

Application Notes

User-definable Functions in the Real-time Frequency Analyzers Types 2123 and 2133

by Roger Upton

1. Introduction

Frequency domain measurements seldom end at the acquisition of spectral data. Very often, it will be necessary to process that data further to obtain a finished result. User-definable functions in the Real-time Frequency Analyzers Types 2123 and 2133 provide a simple and effective means of carrying out such processing, often in real-time, without the need for an external computer. This application note gives a brief introduction to user-definable functions and their use in the 2123/33.

2. User-definable Functions in the 2123/33

User-definable functions, (hereafter called UDFs), in the 2123/33 can best be described as a high-level block-math programming language which allows processing on or between single measurements and/or complete arrays of measurement data. Little or no previous programming experience is necessary to use them. At a lower level, the user can select from a list of 60 pre-defined functions pre-programmed into the 2123/33 and covering a wide variety of applications, (see Section 3). At a higher level, the user can modify the pre-defined functions according to individual requirements, or program in his or her own UDFs of varying complexity. UDFs can be stored in the 2123/33 non-volatile memory or on disc.

UDFs consist of operands, operators and constants. Fig. 1 shows a typical UDF, taken from the 2133 list of pre-defined functions. The purpose of the function is to calculate sound power from a series of sound intensity measurements. It consists of one operand, (\$:Intensity), four operators, (AVG, +, *, and LOG), and two constants, (10 and S). Operands, operators and con-

```
Function Setup no: 39
Lw.I.S      = AVG( $:Intensity ) + 10*LOG( S )

Data are in: dB           Data type, ref: Pwr_spec.  1.00p
A & L bands: From result freq. bands   Pwr_spec.  1.00p
```

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Fig. 1. A typical UDF in the 2133

stants are described in more detail in the following sections.

2.1. Operands in UDFs

Operands in UDFs can be data in the 2123/33 itself, or data stored on the disc. Such data operands, which can be single measurements or complete arrays of measurements, are called into a UDF by naming the data source, that is the input memory, buffer memory, or the relevant disc-file. Where the operand consists of two measurement parameters, as is possible in the 2133, it is possible to select just one of those parameters for the subsequent operation.

Referring again to Fig. 1, the UDF contains just one data operand which is \$:Intensity. The \$ is a shorthand which is used when the data source for the operand has already been named in the display set-up where the UDF is operating. This avoids the need of having to name the data source twice. When using the UDF of Fig. 1, the data operand will most probably be an array of measurements, where each measurement consists both of mean spectrum and intensity data. \$:Intensity selects only the intensity data for the operation in question.

Where data operands come from disc-files, the disc-files can be named symbolically in the UDF, and then the actual file names assigned to the symbols in a list of file names (see Fig. 2). This allows greater flexibility when processing large amounts of data. Up to ten files can be so named at any one

time, using the symbols \$1 to \$10.

In addition to the data operands, a number of special operands can be called into a UDF. These are A-, B-, C- or D-weighting, (A_W, B_W, C_W and D_W), angular frequency, (ω), or $\sqrt{-1}$, (j).

2.2. Operators in UDFs

Referring once again to Fig. 1, the UDF shown there contains four operators, namely, AVG, +, *, and LOG. Looking first at + and *, these define the arithmetic operations of addition and multiplication. AVG and LOG, on the other hand, are special operators which command the averaging of data and the taking of logarithms to the base 10, respectively. In the UDF of Fig. 1, AVG is used to find the average intensity spectrum across the array of measured intensity data, while LOG is used to take the \log_{10} of what we will later see is the area of the measurement surface.

```
Function Setup [ ]
No function specified

File names: [ $1 ] = NOISE
Function files:
$1 NOISE
$2 LWREF
$3 LPREF
$4 LKO
$5 REF_AIR
$6 TOL
$7 FILE01
$8 FILE02
$9 FILE03
$10 FILE04
```

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Fig. 2. Example of a table of file names for UDFs

The UDF of Fig. 1 illustrates an important principle of the use of operators in UDFs, this being their transparency. For instance, when using the AVG operator, it is only necessary to name the array of data to be averaged, and it is not necessary to define the size or any other characteristics of the array, (although limits can be applied within the array, where required). This is true of all operators used in UDFs, and allows what might be a very complicated operation to be defined in a very simple way.

