RECOMMENDATION ITU-R P.842-2*

COMPUTATION OF RELIABILITY AND COMPATIBILITY OF HF RADIO SYSTEMS

(Question ITU-R 224/3)

(1992-1994-1999)

The ITU Radiocommunication Assembly,

considering

a) that the reliability of a radio system is defined as the probability that a required performance is achieved;

b) that reliability is a figure of merit of performance;

c) that compatibility is a measure of the degradation caused by interference to the performance of a radio system;

d) that predicted reliabilities and compatibilities are valuable in the selection of preferred combinations of antennas (including, where necessary, their design optimization), frequencies and necessary transmitter power to achieve a desired performance,

recommends

that the following methods for calculating the various types of reliability and compatibility should be used in the planning and design of radio systems.

1 Introduction

The reliabilities discussed in this Recommendation form a hierarchy as illustrated in Fig. 1. Basic reliabilities are discussed in § 2 to 5 and 9, overall reliability in § 6, reliability in HF networks in § 7 and compatibility in § 8. The computation of basic circuit reliability (BCR) for digital modulation systems is described in § 9.

Specific definitions of different types of reliability are given in Appendix 1.

2 Inputs to the basic reliability computation

For the computation of BCR the method involves the following parameters: monthly median available receiver signal power (Recommendation ITU-R P.533); monthly median atmospheric, man-made and galactic noise powers (Recommendation ITU-R P.372); upper and lower decile deviations from the monthly median signal and noise powers – long term (day-to-day) and short term (within-the-hour); required signal-to-noise ratio (Recommendation ITU-R F.339).

3 Computation of basic circuit reliability (BCR)

BCR may be estimated according to the procedure outlined in Table 1 using the information in Table 2.

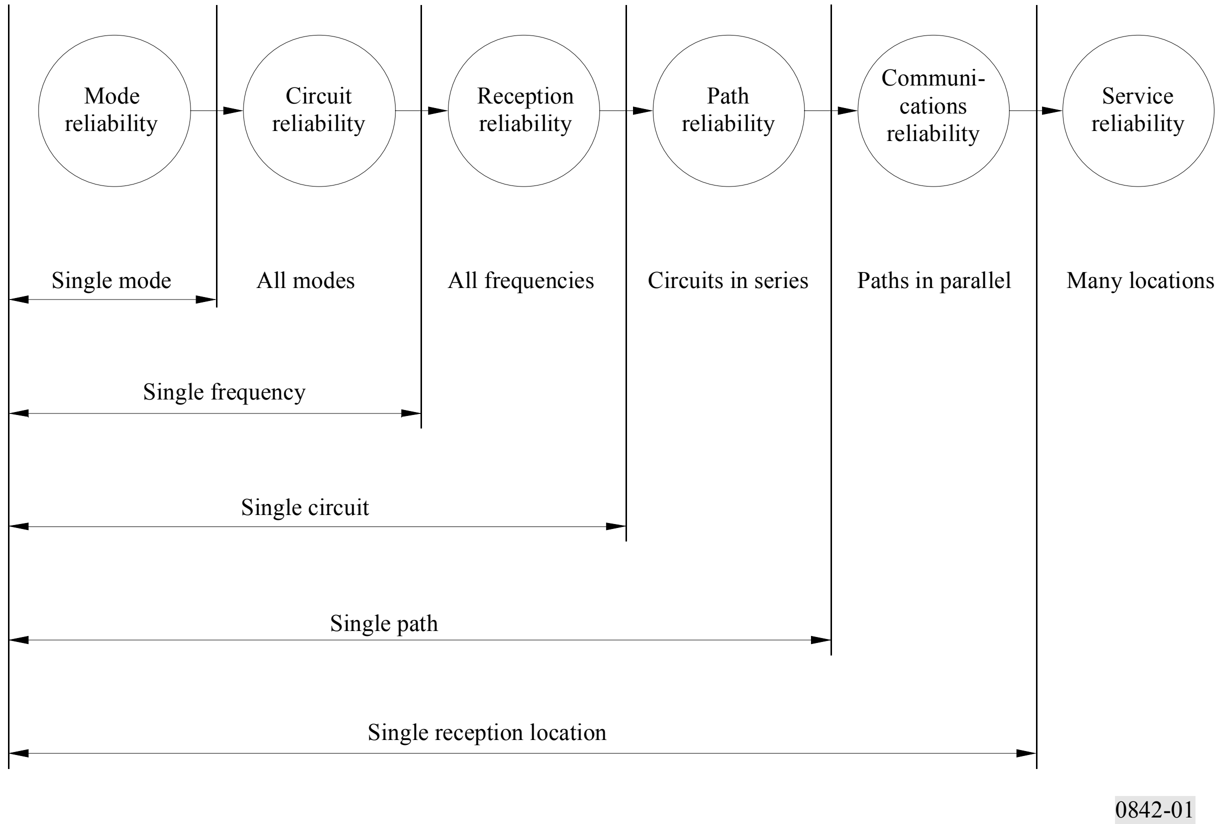
This procedure involves the intermediate calculation of the composite median available receiver power of the wanted signal (Step 1), the median signal-to-noise ratio (Steps 2 and 3), the resultant upper decile of the signal-to-noise ratio (Steps 4 to 6), and the resultant lower decile of the signal-to-noise ratio (Steps 7 to 9).

