(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 1 189 381 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
20.03.2002 Bulletin 2002/12

(51) Int Cl.⁷: **H04L 1/24**, H04L 27/26

(21) Application number: **00202378.6**

(22) Date of filing: **07.07.2000**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

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(54) Random test signal for communication systems

(57) A signal is disclosed comprising at least a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers.

Furthermore is a method disclosed for arranging a signal for use on or in a communication system, the method comprising the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal according to a non-linear transformation, the non-linear transformation achieving a predetermined quality criterion.

Yet furthermore is a disclosed a method of arranging a signal for use on or in a communication system, the method comprising the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and filtering the signal in representation in frequency domain including the steps of evaluating at least part of the signal representation in frequency domain and thereafter processing the signal representation in frequency domain.

A set of instructions in a code format and executable in a predetermined order and compiled on a device and the use thereof for generating or arranging a test signal and/or a noise signal is disclosed. The set of instructions is arranged for generating a random noise signal and/or a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion.

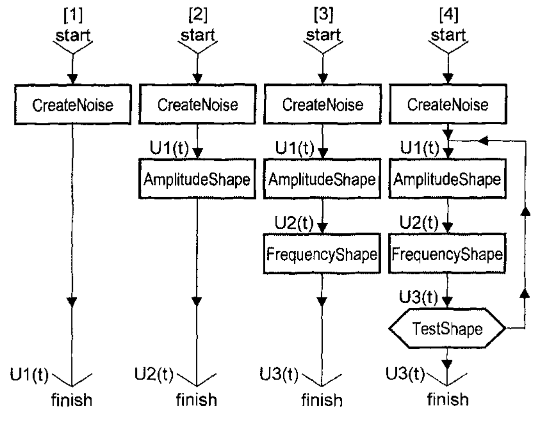

FIG. 2

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Description

FIELD OF THE INVENTION

[0001] The present invention is related to the field of testing communication systems such as xDSL transceivers or cables or networks. More in particular a signal, a method of generating a signal, a method of arranging a signal, a test system and a telecommunication network are disclosed that are arranged for an improved application of communication systems such as xDSL transceivers or cables or networks.

BACKGROUND

[0002] It is known in the art that transmission performance tests are needed for stressing communication systems such as xDSL transceivers in a way that is representative for the actual operation conditions in operational access networks. Specifically the transceivers are tested in a way that is representative to a high penitration of systems scenario in operational access networks. This high penitration approach enables operators to define deployment rules that apply to most of the operational situations. This high penitration approach also enables communication system manufacturers to quantify performance and to use the results thereof for improving design or proving complience with specifications given by the operators or other instances.

[0003] A method of executing the transmission performance tests is to generate a noise signal. The tests in such case are focused on the noise margin, with respect to the crosstalk noise or impulse noise levels when xDSL signals are attenuated by a test loop and interfered with such crosstalk noise or impulse noise. The tests are to simulate noise signals that can be generated (i) by crosstalk noise e.g. from neighboring xDSL systems ; (ii) by rfi-tones that have a discrete frequency spectrum and originate e.g. from amateur broadcasting ; (iii) by pulses originating from switch components or operations ; and (iv) by lightning impact. A signal that contains the (i) crosstalk noise e.g. from neighboring xDSL systems , and (ii) the rfi-tones that have a discrete frequency spectrum, is called impairment noise and the generator for making such noise signals is called an impairment generator.

PROBLEM DEFINITION

[0004] Methods of generating noise signals are known in the art. However the test systems that have been used so far for generating noise signals for the testing of communication systems are complicated in fabrication and request an adaptation of the hardware that forms part of the test systems for each different operational condition that is to be tested. For instance, each different type or length of a transmission medium such as a cable, a copper cable or an optical fiber or other cables, request a different noise signal. Thus there is need in the art for a test method and a test system that is flexible in use but provides satisfactory results on the issue of tests representativity to a high penitration of systems scenario in operational access networks. Appropriate noise signals are needed hereto and methods of generating such noise signals are needed and appropriate test systems and use in or on communication systems and in or on telecommunication networks are needed in the art.

[0005] The needed means recited hereabove will allow to have a better quality of signal transmission over media such as telephone cables or wireless media. A better transmission of signals allows for a broader providing of more services for the users of communication systems.

SUMMARY

[0006] A signal is disclosed comprising at least a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers.

[0007] Furthermore is a method disclosed for arranging a signal for use on or in a communication system, the method comprising the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal according to a non-linear transformation, the non-linear transformation achieving a predetermined quality criterion.

[0008] Yet furthermore is a disclosed a method of arranging a signal for use on or in a communication system, the method comprising the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and filtering the signal in representation in frequency domain including the steps of evaluating at least part of the signal representation in frequency domain and thereafter processing the signal representation in frequency domain.

[0009] A set of instructions in a code format and executable in a predetermined order and compiled on a device and the use thereof for generating or arranging a test signal and/or a noise signal is disclosed. The set of instructions is arranged for generating a random noise signal and/or a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion.

[0010] The signal, the methods and the set of instructions recited hereabove will allow to have a better quality of signal transmission over media such as telephone cables or wireless media. A better transmission of signals allows for a broader providing of more services for the users of communication systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

Figure 1 : shows according to an embodiment of a system of the present invention a functional description of the set-up of the performance tests.

Figure 2 : shows schematically an embodiment of a method for arranging a signal for use on or in a communication system.

Figure 3 : shows an amplitude distortion (non-linear transformation) function Q(x) that amplifies the high amplitude peaks or tones in a signal.

Figure 4 : shows in a flow diagram an example embodiment of the invention.

Figure 5-9 : show results that are obtained according to the best mode embodiment of the invention.

DESCRIPTION

[0012] For the purpose of teaching of the invention, aspects and embodiments of the signal and method and systems of the invention are described in the sequel. It will be apparent to the person skilled in the art that other alternative and equivalent embodiments of the invention can be conceived and reduced to practice without departing form the true spirit of the invention, the scope of the invention being limited only by the appended claims.

[0013] In a first aspect of the present invention a method is disclosed of arranging a signal for use on or in a communication system. Preferably the signal is a noise signal. The signal can comprise crosstalk noise that is a random signal with predetermined properties in the frequency domain and in the time domain. The signal can furthermore comprise rfi-tones that have a discrete frequency spectrum. Also other signal components can be included in the signal. The method comprises the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal according to a non-linear transformation, the non-linear transformation achieving a predetermined quality criterion.

[0014] The method can further comprise the step of comparing the amplitude distribution of said represented signal with a predetermined amplitude distribution and thereafter arranging the non-linear transformation in order to achieve a processed represented signal with an amplitude distribution approaching the predetermined amplitude distribution.

[0015] In a second aspect of the present invention a method is disclosed of arranging a signal, preferably a noise signal for use on or in a communication system, the method comprising the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal until a signal is achieved having a spectral density according to a predetermined spectral density quality criterion. According to the second aspect of the invention the method can also comprise the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and filtering the signal in representation in frequency domain including the steps of evaluating at least part of the signal representation in frequency domain and thereafter processing the signal representation in frequency domain.

[0016] The methods of the first and second aspect of the invention can be combined. The methods of the first and second aspect of the invention allow to make a signal in different iterative steps that has a predetermined amplitude distribution and/or that has a predetermined spectral density or that has a amplitude distribution and/or that has a spectral density according to a predetermined quality criterion. The predetermined quality criterion can be the crest factor of the signal that is relation of the maximal tones of the signal compared to the average of the tones of the signal. The processing steps as recited hereabove can comprise the steps of a Fast Fourier Transformation (FFT) or Inverse

Fast Fourier Transformation (IFFT). The processing steps can also a include operations such as a convolution or deconvolution or multiplication or add-on of signals . The signals can be generated and stored using a set of instructions in a code format and executable in a predetermined order and compiled on a device. Such set of instructions can be software code compiled on a computer and stored in the computer or a network of computers or a floppy or CD-ROM or through the internet. The software can also be stored on an Arbitrary Wave Form Generator (AWG) card and the AWG can be used to generate the signals or reproduce stored signals from the memory. It is therefore possible to have a library of signals available that can be used in the execution or use of the methods of the first and second aspect of the invention. The communication systems can be devices such as xDSL modems, or chips within or for such modems, or cables in the network, or networks for telecommunication.