A complete list of operators available for use in UDFs, together with a brief description of them is given in the Appendix.

2.3. Constants in UDFs

The UDF of Fig. 1 contains two constants, namely 10 and S. The first of these, 10, is an example of a constant which is fundamental to the processing equation represented by the UDF. Therefore, it will not change from measurement to measurement, and is written directly into the UDF. S, on the other hand, is the area of the measurement surface used, and can easily change from measurement to measurement. Hence, this is an example of where it is better to name a constant symbolically, and then assign a value to the constant through the table of constants. This allows greater flexibility when changing the value of the constant. Up to 20 constants can be so defined at any one time, (see Fig. 3).

In addition to the table of constants shown in Fig. 3, the 2123/33 contains a further, special table of constants. This allows the parameters used in calculation of reverberation time to be defined individually from frequency band to frequency band, instead of globally where they are the same for all frequency bands.

Function constants:		
1	S	20.000
2	γ	1.5000
3	S_device	10.000
4	S_party	10.000
5	R _w	52.000
6	N	10.000
7	B	1.0130
8	Temp	20.000
9	K	7.0000
10	Noiselim	6.0000
11	V _r	200.00
12	S _r	220.00
13	Y _{avg-Y1}	5.0000
14	delta_Y	20.000
15	U _{limit}	10.000
16	L _{limit}	10.000
17	c ₀	331.36
18	rho ₀	1.2929
19	e	2.7183
20	pi	3.1416

