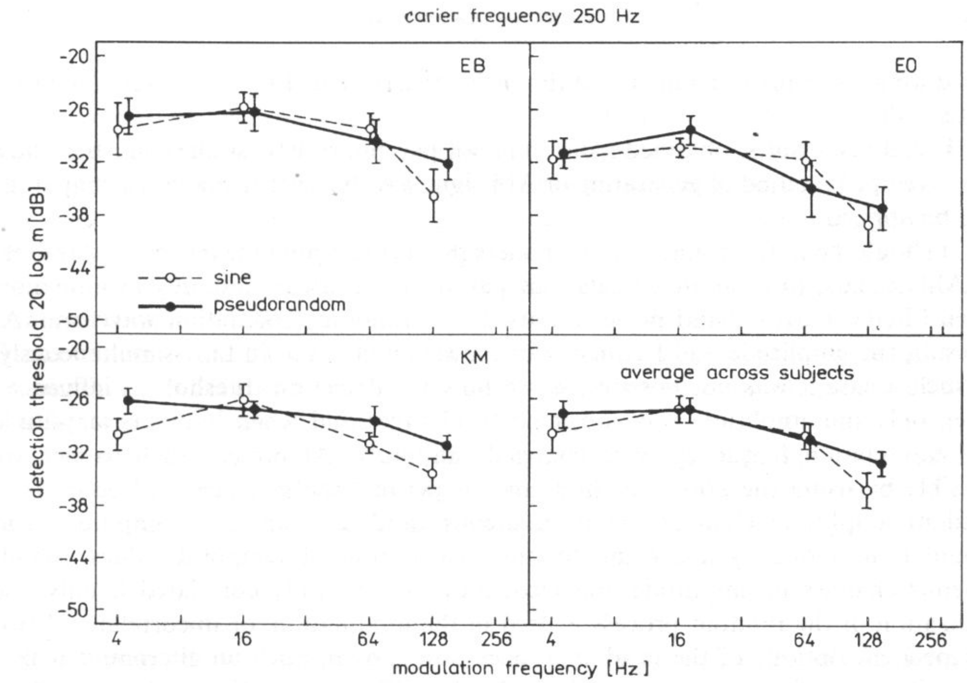

Fig. 6. Detection thresholds of pseudorandom changes in amplitude for the carrier frequency of 250 Hz.

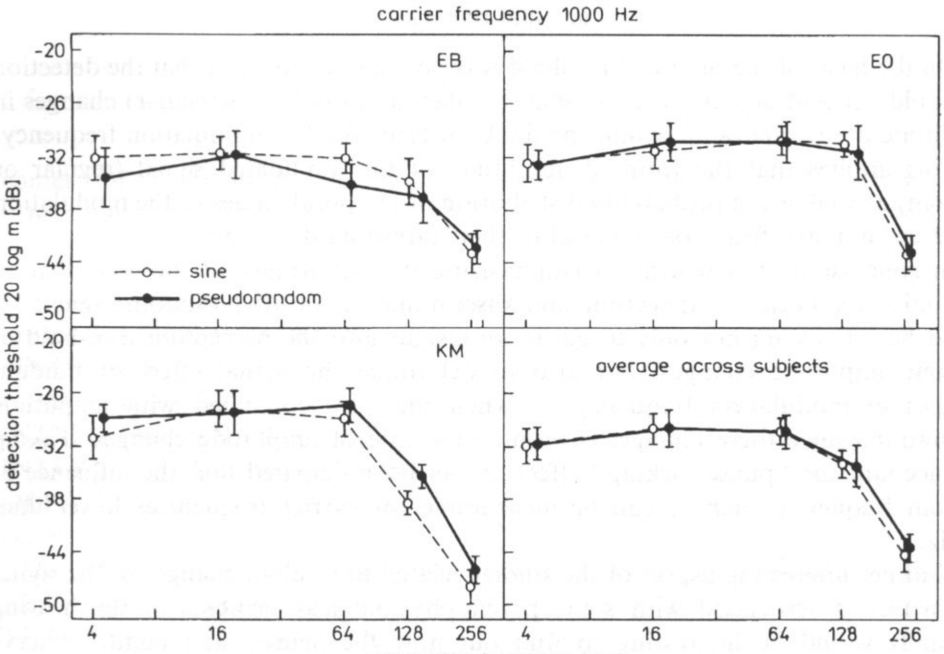

Fig. 7. Detection thresholds of pseudorandom in signal amplitude for the carrier frequency of 1000 Hz.

the testing have proved that the differences observed in Fig. 6 are not significant statistically.