[0017] Several embodiments of the first and second aspect of the invention are recited herebelow. In the method of the first aspect, the amplitude distribution of said represented signal can be processed including a function of the predetermined amplitude distribution. This can include an inverse function of the predetermined amplitude distribution. The processed represented signal g(t) furthermore can be a function Q{f(t)} of the represented signal f(t) and wherein Q is defined as

$$Q(x) = sign(x) \cdot G^{-1}\left(F\left(|x|\right)\right)$$

with

sign(x)=x/|x| for x<>0; sign(x)=0 for x=0 ;

and with F being the amplitude distribution of said represented signal.

[0018] The method as recited of the first and second aspect of the invention can further comprise the steps of transforming the first signal in frequency domain ; and multiplying the first signal in frequency domain with spectral envelope thereby achieving a multiplied signal ; and thereafter representing the multiplied signal in time domain. In the methods said first signal in the representation in frequency domain can be generated as a set of random numbers, preferably complex numbers the modulus of the complex number characterizing amplitude, the argument of the complex number characterizing phase and the real and/or the imaginary part of essentially each of the complex numbers can be chosen according to a Gaussian distribution. Each of the complex numbers can be substantially equal to the amplitude of the predetermined spectral density.

[0019] In a third aspect of the present invention, a signal is disclosed comprising at least a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers. The signal can further comprise a discrete frequency spectrum. The noise signal can be generated using a set of instructions in a code format and being executed in a predetermined order. Such set of instructions can be software code compiled on a computer and stored in the computer or a network of computers or a floppy or CD-ROM or through the internet. The software can also be stored on an Arbitrary Wave Form Generator (AWG) card and the AWG can be used to generate the signals or reproduce stored signals from the memory. It is therefore possible to have a library of signals available that can be used in the execution or use of the methods of the first and second aspect of the invention.

[0020] In a fourth aspect of the present invention, a is disclosed of generating a signal comprising at least a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers, the method comprising the step of generating a random set of numbers using a set of instructions in a code format and being executed in a predetermined order. The method can further comprise the step of generating a discrete frequency spectrum, the discrete frequency spectrum using goniometry functions and modulating essentially each of the discrete frequencies with a noise characteristic. The random noise signal and the discrete frequency spectrum can be combined using a set of instructions in a code format and being executed in a predetermined order.

[0021] In a fifth aspect of the present invention, a set of instructions is disclosed in a code format and executable in a predetermined order and compiled on a device, the set of instructions being arranged for generating a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion. Such set of instructions can be software code compiled on a computer and stored in the computer or a network of computers or a floppy or CD-ROM or through the internet. The software can also be stored on an Arbitrary Wave Form Generator (AWG) card and the AWG can be used to generate the signals or reproduce stored signals from the memory. It is therefore possible to have a library of signals available that can be used. The software can be C-code or can be compiled in a MATLAB environment.

[0022] In a sixth aspect of the present invention, a system for testing the operation of a communication system is disclosed comprising a set of instructions in a code format and executable in a predetermined order and compiled on a device, the set of instructions being arranged for generating a noise signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion. The test system according to this aspect of the invention can comprise an impairment generator for generating the noise signal. The connection elements (transformers, active devices, attenuators, etc.) that connect the impairment generator to the communication system that is tested can have an unwanted frequency dependent response. The connection element is the adding element in figure 1. The unwanted frequency dependent response can be measured for instance by generating specific test signals in the impairment generator. The unwanted frequency dependent response can be compensated by multiplying the desired spectral density of the signal divided by the unwanted frequency dependent response of the connection element.

[0023] In a seventh aspect of the present invention, a method of testing the operation of a communication system such as a xDSL modem is disclosed. The method comprises the step of superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion., the noise signal furthermore being composed of an array of random numbers.

[0024] In an eigth aspect of the present invention a method of testing the quality of operation of a communication system is disclosed. The method comprises the steps of superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers ; and evaluating the transceived signal according to a predetermined quality criterion.

[0025] Yet in a ninth aspect of the present invention, a method of improving the design and/or production of a communication system is disclosed , the method comprising the steps of superposing on a signal transceived by a said modem, superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers ; evaluating the transceived signal according to a predetermined quality criterion ; and iteratively arranging the design of said modem in order to approach closer to the quality criterion for evaluating the transceived signal.

[0026] In a tenth aspect of the present invention, a telecommunication network is disclosed including a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers.

[0027] The features of the above-described aspects and embodiments of the invention can be combined.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0028] For the purpose of teaching of the invention, preferred embodiments of the method and devices of the invention are described in the sequel. It will be apparent to the person skilled in the art that other alternative and equivalent embodiments of the invention can be conceived and reduced to practice without departing form the true spirit of the invention, the scope of the invention being limited only by the appended claims.

[0029] In an embodiment of the invention, a system for testing the operation of a communication system such as a xDSL transceiver is disclosed. The set up of a test equipment for a high penitration of systems scenario in operational access networks is described. A method is disclosed of arranging a signal for use on or in a communication system. The purpose of transmission performance tests is to stress xDSL transceivers in a way that is representative to a high penitration of systems scenario in operational access networks. This high penitration approach enables (i) component and system designers to quantify the performance and to use it to improve their design and to prove complience with standards ; and (ii) operators to define deployment rules that apply to most operational situations.

[0030] Figure 1 illustrates the functional description of a possible test set-up. It includes:

- The test loops, being a reel cable or a cable simulator;

- An adding element to inject the impairment noise (a mix of random, impulsive and harmonic noise (the rfi-tones)), into the test loop
- A high impedance, and well balanced differential voltage probe connected with level detectors such as a spectrum analyser or a rms volt meter.

When external splitters are required for the xDSL system under test (for POTS or ISDN signals), this splitter can be included in the modem under test.

[0031] The signal flow through the test equipment set-up is from port Tx to port Rx, which means that measuring upstream and downstream performance requires an interchange of transceiver position and test "cable" ends. The received signal level at port Rx is the level, measured between node A2 and B2, when port Tx as well as port Rx are terminated with the xDSL transceivers under test. The impairment generator is switched off during this measurement. The transmitted signal level at port Tx is the level, measured between node A1 and B1, under the same conditions.

[0032] The noise that the impairment generator should inject into the test setup is frequency dependent. In order that the noise that the impairment generator should inject into the test setup is a realistic representation of a real (spectral polluted) access network, is to be (a) dependent on the length of the testloop, and (b) different for downstream performance tests and upstream performance tests. This impairment noise, measured between node A2 and B2, is usually a mix of random, impulsive and harmonic noise (the rfi-tones). A set of characteristics is identified as a "noise profile".

[0033] The signal and noise levels are probed with a well balanced differential voltage probe. The noise that the impairment generator injects into the test setup is frequency dependent, is dependent on the length of the testloop and is also different for downstream performance tests and upstream performance tests. Definitions that are relevant for the use of the test equipment are the following:

- Probing an rms-voltage U_{rms} [V] in this set-up, over the full signal band, means a *power level* of P [dBm] that equals:

$$P = 10 \times \log_{10}(U_{rms}^2/R_v \times 1000) \text{ [dBm]}$$

- Probing an rms-voltage U_{rms} [V] in this set-up, within a small frequency band of Δf (in Hertz), means an *power spectral density level* of P [dBm/Hz] within that filtered band that equals:

$$P = 10 \times \log_{10}(U_{rms}^2 / R_v \times 1000 / \Delta f) \text{ [dBm/Hz]}$$

- The bandwidth Δf identifies the noise bandwidth of the filter, and not the-3dB bandwidth.

[0034] Figure 2 shows schematically an embodiment of a method for arranging a signal for use on or in a communication system. The signal comprises crosstalk noise that is a random signal with predetermined properties in the frequency domain and in the time domain. The signal can furthermore comprise rfi-tones that have a discrete frequency spectrum. Also other signal components can be included in the signal. The method comprises the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal according to a non-linear transformation, the non-linear transformation achieving a predetermined quality criterion. This is shown as amplitude shaping in figure 2 [2-4].

[0035] The method can also comprise the steps of representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and processing said represented signal until a signal is achieved having a spectral density according to a predetermined spectral density quality criterion. This is shown as frequency shaping in figure 2 [2-4]. The frequency shaping step can also comprise the step of filtering the signal in representation in frequency domain including the steps of evaluating at least part of the signal representation in frequency domain and thereafter processing the signal representation in frequency domain.