Fig. 3. Example of a table of constants for UDFs

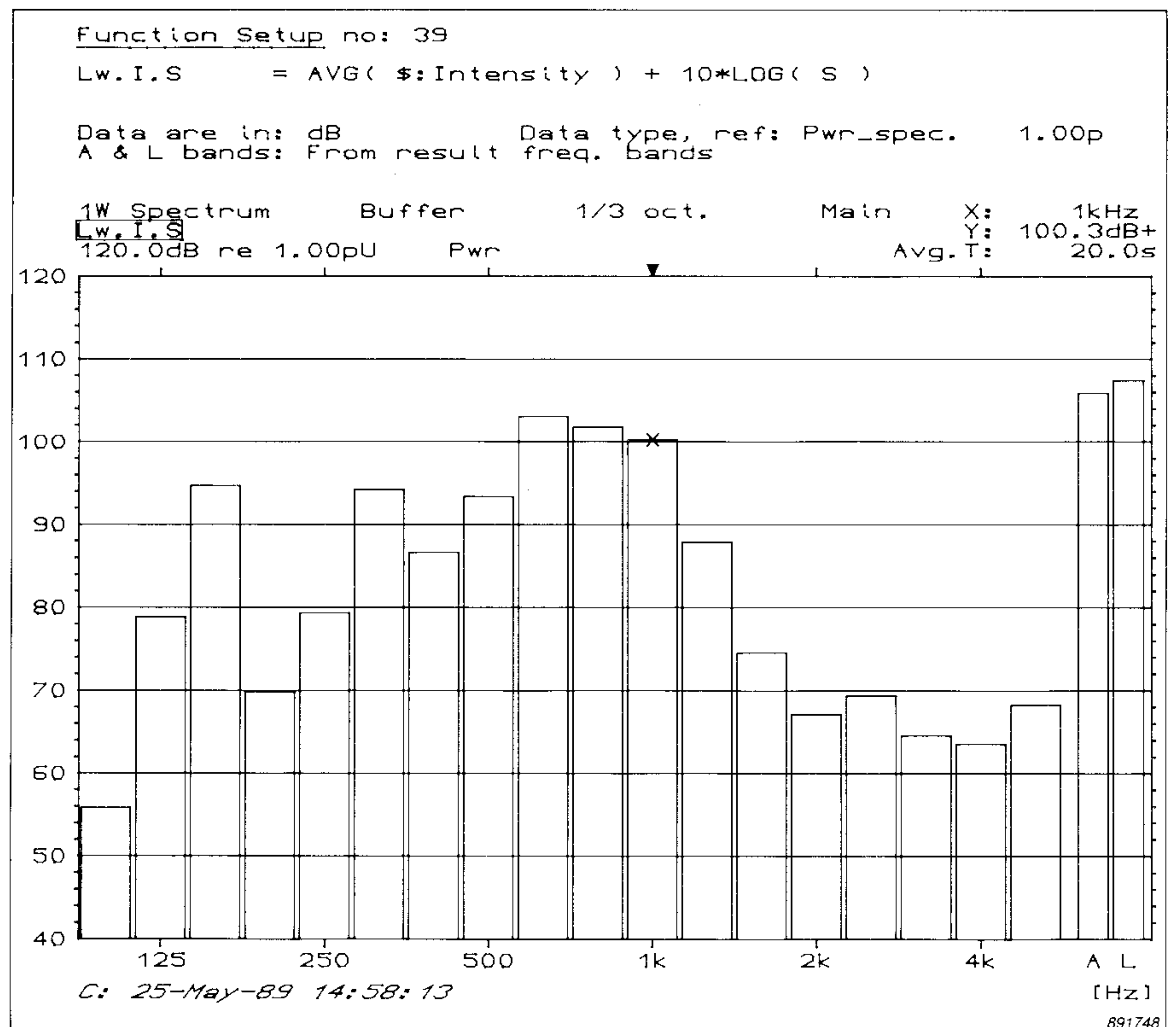


Fig. 4. A sound power spectrum calculated from intensity using UDF 39

2.4. Other factors in UDFs

Referring again to Fig. 1, three further fields complete the definition of the UDF. These define that the data in the operand(s) are to be in dB, (they could also be defined as absolute power), how the results are to be represented, and how the A and linear bands are to be calculated, (from the operand data, from the result data, or not at all). Note that some operators, including AVG, **always** operate on absolute power, irrespective of how the data are defined.

2.5. Using A UDF

Fig. 4 shows an example of a sound power spectrum calculated from a series of intensity measurements using the UDF of Fig. 1. The UDF is commanded by calling it into the display set-up, whereby the name of the UDF is shown as part of the set-up, and the corresponding operation is carried out. Should the UDF require that any discfile data be recalled, this will be requested through the 2123/33 display.

3. Pre-defined UDFs in the 2123/33

Fig. 5 shows a menu of the pre-defined UDFs in the 2133. These UDFs are pre-programmed, and their use requires only the measurement of the

necessary data and entry of the values of any corresponding constants. The following gives a very brief description of the uses of these UDFs, (note that use of many of these UDFs is described in much greater detail in other Brüel & Kjær 2123/33 application notes). The function numbers referred to are with reference to the function numbers in Fig. 5.

(Note that Fig. 5 shows the pre-defined UDFs for the 2133. Some of these are not available on the 2123, since they require dual-channel measurements. Those not available on the 2123 are marked with a *.)

UDF No.s 1-6 allow arithmetic operations between single measurements or complete arrays of measurements, on a dB or absolute power basis.

UDF No. 7 extracts a single measurement from an array of measurement data.

UDF No. 8 averages an array of measurement data on a power basis.

UDF No.s 9-11 allow measurement of weighted sound reduction index according to ISO 717/1 and ISO 717/3, (with easy modification to ISO 717/2).

UDF No. 12 for differentiation of real-valued measurements.

UDF No. 13 for integration of real-valued measurements.

UDF No. 14* for differentiation of complex-valued measurements.