The above results, obtained from the pilot psychoacoustic studies, illustrate how the developed method of generating of AM signals with random changes in amplitude can be applied.

It should be noticed that in some papers [8, 9] concerning the detection threshold of AM signals, to generate signals that parameters change randomly in time most often filtered narrow-band noise was used as a random modulation waveform. As a result, the amplitude and frequency of the signal changed in time simultaneously. In such a case it was not possible to see how the detection threshold is influenced when only the amplitude was subjected to changes and when both the amplitude and modulation frequency were changed randomly. At present such studies are possible by using the above method since it permits the generating of either only random amplitude changes or simultaneous random changes in amplitude and modulation frequency according to any distribution of temporal values. Simultaneous changes in amplitude and frequency may be fully correlated if only one realization of the random process is used in the modulation, or uncorrelated if two independent options of the random process are chosen. Such an alternative makes it possible to perform psychoacoustic studies for different detection or discrimination purposes.

6. Final remarks

On the basis of the obtained results it was possible to conclude that the detection thresholds of AM signal for sinusoidal (regular) and random (irregular) changes in amplitude are comparable within the limits of error for low modulation frequency.

This implies that the form of amplitude of the modulated signal (regular or random) as well as the probability distribution of temporal values of the modulation signal are not significant on the level of their threshold detection.

In conclusion, it is worthy of emphasizing the importance of the continuation of studies on both the detection and discrimination of AM random signals. It would be interesting not only to get more insight into the perception threshold of random amplitude changes, but also to determine the actual effect of random changes in modulation frequency — when they are combined with amplitude fluctuations since these changes determine the rate of amplitude changes. Taking into account the "phase locking" effect, it can be anticipated that the influence of random frequency changes can be measurable for carrier frequencies lower than 4 kHz.

Another interesting aspect of the studies related to random changes of the signal parameters is associated with some psychophysiological elements of the hearing organ. It would be interesting to find out how the neuron and auditory nerve responses are correlated with random changes in the stimulus parameters and how the mechanism of "phase locking" operates for these signals. Previous papers [7, 10, 14] have mostly concerned sinusoidal (regular) amplitude changes. The results given in those papers have proved a specific sensitivity of the peripheral auditory neurons to stimuli subjected to amplitude modulation. This sensitivity may additionally affect the ability of the perception system to differentiate particular types of modulation. In this context it is justifiable to put the question whether the responses of the neurons of the auditory system on the level of threshold values are the same for sinusoidal and random changes in the stimulus amplitude. In detection thresholds for sinusoidal and random amplitude changes, the answer to that question seems to be positive. However, Rees and Palmer found [14] that the addition of broadband noise to the sinusoidally modulated stimulus increased the neuron's temporal response to low modulation frequencies.

It would suggest that for these frequencies the detection thresholds for random amplitude changes should decrease in comparison with those for regular changes which, however, has not been reported in our study.

7. Acknowledgements

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The authors wish to thank Dr. R. Ewertowski for preparing the computer program AM RNDA.

Appendix

Annex 1 ("Condition File")

