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Radiocommunication Sector of ITU

Recommendation ITU-R SM.331-4

(07/1978)

Noise and sensitivity of receivers

SM Series

Spectrum management

International Telecommunication Union

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***Note**: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R SM.331-4*

NOISE AND SENSITIVITY OF RECEIVERS

(1951-1953-1956-1959-1963-1966-1970-1974-1978)

Scope

This Recommendation provides measurements on noise and sensibility of receivers to assess the quality of the output.

Keywords

Linear receiver, noise factor, noise temperature, width effective overall noise band, maximum usable sensibility

The ITU Radiocommunication Assembly,

considering

a) that the sensitivity of a receiver is a measure of its ability to receive weak signals and to produce an output having usable strength and acceptable quality; in many cases, to assess the quality of the output, it might be necessary to take into consideration the receiving equipment as a whole, including the parts giving the information in a printed, aural or visual form;

b) that the following parameters, which are determined by the particular service for which the receiver is used, are of special importance in relation to sensitivity;

– necessary output level;

– necessary overall signal bandwidth;

– necessary signal-to-noise ratio at the output;

c) that the following parameters relating to the internal noise of the receiver, which are determined by the receiver design, are also of importance in relation to the sensitivity of the receiver:

– the level of the internal noise, as defined, for example, by the noise factor;

– the width of the effective overall noise band, which is not necessarily identical with the width of the signal band (see Recommendation ITU-R SM.332);

d) that, in many cases, to economize in transmitted power, it is desirable that the sensitivity shall be as great as economic and technical considerations permit and justified by the external noise level;

e) that the conditions for obtaining high sensitivity, viz. the ability of the receiver to receive weak signals of the desired transmission, should be considered in connection with those for obtaining good protection against interfering signals (see Recommendation 332);

f) that additional data on noise factor and noise temperature for the various types of receiver used for reception of different classes of emission in the different services are required;

g) that, for the purpose of presenting, comparing, and using data on the sensitivity of receivers, it is desirable to define the following terms:

– maximum usable (noise-limited) sensitivity;

– maximum usable (gain-limited) sensitivity;

– reference sensitivity;

– noise factor or noise temperature;

h) that often values for noise factor or noise temperature are particularly useful, since they are more uniform than values of maximum usable sensitivity for the various types of receiver used for the reception of different classes of emission in the different services and, other factors remaining unchanged, indicate the degree of improvement in maximum usable sensitivity which is theoretically possible;

j) that the noise factor or noise temperature is useful only for a linear receiver or for the linear part of a receiver, since in a non-linear receiver the noise factor is dependent on the signal input level;

k) that reference sensitivity is chiefly of value in comparing linear receivers;

l) that it is desirable to define a "linear" receiver;

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* Radiocommunication Study Group 1 made editorial amendments to this Recommendation in the years 2011, 2015, 2019 and 2023 in accordance with Resolution ITU-R 1.

m) that, for radiotelegraphy receivers for automatic reception:

– the use of a non-linear demodulator, discriminator or telegraph shaping circuit, or the use of narrow-band filters changes the effect of noise from an amplitude variation into a variation of the duration of the telegraph signal elements at the output of the receiver (signal distortion);

– noise may cause mutilation of the signals by splits or extras;

– signal distortion and signal mutilation may cause erroneous characters in the reproduced text;

– the foregoing considerations make it desirable to define receiver sensitivity with reference to signal distortion and mutilation or character errors in the reproduced text;

n) that for sound broadcast and television receivers, it is desirable to define sensitivity not only for a reasonably good output signal, but also for any usable output signal,

recommends

1. that a *linear* receiver should be defined as one operating in such a manner that the signal-to-noise ratio at the output is proportional to the signal level at the input, and/or to the degree of modulation;

2. that the *noise factor* should be defined as follows: the noise factor is the ratio of noise power measured at the output of the receiver to the noise power which would be present at the output if the thermal noise due to the resistive component of the source impedance were the only source of noise in the system; both noise powers are determined at an absolute temperature of the source equal to T = 293 K;

2.1 that the *noise temperature* be defined as the value by which the temperature of the resistive component of the source impedance should be increased, if it were the only source of noise in the system, to cause the noise power at the output of the receiver to be the same as in the real system;