UDF No. 15* for integration of complex-valued measurements.

UDF No.s 16–17* calculate the frequency response functions H_1 and H_2 , respectively.

UDF No. 18 calculates the frequency response function H_3 .

UDF No. 19 is not used.

UDF No.s 20–23 apply A-, B-, C- or D-weighting to single measurements or complete arrays of measurements, as a postprocessing function.

UDF No. 24 compares incoming measurement data with pre-defined tolerances, (generated, for example, using UDF 38) with the tolerances aligned according to the 1 kHz band in the measured data.

UDF No.s 25–28 calculate sample standard deviation and variance and population standard deviation and variance, respectively, across an array of measurement data.

UDF No. 29 compares incoming measurement data with pre-defined tolerances, (generated, for example, using UDF 38) with the tolerances “centred” on the incoming data.

UDF No. 30 calculates directivity index according to ISO 3745, (ANSI equivalent, ANSI S1.35), ISO 4872, and with slight modification, ISO 3744, (ANSI equivalent, ANSI S1.34).

UDF No.s 31–35 calculate sound power based on sound pressure measurements according to ISO 3741 through ISO 3745, (ANSI equivalent ANSI S1.31 through ANSI S1.35), and by default, according to ISO 3746 through ISO 3748.

UDF No. 36 shows if measured sound pressure data is sufficiently above the background noise for sound power determinations using UDFs 31–35.

UDF No. 37 allows single measurement or complete arrays of measurements to be corrected for background noise.

UDF No. 38 allows the generation of tolerances from incoming measurement data.

UDF No.s 39–40* allow calculation of sound power from sound intensity data.

UDF No. 41* allows calculation of pressure-intensity index or residual pressure-intensity index for sound intensity data.

UDF No.s 41–44* allow calculation of the indicators defined by ISO/DIS 9614-1 for sound power determination based on sound intensity measurements.

UDF No. 45* allows correction of intensity data for the residual pressure-intensity index of the measuring equipment.

UDF No. 46* allows calculation of sound power from sound intensity

Function numbers:		
F		18 H3
F		19
W		20 A-weight
0	[]	21 B-weight
1	dB.sub.	22 C-weight
2	dB.add	23 D-weight
3	Abs.sub.	24 Aligned_tol
4	Abs.add	25 SD.Sample
5	Abs.divide	26 Var.Sample
6	Abs.mult.	27 SD.Popul.
7	SINGLE	28 Var.Popul.
8	AVG	29 Fltting_Tol
9	Unfav_dev	30 Dir_index
10	Rw_calcul.	31 Lw.dir.1
11	Ref.shift	32 Lw.com.1
12	ø	33 Lw.rev.3
13	1/ω	34 Lw.free.4
14	δ	35 Lw.free.5
15	J	36 Noisecheck
16	H1	37 Noise.cor.
17	H2	38 Tol
		39 Lw.I.S
		40 Lw.I
		41 P-I-index
		42 Global-P-I
		43 Extr.noise
		44 NonUniform
		45 I.cor.
		46 Lw.I.cor.
		47 Dyn.cap
		48 I.Wide
		49
		50 Reverb
		51 ReverbBack
		52 Back_Int
		53 Lossfactor
		54 Alpha_S
		55 Lev.diff.
		56 Stan.L.dif
		57 Norm.L.dif
		58 Stan.I.Lev
		59 Norm.I.Lev
		60

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Fig. 5. Menu of the pre-defined UDFs in the 2133

data with correction for the residual pressure-intensity index of the measuring equipment.

UDF No. 47* shows the effective dynamic range available for intensity measurements based on the maximum acceptable measurement error.

UDF No. 48* allows combination of intensity measurements made with different microphone spacings to be combined into a single measurement.

UDF No. 49 is not used.

UDF No. 50 calculates reverberation time where the room excitation is interrupted random noise.

UDF No. 51 calculates reverberation time where the room excitation is an impulse.