---

* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

FIGURE 1

Chart of reliabilities



The required signal-to-noise ratio (Step 10) is user defined (Recommendation ITU-R F.339 tabulates signal-to-noise ratios required to provide specific performances). The BCR is then estimated using the statistical distribution given in Step 11.

4 Basic reception reliability (BRR)

For n frequencies

$$BRR = 100 \left[1 - \prod_{i=1}^{n} \left(1 - \frac{BCR(f_i)}{100} \right) \right] \quad \%$$

where $BCR(f_i)$ is the percentage BCR for frequency f_i.

For a single operational frequency, BRR is equal to BCR.

5 Basic service reliability (BSR)

The determination of BSR involves the use of test points within the required service area. The BSR is the value of BRR exceeded by a required percentage of the test points.

TABLE 1

Computation of BCR

Step	Parameter	Description of parameter	Source of parameter value
1	S	Median available receiver power of wanted signal (dBW)	Prediction method P_r in § 6 of Rec. ITU-R P.533
2	$F_a A$ $F_a M$ $F_a G$	Median noise factor for atmospheric noise Median noise factor for man-made noise Median noise factor for galactic noise	Rec. ITU-R P.372
3	S/N	Median resultant signal-to-noise ratio (dB) for bandwidth b (Hz)	$S - 10 \log_{10} \left[10^{\frac{F_a A}{10}} + 10^{\frac{F_a M}{10}} + 10^{\frac{F_a G}{10}} \right] - 10 \log_{10} b + 204$
4	$D_u S_d$ $D_u S_h$	Signal upper decile deviation (day-to-day) (dB) Signal upper decile deviation (within-the-hour) (dB)	Table 2 using basic MUF for the path 5
5	 $D_l A$ $D_l M$ $D_l G$	Lower decile deviation (dB) of: atmospheric noise man-made noise galactic noise	Rec. ITU-R P.372 Rec. ITU-R P.372 2
6	$D_u SN$	Upper decile deviation of resultant signal-to-noise ratio (dB)	Root sum square of $D_u S_d$, $D_u S_h$ and $10 \log_{10} \left[\frac{10^{\frac{F_a A}{10}} + 10^{\frac{F_a M}{10}} + 10^{\frac{F_a G}{10}}}{10^{\frac{F_a A - D_l A}{10}} + 10^{\frac{F_a M - D_l M}{10}} + 10^{\frac{F_a G - D_l G}{10}}} \right]$

TABLE 1 (*continued*)

Step	Parameter	Description of parameter	Source of parameter value
7	$D_l\,S_d$ $D_l\,S_h$	Signal lower decile deviation (day-to-day) (dB) Signal lower decile deviation (within-the-hour) (dB)	Table 2 using basic MUF for the path 8
8	 $D_u\,A$ $D_u\,M$ $D_u\,G$	Upper decile deviation (dB) of: atmospheric noise man-made noise galactic noise	 Rec. ITU-R P.372 Rec. ITU-R P.372 2
9	$D_l\,SN$	Lower decile deviation of resultant signal-to-noise ratio (dB)	Root sum square of $D_l\,S_d$, $D_l\,S_h$ and $10 \log_{10}\left[\dfrac{10^{\frac{F_aA\,+\,D_uA}{10}} + 10^{\frac{F_aM\,+\,D_uM}{10}} + 10^{\frac{F_aG\,+\,D_uG}{10}}}{10^{\frac{F_aA}{10}} + 10^{\frac{F_aM}{10}} + 10^{\frac{F_aG}{10}}}\right]$
10	S/N_r	Required signal-to-noise ratio (dB)	User defined
11	BCR	Basic circuit reliability for $S/N \geq S/N_r$ (%)	$130 - 80 / (1 + (S/N - S/N_r) / D_l\,SN)$ or 100, whichever is smaller
		Basic circuit reliability for $S/N < S/N_r$ (%)	$80 / (1 + (S/N_r - S/N) / D_u\,SN) - 30$ or 0, whichever is greater