[0036] The method can also comprise the step of making a signal in different iterative steps (see figure 2 [4]). Thus the signal can have a predetermined amplitude distribution and/or a predetermined spectral density or a amplitude distribution and/or a spectral density according to a predetermined quality criterion. The predetermined quality criterion can be the crest factor of the signal that is a relation of the maximal tones of the signal compared to the average of the tones of the signal. The signals can be generated and stored using a set of instructions in a code format and executable in a predetermined order and compiled on a device. Such set of instructions can be software code compiled on a computer and stored in the computer or a network of computers or a floppy or CD-ROM or through the internet.

The software can also be stored on an Arbitrary Wave Form Generator (AWG) card and the AWG can be used to generate the signals or reproduce stored signals from the memory. It is therefore possible to have a library of signals available that can be used in the execution or use of the methods of the first and second aspect of the invention. The communication systems can be devices such as xDSL modems, or chips within or for such modems, or networks for telecommunication.

[0037] In detail the following embodiment is shown in figure 2. Using software, random numbers are generated (box CreateNoise in figure 2). In hardware white noise can be generated. The random numbers are filtered until a predetermined spectral density is achieved. The random numbers that are generated each represent a frequency component. The necessary processing to achieve a predetermined spectral density is executed by scaling the amplitude of the complex numbers and thereafter a IFFT processing is done in order to make the desired noise signal. Another way of executing the method is to generate random numbers that represent the phase of each frequency component and thereafter the amplitude of the complex numbers is arranged to approach or be equal to a predetermined spectral density

[0038] The processing in box AmplitudeShape in figure 2 is done for achieving an impact or control on the time domain characteristic. An amplitude distortion (transformation) function Q(x) is chosen that amplifies the high amplitude peaks or tones in the signal is shown in figure 3. The non-linear transformation function Q(x) can be reconstructed from the actual amplitude distribution function of the signal and the predetermined amplitude distribution function. A noise signal *f(t)* in the period *t* inbetween 0 en T. The amplitude distribution *F(a)* of the signal is defined as a fraction of the time that the noise *f* in absolute value is larger than *a*. If *G(a)* is the predetermined amplitude distribution (such as an enhanced-gaussian, see below), and $G^{-1}(a)$ the inverse function thereof. The transformation function *Q(x)* to make an intermediate or final signal *g(t)* from signal *f(t)* can be defined as :

$$Q(x) = sign(x) \cdot G^{-1}\left(F\left(|x|\right)\right)$$

$$g(t) = Q\{f(t)\} ;$$

sign(x)=x/|x| voor x<>0; sign(x)=0 voor x=0;

[0039] As a result *g(t)* will have the predetermined amplitude distribution *G(a)*. *Q(x)* in a number of cases can be an analytical function but can also be numerically constructed.

[0040] An example of an enhanced gaussian function is as follows :

The amplitude distribution of gaussian type of noise is :

$$G(x) = 1 - erf\left(\frac{x}{\sqrt{2}\sigma}\right)$$

with

$$erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x dt \exp\left(-t^2\right),$$

and with σ the RMS value of the signal.

The enhanced Gausian distribution is defined as :

$$G(x) = 1 - \frac{\alpha \, {}^{x}\!/_{A} + erf\left(\frac{x}{\sqrt{2}\sigma}\right)}{\alpha + erf\left(\frac{A}{\sqrt{2}\sigma}\right)},$$

with σ the RMS value of the signal , and with A and α free parameters. Typical values for α are of the order of 1e-2, le-3. An appropriate choice for σ is: $\sigma=\sqrt{}\ (1+\alpha - C_f^2\cdot\alpha/3)$, with C_f a number that is in realtion to or equals the crest factor and with α a number that describes the deviation from gaussian noise.

[0041] In the box FrequencyShape of figure 2, the frequency domain characteristics of the signal are improved. The corrected frequency curve is achieved by comparing (dividing) a prdeterminde spectral density through the measured spectral density of the (intermediate) signal. An example hereof is given in the best mode embodiment desribed in the sequel with a convolution of FFT functions.

[0042] In the part [4] of figure 2, it is shown how an iterative procedure of the steps detailed herabove may lead to a further improvement of the final for use in or on a communication system. The iterative procedure is executed until the predeterminde quality criterions are achieved.