UDF No. 52 allows backwards integration of reverberation data.

UDF No. 53 calculates loss factor from reverberation data.

UDF No. 54 calculates sound absorption coefficient according to ISO 354.

UDF No. 55–59 allow building acoustics measurements according to ISO 140.

UDF No. 60 is not used.

4. Modifying Pre-defined UDFs in the 2123/33

Any of the pre-defined UDFs in the 2123/33 can be modified according to the user's individual requirements. Figs 6 and 7 give a simple example of this. Fig. 6 shows a pink noise spectrum where UDF No.20 has been applied to give a post-A-weighting, (note that the 2123/33 can also pre-A-weight data). A frequently asked question is whether it is then also possible to “un-A-weight” data, for example, to remove the effects of a previously applied A-weighted. This can be very simply achieved by modifying UDF 20 to subtract rather than add the A-weighting coefficients. The effect of the resulting UDF on a pink noise spectrum is shown in Fig. 7.

Note that when a pre-defined UDF is modified, it immediately goes into a “working” UDF set-up, leaving the original UDF unchanged. The modified UDF can then be saved in one of the UDF set-ups 1–8, if required, or stored on the 2123/33 disc.

5. Writing New UDFs into the 2123/33

Where the pre-defined functions do not allow the desired processing, it is often possible for the user to provide this by writing in a new UDF. Such a UDF, which is written in using the 2123/33 keyboard in “Alpha” mode, can consist of up to 144 characters, (including spaces), and can be stored for future use in the 2123/33 non-volatile memory or on disc.

6. Real-time processing and UDFs

Depending on how they are written, it is often possible to process UDFs in real-time. Where the final processing is carried out on incoming real-time data, and all other data required for the processing can be held in the 2123/33 internal memory, then the processed data is recalculated each time the 2123/33 screen is updated, so producing a real-time display. It should be pointed out, though, that in such cases, the screen update rate will depend on the complexity of the function being processed. Where, however, the screen update rate is critical, complex functions can be broken down into two or more parts, the first parts calculating intermediate results which are stored in the 2123/33 internal memory, and the last part combining these intermediate results with the incoming real-time data.

7. Conclusions

It has been shown that user-definable functions form an easy-to-use but powerful means of processing analyzed data on the 2123/33. The wide range of pre-defined functions covers many types of everyday signal processing, while where more special processing is required, the pre-defined functions can be modified as required, or completely new functions can be written in.

Appendix. Operators in UDFs

The following gives a list of operators available in the 2123/33 for use in UDFs. The term "multispectrum" is used to describe a complete array of measurement data.

+, **-**, *****, **/** add, subtract, multiply, divide

^ raises to a power N or $1/N$

EXP takes an exponential

LOG, **ALOG** takes the logarithm/antilogarithm to the base 10

ABS takes the absolute value

CONJUG takes the complex conjugate

COMBINE combines two one-parameter functions into one two-parameter function

INSERT inserts a spectrum into a multispectrum

SINGLE extracts a spectrum from a multispectrum

SLICE extracts a slice from a multispectrum

SHIFT shifts the frequency range of a spectrum or multispectrum

AVG averages the absolute power in each frequency band of a multispectrum

TOT sums the absolute power in each frequency band of a multispectrum

DELTATOT sums the absolute power in a spectrum or slice

DELTAMAX extracts the maximum value in a spectrum or slice

DELTASUM sums the dB levels in a spectrum or slice

S_PWR calculates the sound power flowing through an area from a sound intensity measurement