content of the so called condition file constitutes a programmable script of the experiment.

```
COND: 1 5
; Change of the numerical content of position to "*" is
; irrelevant for the experiment
; PLOT: 1200
NUM_TRIALS: 40
INTER_INT_DELAY: 400.0
INTER_TRIAL_DELAY: 1.0
DEFAULT_GATE_TIME: 20.0
GEN_USING: 20.0
; The "track" function concernes the range of variability of modulation index
; 8% 1% 15% (Am/an*100)
TRACK: 1 -20.0 -34.0 -16.0
BIG_STEP: 2.0
SMALL_STEP:1.0
```

```
ENDTRACK
; Signal definition ch.A
SIGNAL: 1 1000.0 −40.00.0
;tone   *c_lev* *c_frq* c_phase rnd_lvr rnd_fqr
TONE: −20.0     1000.0     0.0       0.0       0.0
ENDSIGNAL
SIGNAL: 3   1000.0   −30.0   0.0
;tone   *m_lev* *mod_frq* *m_phase*  *rnd_lvr*  rnd_fqr*
TONE: TRACK1   4.0     0.0    0.0    0.0
ENDSIGNAL
; Signal definitino ch.B
SIGNAL: 4   1000.0   −40.0   0.0
;tone     *c_lev* *c_frq* c_phase rnd_lvr  rnd_fqr
TONE:  −20.0      1000.0      0.0       0.0       0.0
ENDSIGNAL
SIGNAL:   6   1000.0    −30.0   0.0
;tone    *m_lev* *mod_frq* *m_phase* *rnd_lvr* *rnd_fqr*
TONE: −6.0          4.0          0.0          0.0          0.0
ENDSIGNAL
; Standard definition ch.A
SIGNAL:   7   1000.0    −40.0   0.0
;tone    *c_lev* *c_frq* c_phase  rnd_lvr  rnd_fqr
TONE:  −20.0  1000.0      0.0          0.0          0.0
ENDSIGNAL
SIGNAL: 9   1000.0   −30.0   0.0
;tone    *m_lev* *mod_frq* *m_phase* *rnd_lvr* *rnd_fqr*
TONE:  −6.0         256.0           0.0           0.0           0.0
ENDSIGNAL
; Standard definition ch.B
SIGNAL: 10   1000.0   −40.0   0.0
;tone    *c_lev* *c_frq* c_phase  rnd_lvr  rnd_fqr
TONE:  −20.0  1000.0      0.0          0.0          0.0
ENDSIGNAL
SIGNAL: 12   1000.0   −30.0   0.0
;tone    *m_lev* *mod_frq* *m_phase* *rnd_lvr* *rnd_fqr*
TONE:  −6.0         256.0          0.0              0.0          0.0
ENDSIGNAL
; Calibration TONE for Channel-A
SIGNAL: 15   1000.0   −40.0   0.0
TONE: 0.0   1000.0   0.0   0.0   0.0
CALIBRATE_LEVEL: 124.0
ENDSIGNAL
ENDCOND
```