3. that the *width of the effective overall noise band* should be defined as the width of a rectangular frequency response curve, having a height equal to the maximum height of the receiver frequency response curve and corresponding to the same total noise power (see [CCIR, 1951]);

4. that the *maximum usable sensitivity* should be defined as the larger of the minimum input signal levels (expressed as the e.m.f. of the carrier)*, which must be applied in series with the specified source impedance (dummy antenna) to the input of the receiver to produce at the output:

$$\left.\begin{array}{ll}\text{4.1} & \text{– the signal level} \\ \text{4.2} & \text{– the signal-to-noise ratio}\end{array}\right\} \begin{array}{l}\text{necessary for normal operation when the normal degree of modulation}^{**} \\ \text{is applied to the carrier}\end{array}$$

If the gain is sufficient to enable both conditions to be satisfied simultaneously, the maximum usable sensitivity is described as "noise-limited". Otherwise, the gain being insufficient, the maximum usable sensitivity is described as "gain-limited"; in this case the gain, being adjusted to a maximum, enables the condition of § 4.1 (necessary output level) to be satisfied without regard to the output noise level (condition of § 4.2);

4.3 – the ratio of (signal + noise + distortion) to (noise + distortion) necessary for normal operation; or

4.4 – the signal distortion or mutilation just acceptable for normal operation;

5. that, for the purpose of presenting and comparing data for particular classes of linear receivers and classes of emission for the different services (normally noise-limited) and for a particular frequency range, the *reference sensitivity* should be defined as the maximum usable sensitivity for specified values of:

– signal-to-noise ratio;

– receiver bandwidth;

– degree of modulation;

– source impedance (dummy antenna).

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* For frequencies above about 30 MHz, the input signal strength is sometimes taken as the available power from the source.

** Classes of emission A1A and A1B are considered 100% modulated.

Within the linear range, the maximum usable sensitivity for any of these conditions should be derived from the reference sensitivity (the noise factor being considered as constant), and vice versa (see Annex I);

6. that in case of uncertainty with regard to terms of the formulae relating noise factor and reference sensitivity (see Annex I), e.g. the width of the effective overall noise band, independently measured values for these two quantities should be given;

7. that values for the maximum usable sensitivity and for reference sensitivity should be considered in connection with the values for the single signal and multiple signal selectivity (see Recommendation ITU-R SM.332);

8. that, since the reference sensitivity is of particular value for a receiver working in a linear condition, for the markedly non-linear condition only, the maximum usable sensitivity and the noise factor for the normal operating conditions should be given;

9. that, although radiotelegraph receivers for aural reception can be operated linearly, those for automatic operation, in which non-linearity usually occurs, must be given separate consideration;

9.1 *maximum usable sensitivity* should be defined as the minimum input signal (expressed as the e.m.f. of the carrier), which must be applied in series with the specified source impedance (dummy antenna), to the input of the receiver to obtain at the output the desired signal level and the amount of signal distortion or mutilation permissible in normal operation; the maximum usable sensitivity as defined above should be described as “distortion limited” or “mutilation limited”;

9.2 *maximum usable sensitivity, including the reproducing equipment,* should be defined as the minimum input signal (expressed as the e.m.f. of the carrier), which must be applied in series with the specified source impedance (dummy antenna), to the input of the receiver to obtain a specified character error ratio in the reproduced text;

9.3 defined methods for measuring signal distortion, signal mutilation, element error ratios and character error ratios should be used (see [CCIR, 1956; 1958a, b, c and CCIR, 1966-69a and b]);

9.4 for the purpose of comparing and presenting data (see Annex I, § 5), the maximum usable sensitivity should be given for specified values of:

– the amount of signal distortion and signal mutilation at the receiver output with a specified probability of occurrence (see § 9.1 and Annex I, § 5.4); or the character error rate in the reproduced texts (see § 9.2 and Annex I, § 5.5) and the receiver pre-detector and post-detector signal bandwidth;

– the frequency shift for F1B emissions;

– the source impedance (dummy antenna);

9.5 the performance of the receiving equipment in terms of signal distortion, signal mutilation or character error rate, instead of being defined by the maximum usable sensitivity, is often described by the *signal-to-noise* power ratio value in the receiver, just prior to the non-linear part; in this case, it is convenient to use a parameter called the “normalized signal-to-noise ratio” which is defined as the signal-to-noise power ratio per baud per unit bandwidth*; in Annex I, § 6, a formula is given relating the normalized signal-to-noise ratio to the e.m.f. of the carrier at the receiver input (in series with the equivalent source resistance);