TABLE 2

Lower decile (LD) and upper decile (UD) deviations from the predicted monthly median value of available receiver power of the wanted signal and interfering signals, arising from day-to-day variability

Geomagnetic latitude [(1)]	<60°		≥60°	
Transmitting frequency/predicted basic MUF	LD	UD	LD	UD
≤0.8	8	6	11	9
1.0	12	8	16	11
1.2	13	12	17	12
1.4	10	13	13	13
1.6	8	12	11	12
1.8	8	9	11	9
2.0	8	9	11	9
3.0	7	8	9	8
4.0	6	7	8	7
≥5.0	5	7	7	7

(1) If any point on that part of the great circle which passes through the transmitter and the receiver and which lies between control points located 1 000 km from each end of the path, reaches a geomagnetic latitude of 60° or more, the values of ≥60° have to be used (see Recommendation ITU-R P.1239, Fig. 2).

6 Computation of overall circuit, reception and service reliability

The computation of overall circuit reliability (OCR) parallels the computation of BCR except the received powers from the potentially interfering transmitters are summed and compared with the available signal to determine the within-the-hour and the day-to-day distribution of hourly median signal-to-interference ratios (*S*/*I*). This distribution is entered with the hourly median *S*/*I* required for the specified performance to determine the fraction of time within the month the circuit can be expected to operate successfully in the presence of interference only. This percentage is compared with the BCR, and the OCR is the lower of these percentages.

In a similar way to the methods used in computing the basic reception and service reliabilities from *S*/*N* ratios, the overall reception and service reliabilities may also be computed from the assumed distributions of hourly median *S*/*I* ratios (see Table 3). The required RF protection ratio at Step 3 may be obtained from Recommendation ITU-R F.240 for the fixed service or from Recommendation ITU-R BS.560 for the broadcasting service.

7 Reliability estimation in HF networks

In networks, where a number of circuits are available between terminals, path and communications reliabilities (see Fig. 1) may be used.

7.1 Basic path reliability (BPR)

For more than one circuit, a lower estimate of BPR is the product of the BRRs for all the circuits on the path: i.e.

$$BPR = 100 \left[1 - \prod_{i=1}^{n} \left(1 - \frac{BRR_i}{100} \right) \right] \quad \%$$

where BRR_i is the BRR for path *i*, and an upper estimate is the minimum BRR.

For a single circuit, BPR is equal to BRR.

TABLE 3

Computation of OCR

Step	Parameter	Description of parameter	Source of parameter value
1	S	Median available receiver power of wanted signal (dBW)	Prediction method P_r in § 6 of Rec. ITU-R P.533
2	$I_1, I_2, ..., I_i$	Median available receiver power of interfering signals (dBW)	Prediction method P_r in § 6 of Rec. ITU-R P.533
3	$R_1, R_2, ..., R_i$	Relative protection ratio of interfering signals (dB)	User defined
4	S/I	Median resultant signal-to-interference ratio (dB)	$S - 10 \log_{10}\left[10^{\frac{I_1 - R_1}{10}} + 10^{\frac{I_2 - R_2}{10}} + \ldots + 10^{\frac{I_i - R_i}{10}}\right]$
5	$D_u S_d$ $D_l I_{1d}$ $D_l I_{2d}$ ... $D_l I_{id}$	Upper decile deviation of wanted signal Lower decile deviations of interfering signals (day-to-day) (dB)	Table 2 using basic MUF for the path
6	$D_u S_h$ $D_l I_{1h}$ $D_l I_{2h}$ ... $D_l I_{ih}$	Upper decile deviation of wanted signal Lower decile deviations of interfering signals (within-the-hour) (dB)	5 8
7	$D_u SI$	Upper decile deviation of resultant signal-to-interference ratio (dB)	Root sum square of $D_u S_d$, $D_u S_h$, $10 \log_{10}\left[\dfrac{10^{\frac{I_1 - R_1}{10}} + 10^{\frac{I_2 - R_2}{10}} + \ldots + 10^{\frac{I_i - R_i}{10}}}{10^{\frac{I_1 - R_1 - D_l I_{1d}}{10}} + 10^{\frac{I_2 - R_2 - D_l I_{2d}}{10}} + \ldots + 10^{\frac{I_i - R_i - D_l I_{id}}{10}}}\right]$ and $10 \log_{10}\left[\dfrac{10^{\frac{I_1 - R_1}{10}} + 10^{\frac{I_2 - R_2}{10}} + \ldots + 10^{\frac{I_i - R_i}{10}}}{10^{\frac{I_1 - R_1 - D_l I_{1h}}{10}} + 10^{\frac{I_2 - R_2 - D_l I_{2h}}{10}} + \ldots + 10^{\frac{I_i - R_i - D_l I_{ih}}{10}}}\right]$