BACK_INT backwards integrates each slice in a one-dimensional multispectrum

REVERB calculates reverberation time for each slice in a multispectrum

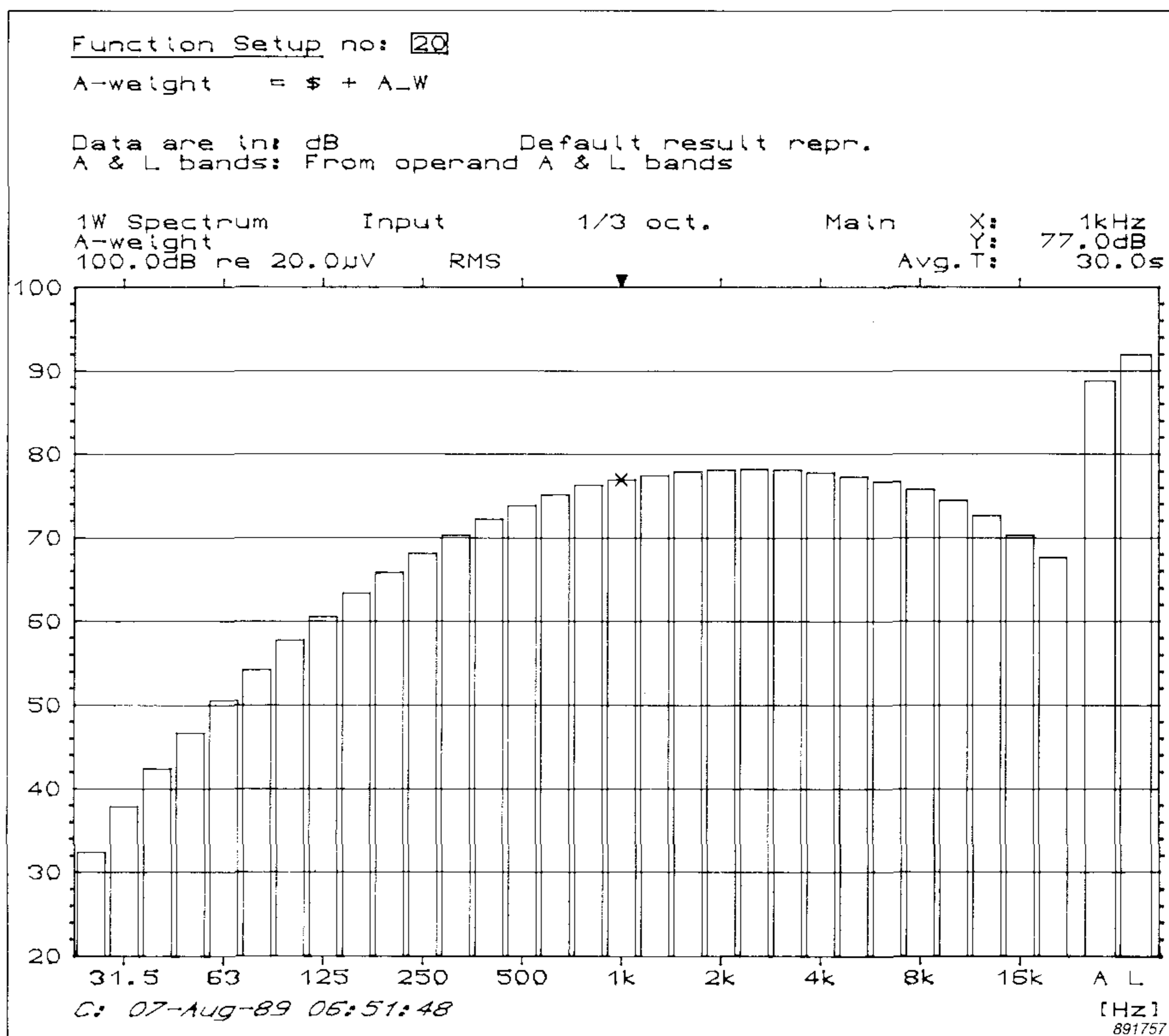


Fig. 6. Post-A-weighting of a pink noise spectrum using pre-defined UDF no. 20