10. that for sound broadcast and television receivers:

10.1 *a maximum sensitivity* should be defined as the minimum input signal applied, in series with the specified source impedance (dummy antenna), to the input of the receiver for which any usable signal with a specified output level can be obtained;

10.2 measurements of sensitivity be made in conformity with Recommendations 237-1 and 330 (Geneva, 1974);

11. that for receivers for single channel frequency-modulation for telephony (class of emission F3EJN) other than those used for sound broadcasting:

* The normalized signal-to-noise ratio is a power ratio and it can be expressed in dB.

11.1 the maximum usable sensitivity should be defined as the minimum input signal applied, in series with the specified source impedance (dummy antenna) to the input of the receiver for which a specified value of

$$\frac{\text{signal + noise + distortion}}{\text{noise + distortion}}$$

can be obtained at the output;

11.2 the measurement of (noise + distortion) should be made with the wanted modulation present, the output due to this modulation being removed by a filter;

11.3 this method of measurement is in accordance with the IEC proposals;

Note. – The characteristics of the filter used to remove the wanted modulation shall be such that, at the point at which the output meter used for sensitivity measurement is connected, the relative attenuation of the 1 kHz signal shall be at least equal to the specified

$$\frac{\text{signal + noise + distortion}}{\text{noise + distortion}}$$

ratio plus 20 dB, and that at 2 kHz it shall not exceed 0.6 dB. Moreover, in the absence of the modulating frequency, the filter shall not cause more than 1 dB attenuation of the total noise signal power occurring within the specified receiver bandpass;

12. that for receivers for amplitude-modulation, other than those used for sound broadcasting, as an alternative to the signal-to-noise ratio, the ratio

$$\frac{\text{signal + noise + distortion}}{\text{noise + distortion}}$$

may be measured as indicated in § 11.1 and 11.2*;

13. that, since measured characteristics vary widely from one receiver to another, measurements should be made as far as possible on several receivers of the same type, and the values given for the type of receiver under consideration should be stated statistically (mean value, standard deviation);

14. that, when a psophometric weighting network is used for sensitivity measurements, this fact should be stated and the response curve given;

15. that, with a view to the ultimate statistical treatment of the presented data, Administrations should be encouraged to provide results of measurements made on receivers of recent design, in accordance with the provisions of this Recommendation.

REFERENCES

CCIR Documents

[1951]: Geneva, 3.

[1956]: Warsaw, 227.

[1958] Geneva: **a.** II/3; **b.** II/11; **c.** II/23.

[1966-69]: **a.** II/29 (Rev.1); **b.** II/30 (Rev.1).

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* Certain Administrations do not agree with the method of measurement described in § 12, but Study Group 1 is awaiting results from the IEC before deciding whether or not to amend this Recommendation.

ANNEX I

EQUATIONS RELATING NOISE FACTOR AND SENSITIVITY OF LINEAR RECEIVERS, MEASUREMENT OF, AND EQUATIONS RELATING TO THE SENSITIVITY AND NORMALIZED SIGNAL -TO -NOISE RATIO OF RADIOTELEGRAPH RECEIVERS FOR AUTOMATIC RECEPTION

1. A1A, A1B, A2A, A2B, A3E emissions (amplitude modulation)

$$E^2 = 8k(T_S + T_N)\frac{B\,R\,n}{m^2} \times 10^{12} \qquad (1)$$

where:

T_S : noise temperature of signal source (antenna) in K;

T_N : receiver noise temperature in K (see Note 1);

when $T_S = T$ or $F \gg 1$, equation (2) can be used:

$$E^2 = 8kT\frac{B\,R\,n}{m^2}F \times 10^{12} \qquad (2)$$

where:

E : e.m.f. of the carrier in series with the equivalent series resistance of the source (μV);

F : noise factor (power ratio);

R : equivalent resistance of source (dummy antenna) (Ω);

n : signal-to-noise power ratio at the output;

m : degree of modulation (modulation considered sinusoidal). For A1A and A1B emissions, take $m = 1$;

k : Boltzmann's constant (1.37×10^{-23} J/K);

T : absolute temperature (K);

(T is commonly taken as 293 K, then $kT \approx 400 \times 10^{-23}$ J);

B : width of the effective overall noise band (Hz), taken as the smaller of the following two quantities:

– the post-demodulation bandwidth;

– half the pre-demodulation bandwidth (see Note 2).