[0043] A best mode embodiment of the set of instructions of the invention is disclosed herebelow. The code given herebelow is compiled in a MATLAB environment gives the signal resulst as shown in the figures 5-9. Comments related to the functionality of the code are given after the % signs.

```
%--------------------------------------------------------------------------
function DemoImpair;
%--------------------------------------------------------------------------
% DemoImpair
%      Code, programmed in the Matlab programming language, that demonstrates
%      algorithms of an Impairment Generator, that has full control
%      over elementairy frequency and time domain characteristics (spectrum
%      probability distribution)
```

```
%       (c) 2000 KPN Research;  Rob van den Brink, Bas van den Heuvel
%
% MAIN FUNCTIONS:
%       DefineShape
%       CreateNoise    - generates noise, as an array with real random numbers
%       FrequencyShape        - modifies the spectral density of this noise
%       AmplitudeShape        - modifies the amplitude distribution of this noise
%
% SUPPORTING FUNCTIONS:
%       CalcSpec       - calculates the spectral density of noise
%       CalcCrest      - calculates the crest factor of noise
%       CalcDistrib    - calculates the probability distribution of noise
%       CalcSmooth     - smoothes a spectrum, like in a real spectrum analyzer
%       CalcEnhancedGaussDistribution - a sample of a near-gaussian distribution
%-----------------------------------------------------------------------------
R=135; CF_min=5.1;
Shape=DefineShape;
%
[U,t]=CreateNoise(Shape);  plot(t,U);                  title('method 1'); shg; %pause
[X,f]=CalcSpec(U,t);              plot(f,X);           title('method 1'); shg; %pause
[X,f]=CalcSpec(U,t);              plot(f,dBm(X,R));    title('method 1'); shg; %pause
[P,u]=CalcDistrib(U);   plot(u,P);               title('method 1'); shg; %pause
%
U=AmplitudeShape(U,Shape); plot(t,U);                  title('method 2'); shg; %pause
[X,f]=CalcSpec(U,t);              plot(f,X);           title('method 2'); shg; %pause
[X,f]=CalcSpec(U,t);              plot(f,dBm(X,R));    title('method 2'); shg; %pause
[P,u]=CalcDistrib(U);   plot(u,P);               title('method 2'); shg; %pause
%
U=FrequencyShape(U,Shape); plot(t,U);                  title('method 3'); shg; %pause
```

```
[X,f]=CalcSpec(U,t);            plot(f,X);            title('method 3'); shg; %pause
[X,f]=CalcSpec(U,t);            plot(f,dBm(X,R));     title('method 3'); shg; %pause
[P,u]=CalcDistrib(U);   plot(u,P);            title('method 3'); shg; %pause
%
for i=2:10
 i
 U=AmplitudeShape(U,Shape);
 [X,f]=CalcSpec(U,t);
 %
 U=FrequencyShape(U,Shape);
 [X,f]=CalcSpec(U,t);
 %
 if CalcCrest(U)>CF_min, break; end;
end;
[P,u]=CalcDistrib(U);
plot(t,U);              title('method 4'); shg; %pause
plot(f,dBm(X,R));       title('method 4'); shg; %pause
plot(u,P);              title('method 4'); shg; %pause
%
[Ut,t]=CreateTones(Shape);
U=U+Ut;
plot(t,U);              title('noise + RFI tones'); shg; %pause
 [X,f]=CalcSpec(U,t);
 plot(f,dBm(X,R));      title('method 4'); shg; %pause



%---------------------------------------------------------------------------
function [Shape] = DefineShape;
```

```
%---------------------------------------------------------------------------
% create the targets for the noise that shout be generated, in terms of
%       spectral density (in this example rechtangular in nature)
%       probability distribution (in this example near Gaussian)
Fmax=4E6; Fl=300E3; Fh=700E3; N=2^18; m=N/2;
Shape.N=N;                    % number of time samples
Shape.m=m;                    % number of freq samples
Shape.dF= Fmax./(m-1);                % frequency spacing
Shape.dT= 1/(N*Shape.dF);  % time spacing
% define target spectrum (in freq domain)
Shape.freq =[0:m-1]' * Shape.dF;
Shape.spec =(Shape.freq>=Fl).*(Shape.freq<=Fh)*(1/300); % in Volt per sqrt(Hz)
% define target Cumulative Amplitude Distribution (in time domain)
cf=5.5; % desired crest factor)
Shape.DistU = 0:cf/1000:cf;
Shape.DistP = CalcEnhancedGaussDistribution(Shape.DistU, cf); %P
% define target RFI-Tones
Shape.ToneF =[99;207;333;387;531;603;711;801;909;981]*1E3;
P_dBm =[-70;-50;-60;-60;-40;-60;-60;-40;-70;-40]; % dBm @ 135 ohm
P=(10).^(P_dBm/10)*1E-3;
Shape.ToneU =sqrt(P*135); % U=sqrt(P*R); effective value
Shape.ModDepth = 0.3;  %=mod index 0.8 )
Shape.ModWidth = 10E3; %= -5 kHz .. +5 kHz)



%---------------------------------------------------------------------------
function [U,t] = CreateNoise(Shape);
%---------------------------------------------------------------------------
% create a noise voltage U(t), whith predefined frequency domain characteristics
```

```
% (spectrum), but with uncontrolled time domain characteristics (distribution)
N = Shape.N;                    % number of samples, to be generated
%U = rand(N,1);                         % Uniform distributed white noise
U = randn(N,1);                         % Gaussian distributed white noise
U = FrequencyShape(U,Shape);            % shaped noise
t=[0:N-1]' * Shape.dT;



%---------------------------------------------------------------------------
function [U,t] = CreateTones(Shape);
%---------------------------------------------------------------------------
% create a voltage U(t), with RFI Tones at predefined frequencies, amplitude
% and 10 kHz modulation bandwidh
%---creation of modulation noise up to Fmod, having an effective value of 1 "Volt"
% Xn=(f<=Shape.ModWidth/2).*exp(j*1000*rand(N,1))/sqrt(Shape.ModWidth);
% Xn(1) = 0;                            % Eliminate DC component.
% Xn(N:-1:m+2)=conj(Xn(2:ceil(m)));           % Append spectrum (negative freq.)
% Noise = (sqrt(t_max)./Shape.dT) .* real(ifft(Xn));% Transform to time-domain
%---proof
% plot(t,Noise); shg;
% N2=sqrt(sum(Noise.*Noise)/length(Noise)) %proof of effective value of 1 "Volt"
%---------------------------------------------------------------------------
Fmod=10E2;
N = Shape.N;                    % number of samples, to be generated
m = Shape.m;
t_max=N*Shape.dT;
f=[0:N-1]' * Shape.dF;
t=[0:N-1]' * Shape.dT;
%
```

```
U=0;
Xn0=(f<=Shape.ModWidth/2) .*  ( sqrt(t_max) ./ Shape.dT ./ sqrt(Shape.ModWidth) );
Xn(1) = 0;                          % Eliminate DC component.
for k=1:length(Shape.ToneF);
 Xn=Xn0.*exp(j*1000*rand(N,1));
 Xn(N:-1:m+2)=conj(Xn(2:ceil(m)));          % Append spectrum (negative freq.)
 Noise = real(ifft(Xn));                % Transform to time-domain
 %
 T=1/Shape.ToneF(k);
 T0=t_max/round(t_max/T);           % force an integer number of periods
 U=U   +   Shape.ToneU(k)   *   sin(2*pi*t/T0+1000*rand)   .*   (1   +   Noise   .*
Shape.ModDepth);
end;



%---------------------------------------------------------------------------
function [U] = FrequencyShape(U,Shape)
%---------------------------------------------------------------------------
% Reshape the spectrum of the sample U, as specified by the target shape
% INPUT:
%       U:        the consecutive values of the sample
%       fs:       the sample frequency
%       spektrum: the desired PSD (in V/sqrt(Hz))
%---------------------------------------------------------------------------
N = length(U);
m = length(Shape.spec);     % m=N/2
t= [0:N-1]'*Shape.dT;
% perform the frequency scaling
Scaling = Shape.spec ./ CalcSpec(U,t);
```

```
X = fft(U);                              % Tranform to frequency domain
X(1) = 0;                                % Eliminate DC component.
X(2:m+1)  = X(2:m+1) .* Scaling;   % Scale  spectrum (positive freq.)
X(N:-1:m+2)=conj(X(2:ceil(m)));              % Append spectrum (negative freq.)
U = real(ifft(X));                       % Transform to time-domain



%---------------------------------------------------------------------------
function [U] = AmplitudeShape(U,Shape)
%---------------------------------------------------------------------------
% This function shapes the amplitude distribution of the function U
% by an amplitude dependend (non-linear) distortion function Q(x).
% The result is U(t) = Q{U(t)}
%
% Let FF be the actual cumulative distribution function of the sample, and
% let GG be the desired cumulative distribution function,
% then the distortion function is given by:
%       Q(x) = GG^{-1} FF (x)
%---------------------------------------------------------------------------
U0=sqrt(sum(U.*U)/length(U)); %scaling farct (for normalization)
% Calculate the distortion function Q
[DistP1,DistU1] = CalcDistrib(U/U0);                % the actual distribution
Q = interp1(Shape.DistP, Shape.DistU, DistP1) ;     % the distortion function
U = U0 *interp1(DistU1,Q,abs(U/U0)) .* sign(U);  % Perform the distortion
% plot(DistU1,Q); shg; %pause



%---------------------------------------------------------------------------
function [X,f] = CalcSpec(U,t);
```

```
%-------------------------------------------------------------------------
% calculate the spectral density of a signal, when it would be 'measured'
% at specified resolution bandwidth
RBW=1E3;    %RBW:         the desired resolution for the spectrum of U
N = length(U); m=N/2;
dT = t(2)-t(1);                     % time spacing
dF = 1/dT;                          % frequency spacing
f= [0:m-1]'*dF;                          % all positive frequencies
X = fft(U)*dT;                           % to frequency domain
X = abs(X(2:m+1));                  % No DC and no negative frequencies.
X = sqrt(CalcSmooth(X.*X, f, RBW));      % average it over bandwidth RBW


%-------------------------------------------------------------------------
function [CF] = CalcCrest(U)
%-------------------------------------------------------------------------
% Calculate the Crest Factor of a signal (U(t), which is the peak value
% divided by the rms-value
Urms = sqrt(sum(U.^2)/length(U));
Upeak = max(abs(U));
CF = Upeak/Urms;


%-------------------------------------------------------------------------
function [F]=CalcEnhancedGaussDistribution(x,Cf);
%-------------------------------------------------------------------------
% Generate a Cumulative distribution function F(x) that is identified as
% "enhanced gaussian distribution"
%       Cf   = crest factor
```

```
Alpha = 1e-3;
Sigma = sqrt( (1+Alpha) - Cf^2 * Alpha/3);
x =  x .* (x>0) .* ( x<Cf) + Cf * (x>=Cf);
noemer = Alpha + erf(Cf/(sqrt(2)*Sigma));
F = 1 - (Alpha * x/Cf + erf(x/(sqrt(2)*Sigma)))/noemer;



%----------------------------------------------------------------------------
function [DistP, DistU] = CalcDistrib(U)
%----------------------------------------------------------------------------
% calculate the (cumulative) amplitude distribution of signal U
len  = length(U);
Ueff = sqrt(sum(U .* U)/length(U));
U    = abs(U/Ueff);
% --- evaluate distribution function
Nbins = min([50,floor(len/10)]);
[cumbin,xx] = hist(U,Nbins);
BinWidth=xx(2) - xx(1);
DistU = xx - BinWidth/2; % shift
for n = [Nbins-1:-1:1];   cumbin(n) = cumbin(n) + cumbin(n+1); end
DistP = cumbin/len;
% --- improve numerical stability for other routines, when they use this result
DistU = [ 0 , DistU(2:end)];  % start at x = 0
DistP = [DistP, 1/len];
DistU = [DistU,xx(Nbins) + 0.999 * BinWidth/2]; % add final (single) point
DistP = [DistP, 1e-100];
DistU = [DistU,xx(Nbins) + (1.001) * BinWidth/2]; % factor 1.001 for stability
```

```
%----------------------------------------------------------------------------
function [PSD,freq]=CalcSmooth(PSD,freq,RBW)
%----------------------------------------------------------------------------
% Imitate a real Spectrum Analyzer, with finite resolution bandwidth, and
% Gaussian shaped band filters
%       PSD = "power spectral density" which is de square of the "spectral
%               density: in Volts per square Hertz.
%----------------------------------------------------------------------------
N = length(PSD);
df = freq(2)-freq(1);
br = 3 * floor(RBW/df);
factor = 2*br + 1;
if (factor > 1)
  ff = df * (-br:br);                % smooth interval
  mask = exp(-ff.*ff/(2*RBW^2));
  mask = mask/sum(mask);             % gaussian mask of resolution bandfilter
  xhulp = [PSD;zeros(2*br,1)];
  yhulp = filter(mask,1,xhulp);      % smart convolution
  PSD = yhulp(br+1:end-br);
  end;
```

Claims

1. A method of arranging a signal for use on or in a communication system, the method comprising the steps of:

   representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and
   processing said represented signal according to a non-linear transformation, the non-linear transformation achieving a predetermined quality criterion.