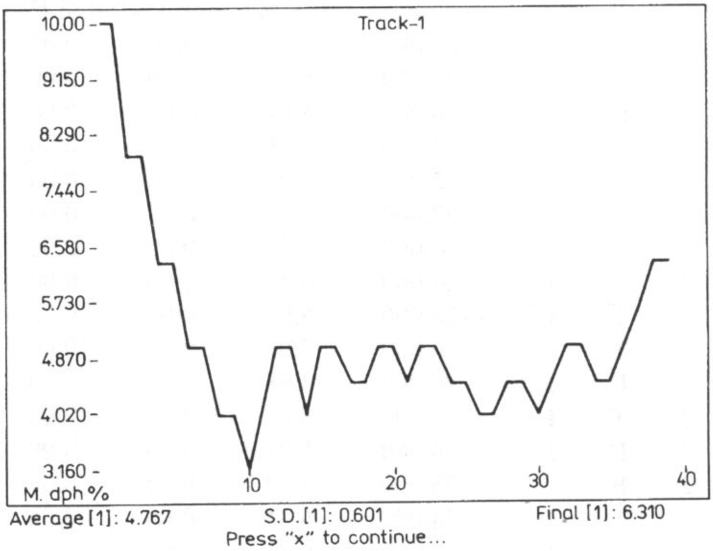
Annex 2

Annex 2 shows an exemplarily final file of the listener's responses:

```
Experimenter Condition File: CONDHAND.RNA. Cond.001
Run : 001                                  Thursday, 3/8/1995    start: 13:04:44
stop: 13:07:51

AM_RND : DIF — Values of Parameters (except Track Mag.) used by Subject: MK

SIGNAL                                                                  STANDARD
Carrier Frequency ch.A=4000.0 Hz          Carrier Frequency ch.A=4000.0 Hz
Carrier Frequency ch.B=4000.0 Hz          Carrier Frequency ch.B=4000.0 Hz
Modulation Frequency ch.A=0.0 Hz          Modulation Frequency ch.A=256.0 Hz
Modulation Frequency ch.B=0.0 Hz          Modulation Frequency ch.B=0.0 Hz
                    SPL ch.A=70.0 dB      SPL ch.A=0.0 dB
                    SPL ch.B=70.0 dB      SPL ch.B=0.0 dB
Modulation depth ch.A=0.0%                Modulation depth ch.A=0.0% T
Modulation depth ch.B=0.0%                Modulation depth ch.B=0.0% T
Phase of Modulation ch.A=0.0 deg          Phase of Modulation ch.A=0.0 deg
Phase of Modulation ch.B=0.0 deg          Phase of Modulation ch.B=0.0 deg

      Track Number:    (1)dph%
           Average:    5.765
Standard Deviation:    0.78111
       Final Value:    6.310

Try  SI  RI  AN  AT    Track1      sigA       sigB      stdA      stdB
                       values    dph[%]   dph [%]   dph [%]   dph [%]
  1   1   1   T   1   -24.000     6.31      0.00      0.00      0.00
  2   1   1   T   1   -24.000     6.31      0.00      0.00      0.00
  3   2   1   F   1   -26.000     5.01      0.00      0.00      0.00
  4   1   2   F   1   -24.000     6.31      0.00      0.00      0.00
  5   1   1   T   1   -22.000     7.94      0.00      0.00      0.00
  6   1   1   T   1   -22.000     7.94      0.00      0.00      0.00
  7   2   2   T   1   -24.000     6.31      0.00      0.00      0.00
  8   2   2   T   1   -24.000     6.31      0.00      0.00      0.00
  9   2   2   T   1   -26.000     5.01      0.00      0.00      0.00
 10   2   2   T   1   -26.000     5.01      0.00      0.00      0.00
 11*  2   1   F   1   -28.000     3.98      0.00      0.00      0.00
 12   2   2   T   1   -26.000     5.01      0.00      0.00      0.00
 13   1   2   F   1   -26.000     5.01      0.00      0.00      0.00
 14   1   2   F   1   -25.000     5.62      0.00      0.00      0.00
 15   2   2   T   1   -24.000     6.31      0.00      0.00      0.00
 16   2   2   T   1   -24.000     6.31      0.00      0.00      0.00
 17   1   1   T   1   -25.000     5.62      0.00      0.00      0.00
```

18	1	1	T	1	−25.000	5.62	0.00	0.00	0.00
19	1	1	T	1	−26.000	5.01	0.00	0.00	0.00
20	1	1	T	1	−26.000	5.01	0.00	0.00	0.00
21	1	2	F	1	−27.000	4.47	0.00	0.00	0.00
22	1	1	T	1	−26.000	5.01	0.00	0.00	0.00
23	1	2	F	1	−26.000	5.01	0.00	0.00	0.00
24	1	1	T	1	−25.000	5.62	0.00	0.00	0.00
25	1	2	F	1	−25.000	5.62	0.00	0.00	0.00
26	2	1	F	1	−24.000	6.31	0.00	0.00	0.00
27	2	2	T	1	−23.000	7.08	0.00	0.00	0.00
28	2	2	T	1	−23.000	7.08	0.00	0.00	0.00
29	1	2	F	1	−24.000	6.31	0.00	0.00	0.00
30	1	1	T	1	−23.000	7.08	0.00	0.00	0.00
31	2	2	T	1	−23.000	7.08	0.00	0.00	0.00
32	1	1	T	1	−24.000	6.31	0.00	0.00	0.00
33	1	1	T	1	−24.000	6.31	0.00	0.00	0.00
34	2	2	T	1	−25.000	5.62	0.00	0.00	0.00
35	1	1	T	1	−25.000	5.62	0.00	0.00	0.00
36	1	2	F	1	−26.000	5.01	0.00	0.00	0.00
37	2	2	T	1	−25.000	5.62	0.00	0.00	0.00
38	1	2	F	1	−25.000	5.62	0.00	0.00	0.00
39	2	2	T	1	−24.000	6.31	0.00	0.00	0.00
40	2	2	T	1	−24.000	6.31	0.00	0.00	0.00

Annex 3



```
Average [1]: 4.767          S.D. [1]: 0.601          Final [1]: 6.310
                        Press "x" to continue...
```

Fig. A. The example of the response curve of a subject.

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