TABLE 3 (*continued*)

Step	Parameter	Description of parameter	Source of parameter value
8	$D_l\,S_d$ $D_u\,I_{1d}$ $D_u\,I_{2d}$ ... $D_u\,I_{id}$	Lower decile deviation of wanted signal Upper decile deviations of interfering signals (day-to-day) (dB)	Table 2 using basic MUF for the path
9	$D_l\,S_h$ $D_u\,I_{1h}$ $D_u\,I_{2h}$ ... $D_u\,I_{ih}$	Lower decile deviation of wanted signal Upper decile deviations of interfering signals (within-the-hour) (dB)	8 5
10	$D_l\,SI$	Lower decile deviation of resultant signal-to-interference ratio (dB)	Root sum square of $D_l\,S_d$, $D_l\,S_h$, $10\log_{10}\left[\frac{10^{\frac{I_1-R_1+D_uI_{1d}}{10}}+10^{\frac{I_2-R_2+D_uI_{2d}}{10}}+\ldots+10^{\frac{I_i-R_i+D_uI_{id}}{10}}}{10^{\frac{I_1-R_1}{10}}+10^{\frac{I_2-R_2}{10}}+\ldots+10^{\frac{I_i-R_i}{10}}}\right]$ and $10\log_{10}\left[\frac{10^{\frac{I_1-R_1+D_uI_{1h}}{10}}+10^{\frac{I_2-R_2+D_uI_{2h}}{10}}+\ldots+10^{\frac{I_i-R_i+D_uI_{ih}}{10}}}{10^{\frac{I_1-R_1}{10}}+10^{\frac{I_2-R_2}{10}}+\ldots+10^{\frac{I_i-R_i}{10}}}\right]$
11	S/I_r	Required signal-to-interference ratio (dB)	User defined
12	ICR	Circuit reliability in the presence of interference only (without noise) for $S/I \geq S/I_r$ (%)	$130 - 80 / (1 + (S/I - S/I_r) / D_l\,SI)$ or 100, whichever is smaller
		Circuit reliability in the presence of interference only (without noise) for $S/I < S/I_r$ (%)	$80 / (1 + (S/I_r - S/I) / D_u\,SI) - 30$ or 0, whichever is greater
13	BCR	Basic circuit reliability (%)	Table 1
14	OCR	Overall circuit reliability (%)	Min (ICR, BCR)

7.2 Basic communications reliability (*R*)

For more than one path, a lower estimate of *R* is given by the maximum path reliability, and an upper estimate by:

$$R = 100 \left[1 - \prod_{i=1}^{n} \left(1 - \frac{BPR_i}{100} \right) \right] \qquad \%$$

where BPR_i is the basic path reliability for path *i*.

For a single path, *R* is equal to BPR.

8 Computation of compatibility

Compatibility is a measure of the degradation a wanted circuit or service will suffer in the presence of interference. In the case of a single point-to-point circuit the circuit compatibility (CC) is defined by the percentage of time during which a specified criterion of service quality is achieved at the receiver location in the presence of interference (OCR) relative to the value that would be obtained if only noise were present (BCR):

$$CC = 100 \frac{OCR}{BCR} \qquad \%$$

which is identical to the ratio of OCR to BCR;

If the wanted service applies to an area rather than to a single reception point the compatibility can be defined in two ways:

– the time service compatibility (TSC) is the percentage of time during which a specified percentage of the target area p_A can be served in the presence of interference (overall service reliability (OSR)) relative to the value that would be obtained if only the environmental noise would be present (BSR):

$$TSC = 100 \frac{OSR(p_A)}{BSR(p_A)} \qquad \%$$

which is identical to the ratio of OSR to BSR;

– the area service compatibility (ASC) is the percentage of the target area which can be served during a specified percentage of time p_T in the presence of interference A_I relative to the value that would be obtained if only the environmental noise were present A_N:

$$ASC = 100 \frac{A_I(p_T)}{A_N(p_T)} \qquad \%$$

where the area *A* may be represented by the number of test points satisfying the required conditions.