2. The method as recited in claim 1 further comprising the step of comparing the amplitude distribution of said represented signal with a predetermined amplitude distribution and thereafter arranging the non-linear transformation in order to achieve a processed represented signal with an amplitude distribution approaching the predetermined amplitude distribution.

3. The method as recited in claim 1 wherein the amplitude distribution of said represented signal is processed including a function of the predetermined amplitude distribution.

4. The method as recited in claim 3 wherein the amplitude distribution of said represented signal is processed at

least with an inverse function of the predetermined amplitude distribution.

5. The method as recited in claim 3 wherein the processed represented signal g(t) is a function Q{f(t)} of the represented signal f(t) and wherein Q is defined as

$$Q(x) = sign(x) \cdot G^{-1}\left(F\left(|x|\right)\right)$$

with

sign(x)=x/|x| for x<>0; sign(x)=0 for x=0 ;

and with F being the amplitude distribution of said represented signal and with G being the predetermined amplitude distribution function.

6. The method as recited in claim 5 further comprising the step of achieving the represented signal with a spectral density according to a predetermined spectral density quality criterion.

7. The method as recited in claim 1 further comprising the steps of:

transforming the first signal to frequency domain ; and
multiplying the first signal in frequency domain with a spectral envelope thereby achieving a multiplied signal ; and thereafter
transforming the multiplied signal to time domain.

8. The method as recited in claim 7 further comprising the step of comparing the amplitude distribution of said represented signal with a predetermined amplitude distribution and thereafter arranging the non-linear transformation in order to achieve a processed represented signal with an amplitude distribution approaching the predetermined amplitude distribution.

9. The method as recited in claim 7 further comprising the step of achieving the represented multiplied signal with a spectral density according to a predetermined spectral density quality criterion.

10. The method as recited in claim 9 wherein at least two the of different steps are iteratively executed.

10. bis. The method as recited in claim 9 wherein at least two the of different steps are iteratively executed until a predetermined crest factor.is fulfilled.

11. The method as recited in claim 1 wherein said signal is a noise signal.

12. The method as recited in claim 11 wherein said first signal in the representation in frequency domain is generated as a set of random numbers, preferably complex numbers the modulus of the complex number **characterizing** amplitude, the argument of the complex number **characterizing** phase.

13. The method as recited in claim 12 wherein the real and/or the imaginary part of essentially each of the complex numbers is chosen according to a Gaussian distribution.

14. The method as recited in claim 12 wherein the modulus of essentially each of the complex numbers is substantially equal to the amplitude of the predetermined spectral density.

14. bis. The method as recited in claim 12 wherein the argument of essentially each of the complex numbers is random.

15. A method of arranging a signal for use on or in a communication system, the method comprising the steps of :

representing a first signal in time domain and with an amplitude distribution and the signal having a spectral

density in the frequency domain, thereby achieving a represented signal ; and
processing said represented signal until a signal is achieved having a spectral density according to a predetermined spectral density quality criterion.

15. bis. A method of arranging a signal for use on or in a communication system, the method comprising the steps of :

representing a first signal in time domain and with an amplitude distribution and the signal having a spectral density in the frequency domain, thereby achieving a represented signal ; and
filtering the signal in representation in frequency domain including the steps of evaluating at least part of the signal representation in frequency domain and thereafter processing the signal representation in frequency domain.

16. The method as recited in claim 15 or 15bis wherein the processing step includes an iterative processing.

16. bis. The method as recited in claim 15 or 15bis wherein the processing step includes an iterative processing until a predetermined crest factor.is fulfilled.

17. A signal comprising at least one of a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers.

17. bis. The signal as recited in claim 17 further comprising a discrete frequency spectrum.

18. The signal as recited in claim 17 wherein the noise signal is generated using a set of instructions in a code format and being executed in a predetermined order.

19. A method of generating a signal comprising at least one of a random noise signal, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the random signal being composed of an array of random numbers, the method comprising the step of generating a random set of numbers using a set of instructions in a code format and being executed in a predetermined order.

20. The method as recited in claim 19 further comprising the step of generating a discrete frequency spectrum, the discrete frequency spectrum using goniometry functions and modulating essentially each of the discrete frequencies with a noise characteristic.

21. The method as recited in claim 20 further comprising the step of combining the random noise signal and the discrete frequency spectrum using a set of instructions in a code format and being executed in a predetermined order.

22. A set of instructions in a code format and executable in a predetermined order and compiled on a device, the set of instructions being arranged for generating a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion.

24. A test system for testing the operation of a communication system, the test system comprising a set of instructions in a code format and executable in a predetermined order and compiled on a device, the set of instructions being arranged for generating a noise signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion.

25. A method of testing the operation of a communication system, the method comprising the step of superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion., the noise signal furthermore being composed of an array of random numbers.

26. A method of testing the quality of operation of a communication system, the method comprising the steps of :

superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers ; and
evaluating the transceived signal according to a predetermined quality criterion.

27. A method of improving the design and/or production of a communication system, the method comprising the steps of :

superposing on a signal transceived by a said modem, superposing on a signal transceived by a said modem, a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers ;
evaluating the transceived signal according to a predetermined quality criterion; and iteratively arranging the design of said modem in order to approach closer to the quality criterion for evaluating the transceived signal.

28. A telecommunication network including a signal comprising at least one of a random noise signal and a discrete frequency spectrum, the random signal having an amplitude distribution in the time domain according to a predetermined quality criterion and having a spectral density in the frequency domain according to a predetermined quality criterion, the noise signal furthermore being composed of an array of random numbers.

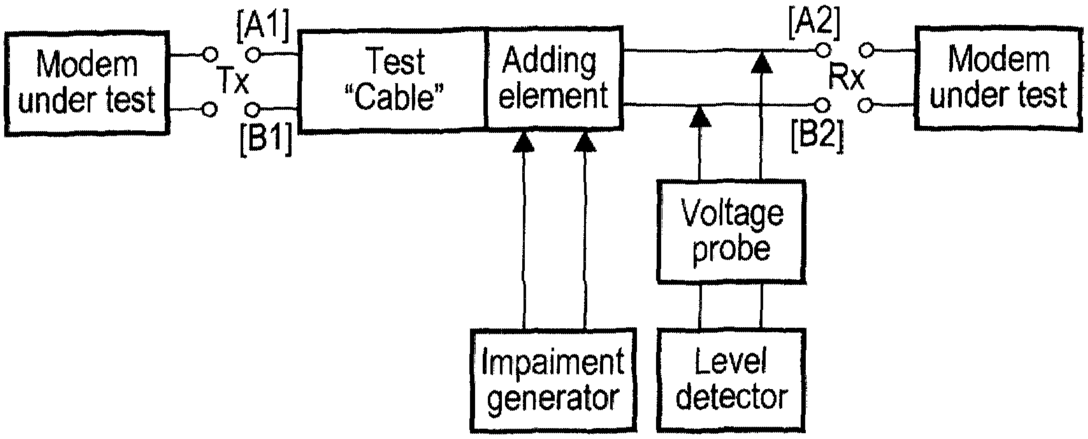

Modem
under test
[A1]
Tx
[B1]
Test
"Cable"
Adding
element
[A2]
Rx
[B2]
Modem
under test
Voltage
probe
Impaiment
generator
Level
detector