Note 1 – The noise temperature T_N is related to the noise factor by the following equation:

$$T_N = T(F - 1)$$

2. B8E emissions (independent-sideband amplitude-modulation)

$$E^2 = 4k(T_S + T_N)\,B\,R\,n \times 10^{12} \qquad (3)$$

When $T_S = T$ or $F \gg 1$, equation (4) can be used:

$$E^2 = 4kTBRnF \times 10^{12} \qquad (4)$$

where:

E : e.m.f. of the sideband component in series with the equivalent series resistance of the source (μV);

F, R, n, k, T_S, T_N and T are as defined in § 1;

B : width of the effective overall noise band (Hz), taken as the smaller of the following two quantities:

– the post-demodulation bandwidth;

– the full pre-demodulation bandwidth (see Note 2).

3. F3E emissions (frequency modulation)

$$E^2 = 8k(T_S + T_N)\frac{B\,R\,n}{q^2} \times 10^{12} \tag{5}$$

when $T_S = T$ or $F \gg 1$, equation (6) may be used:

$$E^2 = 8k\,T\,\frac{B\,R\,n}{q^2}\,F \times 10^{12} \tag{6}$$

where:

$$q^2 = 3\frac{D^2}{B^2}$$

E, F, R, n, k, T_S, T_N and T are as defined in § 1;

$2D$: peak-to-peak value of the reference frequency deviation in telephony (modulation considered sinusoidal);

B : width of the effective overall post-demodulation noise band.

Note 2 – In some cases, it may be sufficient to approximate the bandwidth by taking limiting responses 6 dB below the maximum response; if a more accurate measurement of bandwidth is required, the width of the effective overall noise band may be determined in each case, as explained in § 3 of this Recommendation. It is, however, recommended that a psophometer be used (see § 14 of this Recommendation), since the bandwidth will be known from the psophometer characteristics; this is an advantage since the bandwidth enters the equation to the third power.

Note 3 – Equations (5) and (6) are applicable only to a receiver of perfect design working under idealized conditions, that is with:

– *perfect limiting*, in which case no amplitude modulation remains and the signal-to-noise ratio at the output is proportional to that of the input;

– *receiver noise* mainly produced in the early stages of the receiver.

Equations (5) and (6) should not be used to calculate the noise factor from the reference sensitivity and vice versa, unless the conditions above are satisfied.

Note 4 – The study (see [CCIR, 1966-69a and b and CCIR, 1970-74]) shows that equation 6 is applicable only above the F3E receiver threshold. The threshold may be defined by the 1 dB departure from linear input-output noise characteristic of the receiver. The threshold value of pre-demodulation signal-to-noise ratio n_i may be expressed by the equation:

$$n_i\,(\text{threshold}) = 4.25 + 2.6 \log \frac{B_i\,D}{B_o^2}$$

where:

B_i : effective pre-demodulation bandwidth;

B_o : effective post-demodulation bandwidth;

D : peak frequency deviation with sinusoidal modulation.

Accordingly, equation (6) cannot be applied to sensitivity calculations when the system parameters lead to a signal-to-noise ratio below threshold. This applies also to most of the data in Tables I and II below, concerning F3E emissions [CCIR, 1970-74].

Note 5 – Equations (1) to (6) are valid when the signal source output is matched with the receiver input.

4. Reference sensitivity (see § 5 of this Recommendation)

The reference sensitivity may be calculated from the receiver noise temperature or noise factor (see Annex II) by means of equations (1) to (6) or the following simplified equations:

$$E^2 = C' (T_S + T_N), \quad C' \text{ being a factor of proportionality} \tag{7}$$

when $T_S = T$ or $F \gg 1$:

$$E^2 = C F \quad \text{with } C = C' T \tag{8}$$

Typical reference values for *B*, *R*, *n*, *m*, and *D* are given in Table I, together with the corresponding values of the multiplying factor *C* used in equation (8). For ease of computation the values of *C* given in the table are in decibels.