9 BCR for digital modulation systems

For a digital modulation system a simplified approximate method is available for interim use. This gives:

$$BCR\ (\%) = R_{SN} \cdot R_T \cdot R_F$$

where:

R_{SN}: probability that the required signal-to-noise ratio, SN_0, is achieved,

R_T: probability that the required time spread T_0 at a level of –10 dB relative to the peak signal amplitude is not exceeded,

R_F: probability that the required frequency dispersion f_0 at a level of –10 dB relative to the peak signal amplitude is not exceeded.

Appropriate values for these relative levels may need to be selected in accordance with the modulation method in use.

These three separate probabilities are evaluated as:

R_{SN} (%) = $130 - 80/[1 + (SN_m - SN_0)/D_l]$ or 100, whichever is the smaller, for $SN_m \geq SN_0$

= $80/[1 + (SN_0 - SN_m)/D_u] - 30$ or 0, whichever is the larger, for $SN_m < SN_0$

R_T (%) = $130 - 80/[1 + (T_0 - T_m)/D_{Tu}]$ or 100, whichever is the smaller, for $T_m \leq T_0$

= $80/[1 + (T_m - T_0)/D_{Tl}] - 30$ or 0, whichever is the larger, for $T_m > T_0$

R_F (%) = $130 - 80/[1 + (F_0 - F_m)/D_{Fu}]$ or 100, whichever is the smaller, for $F_m \leq F_0$

= $80/[1 + (F_m - F_0)/D_{Fl}] - 30$ or 0, whichever is the larger, for $F_m > F_0$

SN_m, D_l, and D_u are respectively the S/N ratio monthly median, lower and upper decile deviations from the median, evaluated as described in § 3 following the stages given in Tables 1 and 2. The T_m , D_{Tu}, and D_{Tl} are the corresponding time spread parameters and F_m, D_{Fu} and D_{Fl} the similarly defined frequency dispersion parameters.

With $D_{Tu} = D_{Tl} = 0.15\ T_m$, $D_{Fu} = D_{Fl} = 0.10\ F_m$, the T_m (ms) and F_m (Hz) for propagation to path length, D (km) at a frequency f (MHz) over a path with basic MUF equal to f_b are given as:

$T_m = 2.5 \times 10^{7} D^{-2} (1 - f/f_b)^2$ or $7 - 0.00175D$, whichever is the smaller, for $D \leq 2\,000$ km

= $4.27 \times 10^{-2} D^{0.65}$ or 3.5, whichever is the smaller, for $D > 2\,000$ km

and $F_m = 0.02\, f\, T_m$

APPENDIX 1

The following definitions are given for the purposes of this Recommendation:

1 Terms relevant to the operation and design of HF radio systems

Reliability

Probability that a specified performance is achieved.

Circuit reliability

Probability for a circuit that a specified performance is achieved at a single frequency.

Reception reliability

Probability for a circuit that a specified performance is achieved by taking into account all transmitted frequencies associated with the desired signal.

Path reliability

Probability for a pair of terminals that a specified performance is achieved over a single path between the terminals consisting of one or more contiguous circuits, by taking into account all transmitted frequencies.

Communications reliability

Probability for a pair of terminals that a specified performance is achieved by taking into account all the paths between them and all frequencies associated with the desired signals.

Service reliability

Probability for a service area that a specified performance is achieved by taking into account all transmitted frequencies.

Area reliability

The percentage of test points in a service area for which the basic reception reliability is greater than a specified required value.

NOTE 1 – In the above terms circuit means a transmission link from one transmitter to one receiving location with or without diversity.

NOTE 2 – The above terms are preceded by the word "basic" when the background is noise alone and by "overall" when the background is noise and interference.

NOTE 3 – When the background is noise and interference, the above terms may relate either to the effects of a single interferer or to multiple interference from co-channel and adjacent-channel transmissions.

NOTE 4 – For many applications it is convenient to adopt a given value of signal-to-background ratio as the specified performance.

NOTE 5 – The above terms (i.e. reliabilities) relate to one or more periods of time which should be stated.

NOTE 6 – For broadcasting applications, the term service reliability is replaced by the term broadcast reliability, and is calculated for a specified number of test points within the service area.

2 Terms relevant to prediction techniques

Mode reliability

Probability for a circuit that a specified performance is achieved by a single mode at a single frequency.

Mode availability

Probability for a single circuit that a single mode at a single frequency can propagate by ionospheric refraction alone.

Mode performance achievement

Probability for a single circuit that a specified performance is achieved by a single mode at a single frequency given that the mode can propagate by ionospheric refraction alone.

NOTE 1 – Notes 4 and 5 of § 1 apply.