FIG. 1

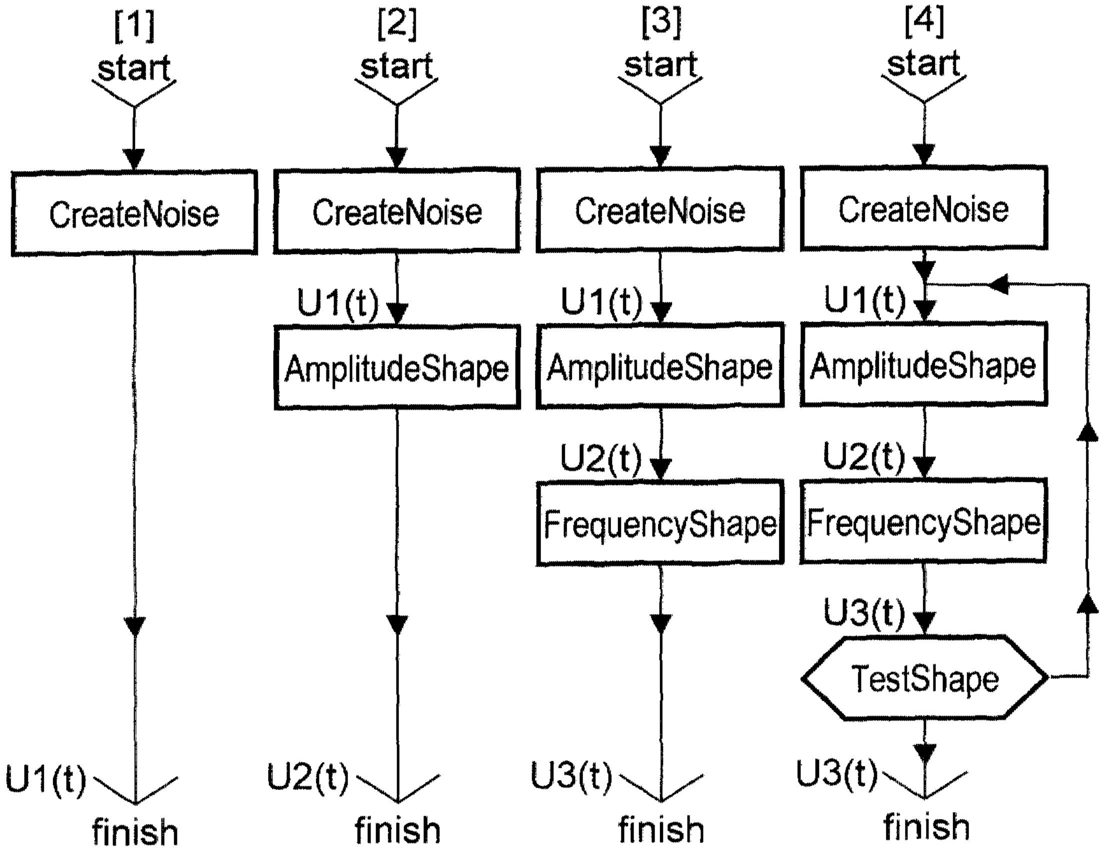

[1]
start
CreateNoise
U1(t)
finish
[2]
start
CreateNoise
U1(t)
AmplitudeShape
U2(t)
finish
[3]
start
CreateNoise
U1(t)
AmplitudeShape
U2(t)
FrequencyShape
U3(t)
finish
[4]
start
CreateNoise
U1(t)
AmplitudeShape
U2(t)
FrequencyShape
U3(t)
TestShape
U3(t)
finish

FIG. 2

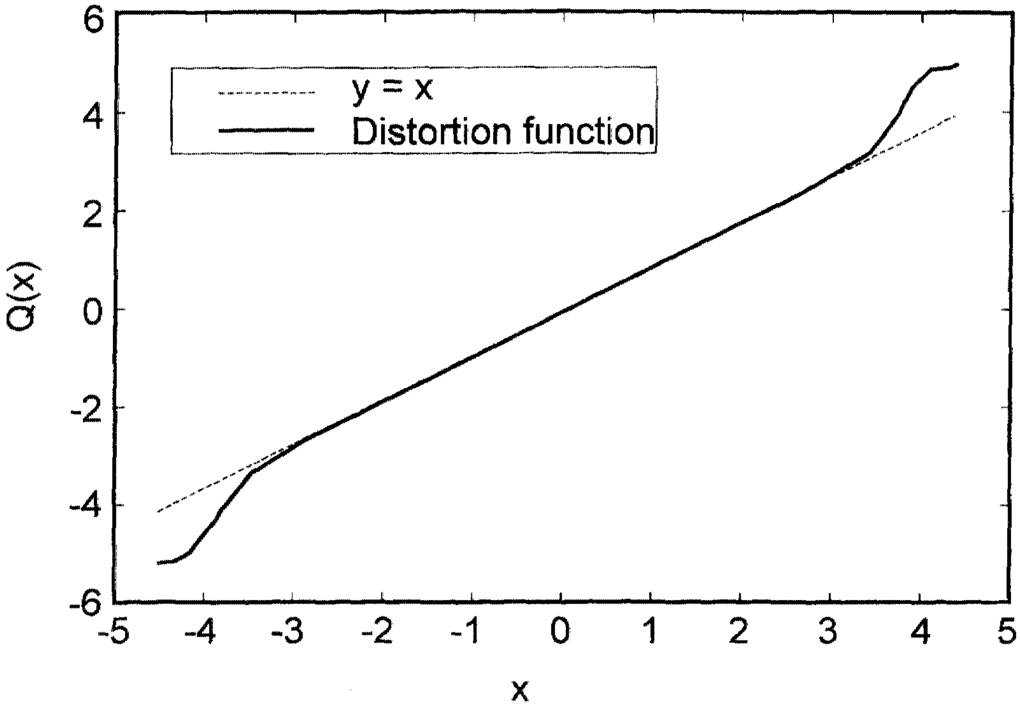

y = x
Distortion function
Q(x)
x
6
4
2
0
-2
-4
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5