While equations (1) to (8) can also be used to calculate the receiver noise temperature or noise factor from the measured sensitivity, this procedure must be employed with caution, because possible uncertainties in the various parameters (e.g. the effective overall noise band) may lead to less precise values for T_N or *F* than can be obtained by direct measurement.

5. Measurement of maximum usable sensitivity and normalized signal-to-noise ratio of telegraph receivers for automatic reception (see [CCIR, 1956; 1963 a, b, c and d]).

5.1 The input signal should be modulated by a square wave at a frequency suitable for the receiver, a frequency corresponding to 50 bauds being used where appropriate;

5.2 the recommended values for the frequency shift for F1B transmissions are 400 Hz, 200 Hz and 100 Hz; the receiver bandwidth just prior to the non-linear part of the receiver and that of the post-demodulator low-pass filter should be chosen in conformity with those given in:

Recommendation ITU-R SM.328, Annex 3,

Recommendation ITU-R SM.338, § 1.2;

5.3 the source resistance should be taken as 75 Ω;

5.4 the amount of distortion or mutilation in the receiver should be taken as either of the following two conditions:

– 20% distortion with an element error ratio of 10^{-3};

– one split or extra in 1000 elements (see § 9.1);

5.5 the character error ratio in the reproduced text should be taken as 1 in 1000 (see § 9.2).

An indication of the critical input level for distortion or mutilation limited sensitivity can be obtained by observing the shape of the signal at the receiver output on an oscilloscope or on a recording apparatus or by observing the appearance of wrong characters in the reproduced text on a printing apparatus. As this procedure is found to be fairly critical, a useful criterion can thus be obtained in a simple way.

TABLE I – *Typical reference values for parameters used in calculating and measuring reference sensitivity*

Class of emission	Service		Effective overall noise band B (Hz)	Source resistance R (Ω)	Output signal-to-noise power ratio n (dB)	Degree of modulation: factor m	Degree of modulation: (kHz)	Peak system deviation for F3E D (kHz)	10 log C (dB)
A1A, A1B	General purpose		1000	75	20	1			–6.2
	Mobile		1000	75	20	1			–6.2
A2A, A2B	General purpose		1000	75	20	0.3			+4.3 (1) –6.2 (2)
	Mobile		1000	75	20	0.3			+4.3 (1) –6.2 (2)
A3E	Fixed General purpose Mobile		3000	75	20	0.3			+9.1
	Sound-broadcast (MF) domestic use		5000	dummy antenna (3)	20	0.3			
	Sound broadcast (HF)	domestic use	5000	dummy antenna (3)	20	0.3			+18.3
		profes-sional use	5000	75	20	0.3			+11.1
B8E	Fixed		3000	75	20				–4.4
F3E	Fixed General purpose Mobile		3000	75	20	0.3	± 4.5 (5)	± 15	–9.7
	Sound-broadcasting		5000	75	20 (4)	0.3	± 22.5 (5)	± 75	–17.0
			5000	75	40	0.3	± 22.5 (5)	± 75	+3
			5000	75	20 (4)	0.3	± 15 (5)	± 50	–13.8
					40	0.3	± 15 (5)	± 50	+6.2
			5000	300	20 (4)	0.3	± 15 (5)	± 50	–7.8
					40	0.3	± 15 (5)	± 50	+12.2

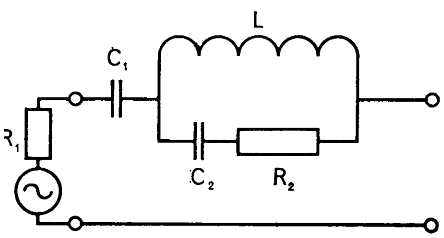
(1) Without IF oscillator.

(2) With IF oscillator.

(3) The values of the elements of the dummy antenna are shown in Fig. 1.

(4) For future measurements, a signal-to-noise ratio of 40 dB should be used in place of the 20 dB value indicated.

(5) This number represents 30% of reference peak deviation (telephony 15 kHz; sound broadcasting 75 and 50 kHz).