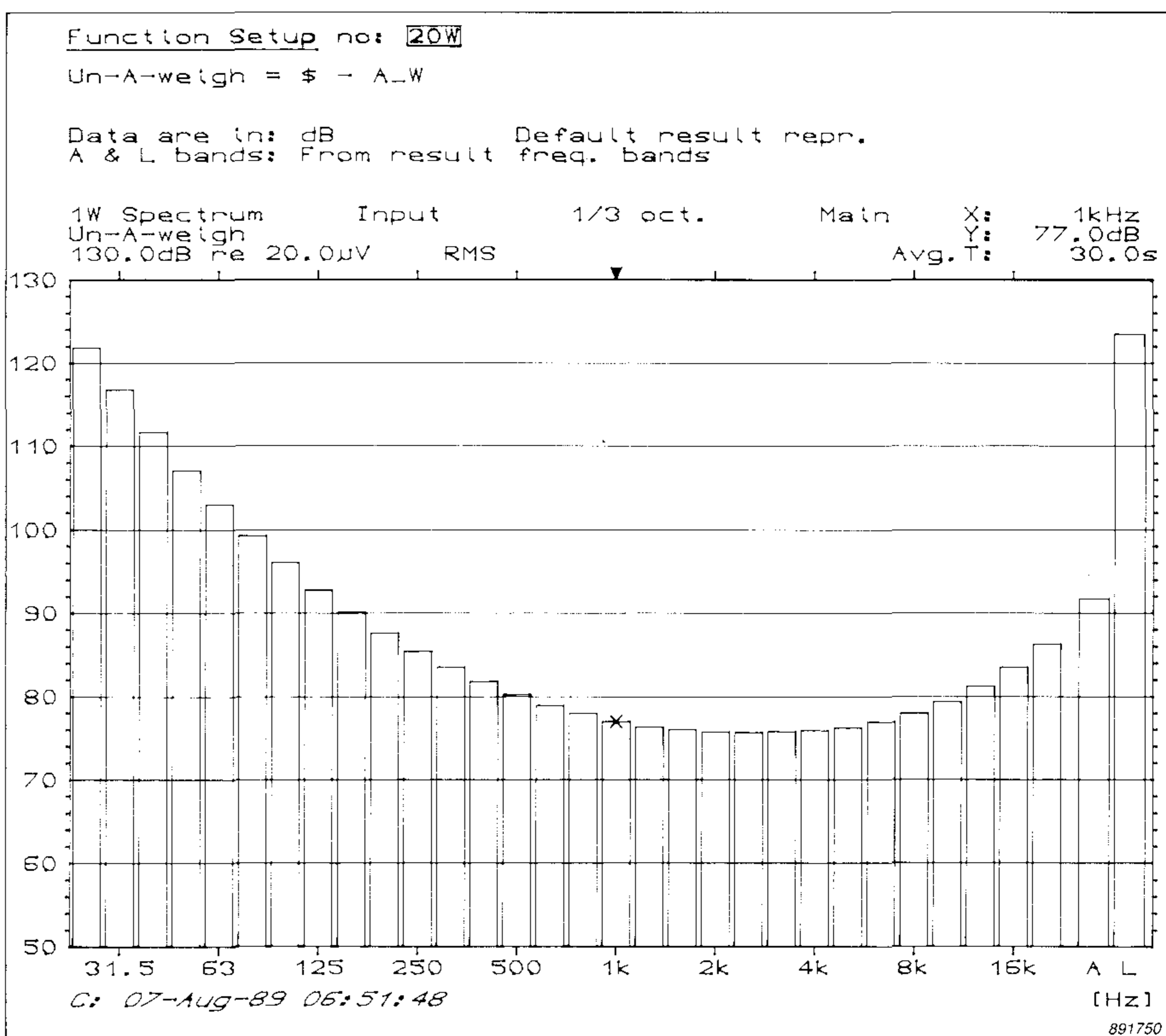


Fig. 7. Post-"un-A-weight" of a pink noise spectrum using pre-defined UDF no. 20 modified to subtract rather than add the A-weighting coefficients

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