FIG. 3

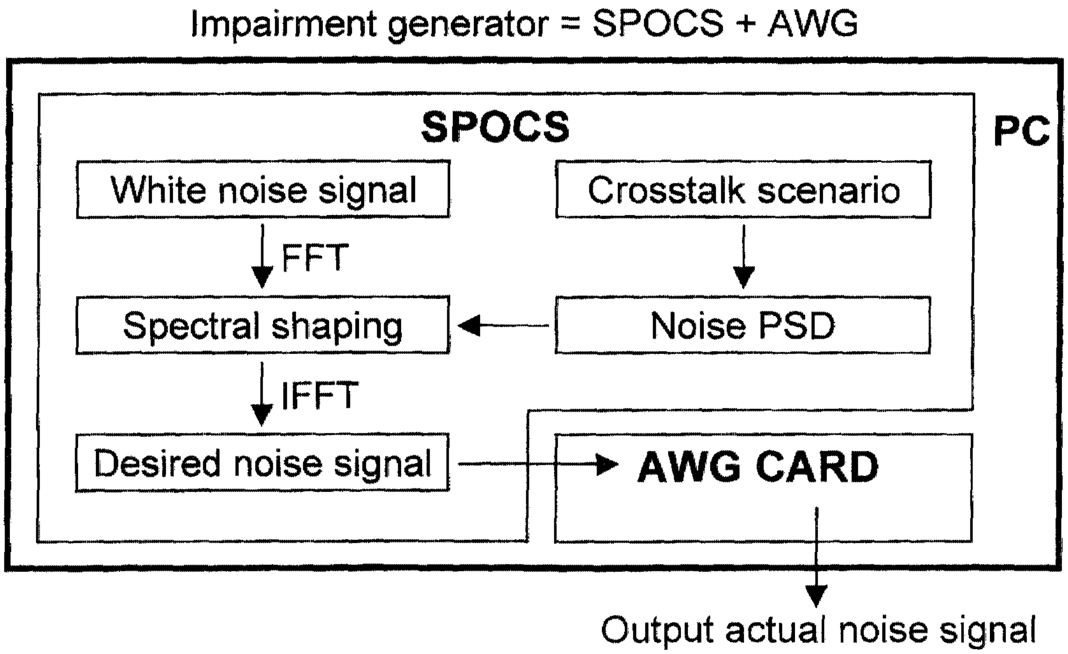
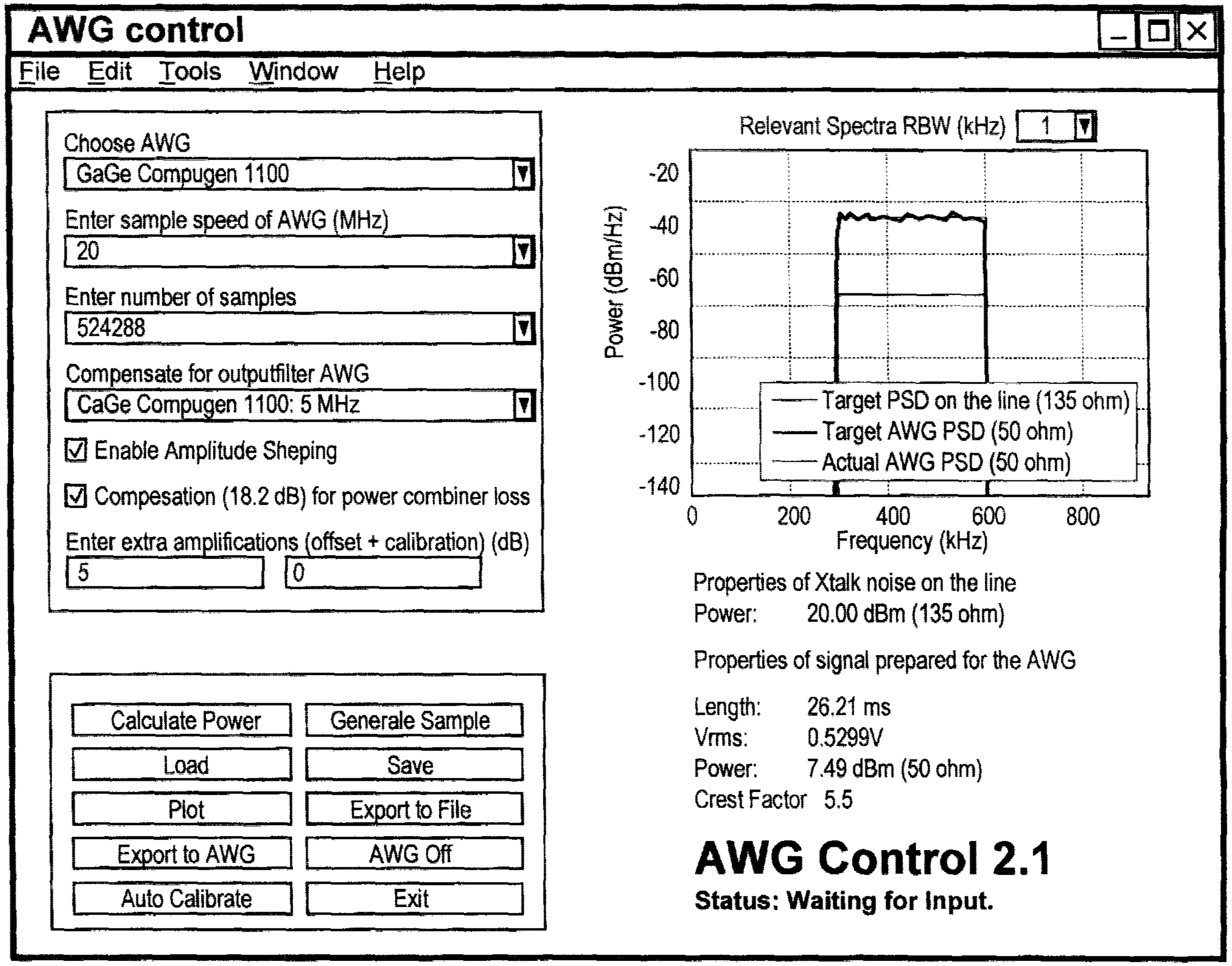

Impairment generator = SPOCS + AWG
SPOCS
PC
White noise signal
Crosstalk scenario
FFT
Spectral shaping
Noise PSD
IFFT
Desired noise signal
AWG CARD
Output actual noise signal

FIG. 4



Choose AWG
GaGe Compugen 1100

Enter sample speed of AWG (MHz)
20

Enter number of samples
524288

Compensate for outputfilter AWG
CaGe Compugen 1100: 5 MHz

☑ Enable Amplitude Sheping

☑ Compesation (18.2 dB) for power combiner loss

Enter extra amplifications (offset + calibration) (dB)
5
0

Relevant Spectra RBW (kHz) 1

Properties of Xtalk noise on the line
Power: 20.00 dBm (135 ohm)

Properties of signal prepared for the AWG

Length: 26.21 ms
Vrms: 0.5299V
Power: 7.49 dBm (50 ohm)
Crest Factor 5.5

AWG Control 2.1
Status: Waiting for Input.

FIG. 5

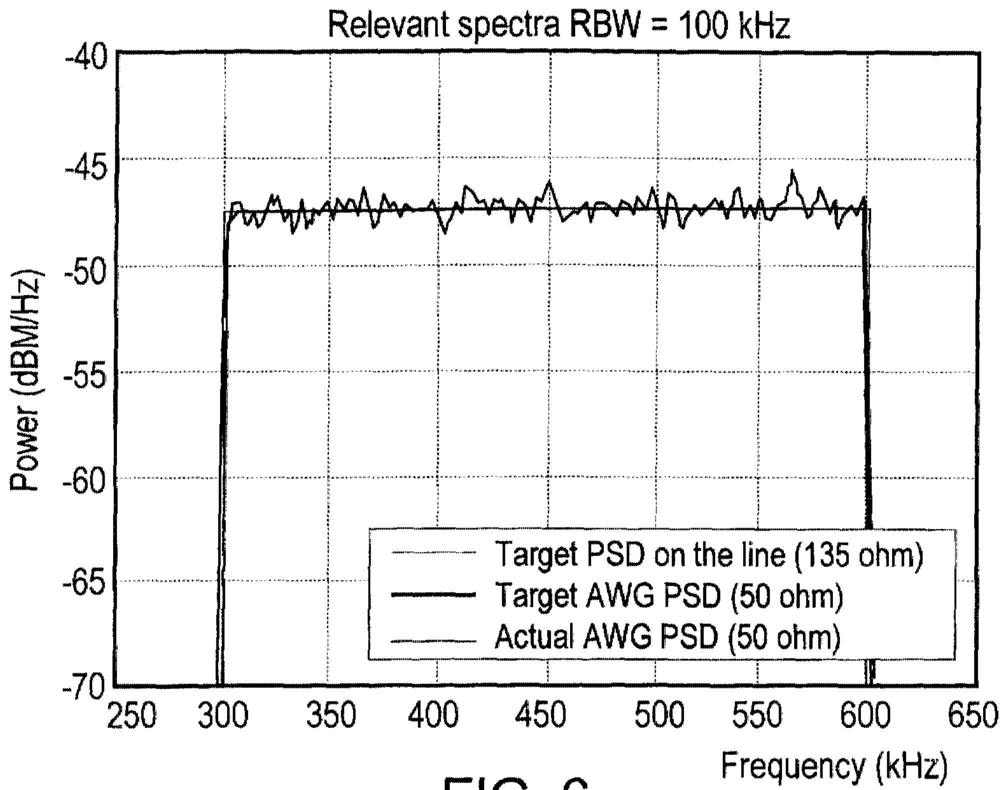

Relevant spectra RBW = 100 kHz
Power (dBM/Hz)
-40
-45
-50
-55
-60
-65
-70
250
300
350
400
450
500
550
600
650
Frequency (kHz)
Target PSD on the line (135 ohm)
Target AWG PSD (50 ohm)
Actual AWG PSD (50 ohm)