C_1 = 125 pF
C_2 = 400 pF
L = 20 μH
R_1 = 80 Ω
R_2 = 320 Ω
Q_L > 15 (at 1 MHz)

FIGURE 1 — *Dummy antenna*

D01-sc

TABLE II – *Typical values for parameters used for non-linear receivers measured according to § 11 of this Recommendation*

Class of emission	Service	Effective overall noise band B (Hz)	Source resistance R (Ω)	Output signal-to-noise power ratio n (dB)	Degree of modulation		Peak system deviation for F3E D (kHz)
					factor m	(kHz)	
A3E	Mobile	3000	75	12	0.3		
F3E	Mobile	3000	75	12	0.6 0.6	±9 ±3	±15 ±5

6. Equations relating "normalized signal-to-noise ratio" and sensitivity

6.1
$$E^2 = 4k\,T\,R\,B_i\;n_i\;F \times 10^{12}$$

E, F, R, k, T are defined in § 1 of this Annex;

B_i : receiver bandwidth, just prior to the non-linear part;

n_i : signal-to-noise power ratio, just prior to the non-linear part (dB):

$$n_i = n_c \frac{S}{B_i}$$

n_c : normalized signal-to-noise ratio (dB);

S : keying speed (bauds).

6.2
$$E^2 = 4\,kTRn_c\,FS \times 10^{12}$$

If R = 75 Ω

$$E^2 = C_1\,F\,n_c\,S$$

C_1 = –59.2 dB

6.3
$$E^2 = C_2\,F\,n_c$$

C_2 = –42.2 dB for 50 bauds,

or –39.2 for 100 bauds.

7. Influence of mismatch of the input on receiver sensitivity

Receiver sensitivity depends on the extent to which the receiver input is matched with the signal source output. Mismatching results in incomplete transfer of signal and noise power from the signal source to the receiver input, and in a difference in measured receiver noise as compared with matching conditions of the receiver input.

Equations characterizing the influence of mismatching on receiver sensitivity are given in [CCIR, 1974-78].

When the reflection coefficient of the receiver input and/or the signal source output is ≤ 0.2, the relative difference between the power required from the signal source and the power calculated from formulae shown in [CCIR, 1974-78], to give an equivalent sensitivity value, may range over the values +25% to –25%. Such a difference may occur with sensitive receivers where there is close correlation between the input and output noise of the receiver. With the reflection coefficient equal to 0.2, and in the absence of correlation, where the relative difference is always equal to or greater than zero, such difference may be as great as +8%.

Where there is no correlation of internal receiver noise, the noise is at a minimum and, correspondingly, there is maximum sensitivity with matching at the receiver input.

Where there is correlation of internal noise, there may be maximum sensitivity with some mismatching between the receiver and the signal source.

REFERENCES

CCIR Documents

[1956]: Warsaw, 227.

[1963] Geneva: **a.** II/3; **b.** II/11; **c.** II/21; **d.** II/23.

[1966-69]: **a.** II/20 (People's Republic of Poland); **b.** II/86 (People's Republic of Poland).

[1970-74]: 1/135 (People's Republic of Poland).

[1974-78]: 1/54 (USSR).

ANNEX II

GENERAL CONSIDERATIONS RELATING TO THE NOISE FACTOR AND THE NOISE TEMPERATURE OF RECEIVERS

In a well-designed receiver, noise originating in the receiver is mainly due to random processes (thermal, shot and flicker noise) generated in the early stages of the receiver.

For the quantitative estimation of internal receiver noise, the noise factor F or the noise temperature T_N are used.

In the case of highly sensitive receivers, where F = 1.05 to 2 or T_N = 15 to 293 K (see definitions of F and T_N in § 1 of Annex I), it is preferable to measure the noise temperature rather than the noise factor.

For medium- or low-sensitivity receivers, either the noise factor or the noise temperature may be used.

When, however, either the external noise level or the input signal level is high, the internal receiver noise is less important. For this reason, some receivers (e.g. many types of broadcasting receivers) are not designed to have the best possible relative values of reference sensitivity (see Annex I, § 4) or of noise factor.

Special methods have been developed for measuring noise temperatures and noise factors. It is often preferable to use direct reading methods – the most commonly used of which is the direct-reading modulation method – in the tuning and operation of receivers.

When the receiver contains a non-linear element (e.g. a detector, limiter or discriminator), it is desirable that overall measurements of noise factor be made under conditions of linear operation, such as may be obtained by simultaneous injection of a carrier at an appropriate frequency and level.