FIG. 6

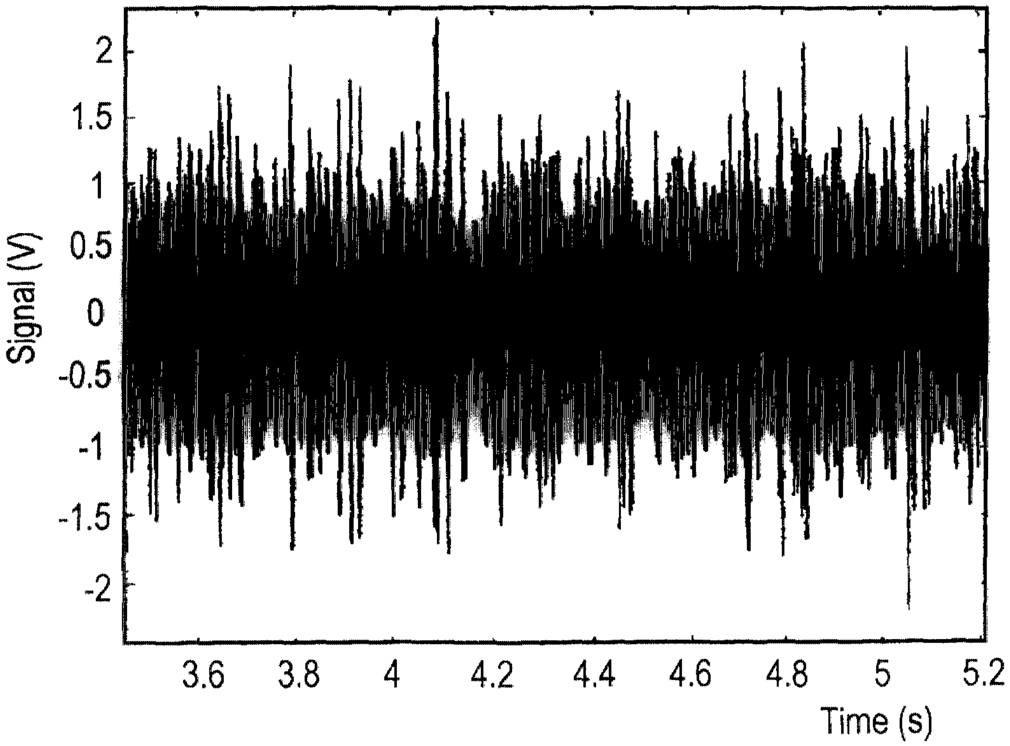

Signal (V)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
3.6
3.8
4
4.2
4.4
4.6
4.8
5
5.2
Time (s)

FIG. 7

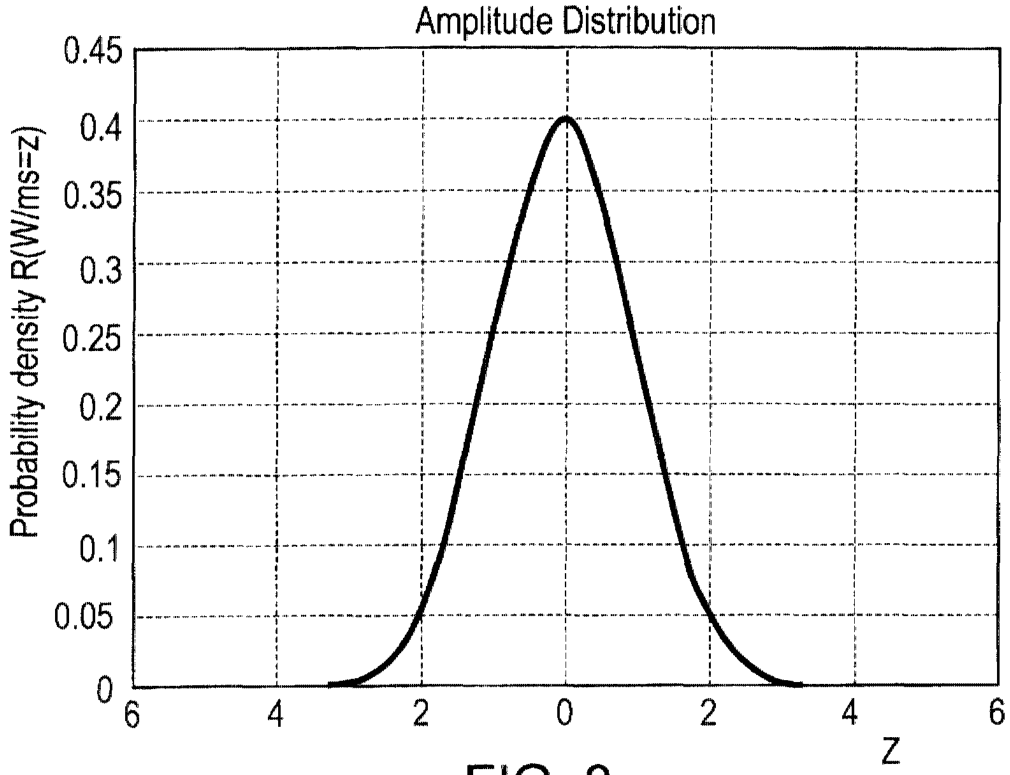

Amplitude Distribution
Probability density R(W/ms=z)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
6
4
2
0
2
4
6
Z

FIG. 8

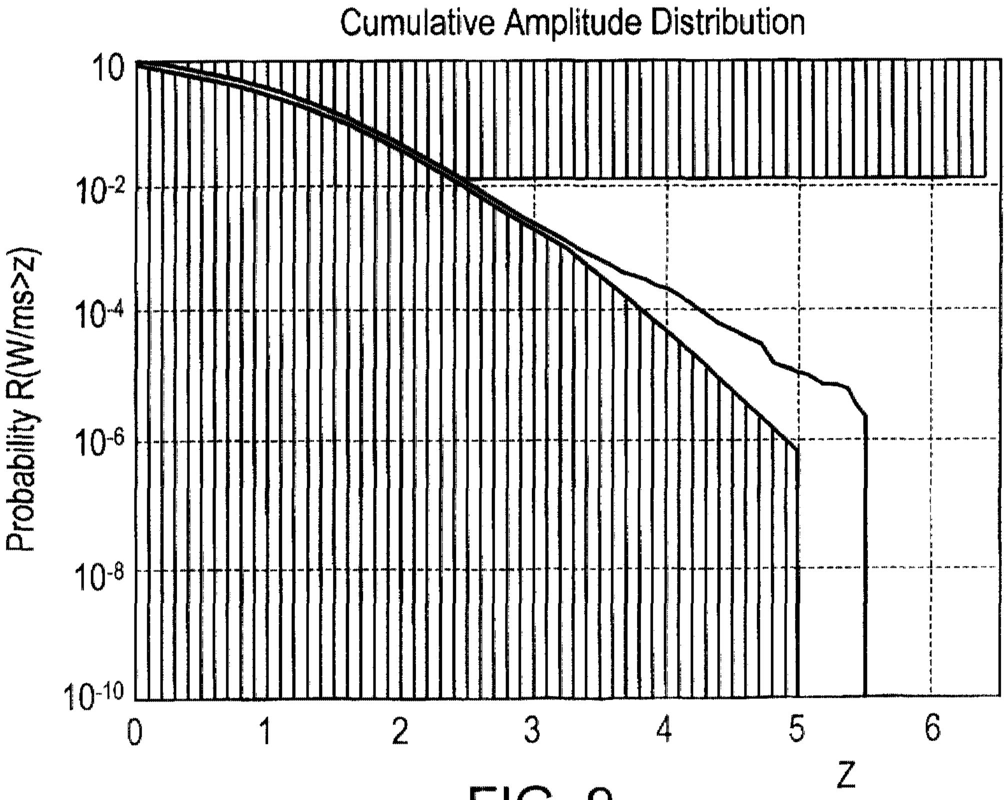

Cumulative Amplitude Distribution
Probability R(W/ms>z)
10
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
0
1
2
3
4
5
6
Z

FIG. 9

European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 20 2378

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	FR 2 783 374 A (THOMSON CSF) 17 March 2000 (2000-03-17) * page 2, line 31 - page 3, line 15 * * figures 3,10 *	1-3,7-19	H04L1/24 H04L27/26
A	---	4-6, 20-22, 24-28	
X	US 4 317 214 A (ATTINELLO JOHN S) 23 February 1982 (1982-02-23) * column 6, line 60 - column 7, line 13 * * column 7, line 29 - line 33 * * column 11, line 28 - line 32 *	17, 19-22, 24-28	
A	---	18	
X	GB 2 031 197 A (MARCONI INSTRUMENTS LTD) 16 April 1980 (1980-04-16) * page 1, line 5 - line 7 * * page 1, line 27 - line 35 * * page 1, line 68 - line 72 * * page 2, line 4 - line 10 *	17,19	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
A	---	1-16,18, 20-22, 24-28	H04L
X	ROLLS R. G.: "Improvements in P.C.M. regenerator testing" MARCONI INSTRUMENTATION, vol. 14, no. 2, August 1973 (1973-08), pages 39-42, XP002164179 UK * page 40, second paragraph * * figures 3,4 *	17,19	
A	-----	18,20,21	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 March 2001	Orozco Roura, C

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
....
& : member of the same patent family, corresponding document

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 00 20 2378

28-03-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		TR 21249 A	05-03-1984
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		FR 2438382 A	30-04-1980

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82