

Measurement of $kTBF$ in Point-to-Point Digital Microwave Radios

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The value of $kTBF$ is used in interference calculations. $kTBF$ is the total thermal noise power at temperature T in a given bandwidth, B , referred to the input of a device with noise factor F . For a given single-entry interference, $kTBF$ tells us how much this interference will degrade the fading margin of the microwave radiolink.

$kTBF$ terms are the noise figure NF ; bandwidth B for 99 percent of the energy; the physical Boltzmann constant ($k = 1.38 \times 10^{-23}$ joules/Kelvin); and the annual mean environment temperature T (expressed in the absolute thermometrical Kelvin scale). The noise figure NF in decibels (dB) and the environment temperature T are given, respectively, by:

$$NF \text{ (dB)} = 10 \log_{10} [F] \quad (2)$$

$$T = 300\text{K} = 27^\circ\text{C} \quad (3)$$

where the logarithm is in base 10 and F is the so-called noise factor. The annual mean environment temperature T was assumed to be 27 degrees Celsius (or 300 Kelvins).

Thermology gives us an equation for conversion between Kelvin and Celsius scales.

$$t_C = t_K - 273 \quad (4)$$

where t_C symbolizes a temperature expressed in Celsius scale and t_K symbolizes a temperature expressed in Kelvin absolute scale. From relation (4), we easily see that if $t_C = 27$ degrees Celsius, we have $t_K = 300$ Kelvins.

The noise factor F is defined by a simple ratio:

$$F = \frac{SNR_{in}}{SNR_{out}} \quad (5)$$

where SNR_{in} is the signal-to-noise linear relationship in the input port of a two-port device and SNR_{out} is the signal-to-noise linear relationship in the output port of the same two-port device.

The noise factor F is greater than or equal to unity ($F \geq 1$). The case $F = 1$ is theoretical; it cannot be realized in practice. The case $F = 1$ means no noise is added by the device (an ideal noiseless device).

Now comparing equations (2) and (5) we can also write the noise figure NF as:

$$NF \text{ (dB)} = SNR_{in} \text{ (dB)} - SNR_{out} \text{ (dB)} \quad (6)$$

where SNR_{in} (dB) and SNR_{out} (dB) are the signal-to-noise ratios (in logarithmic units) in the input and output ports of a two-port device.

NF is typically measured by the manufacturer of the microwave radio equipment, while bandwidth B is defined by receive filter curves (this data is also obtained from the manufacturer of the microwave radios).

In practice, it is common to have differences of up to ten decibels between $kTBF$ s from equivalent microwave radio equipment sets from different manufacturers (e.g., an 18 GHz digital radio, 4x2 Mbit/s capacity).

These differences are easily explained by filtering differences, measurement errors, a combination of the two previous factors, transcription errors, etc.

In this work, the CEPT (or ITU-T) multiplexing hierarchy is used. In this hierarchy the basic rate is named $E1$ (2.048 Mbit/s or 2 Mbit/s abbreviated).

Although the North-American hierarchy (based on the basic rate named $T1$) is not the same, this causes no problem in the approach; the reasoning is the same for both cases.

Recommendation

A factory measurement of the $kTBF$ of point-to-point digital microwave radios (P-P DMRs) is recommended. The value needs to be available for system design before field installation in order to use it for dimensioning the microwave radiolinks.

The measurement of $kTBF$ is valid as a reference for interfering calculations.

For this reason, it has vital importance for a good dimensioning of radiolinks (access radios as well as high-capacity long-distance microwave digital radios).

A set of factory measurements equal to the number of frequency bands and capacities in use in the radio system is taken. For example, with two frequency bands in use (in this case, 18 and 23 GHz) and three capacities per band (in this case, 1x2, 2x2 and 4x2 Mbit/s), the table looks like:

18 GHz → 1 x 2 Mbit/s (= 1 E1)
 2 x 2 Mbit/s (= 2 E1)
 4 x 2 Mbit/s (= 4 E1)

23 GHz → 1 x 2 Mbit/s (= 1 E1)
 2 x 2 Mbit/s (= 2 E1)
 4 x 2 Mbit/s (= 4 E1)

This means there will be six series of factory measurements (one series per band/capacity). Each series of measurements will be done over a certain number of radio equipment units (samples) in order to lend statistical validity to the tests.

The process of direct measuring the $kTBF$ of digital microwave radio equipment signifies that the determined value is independent of the measurement of the bandwidth B and the noise figure NF .

First measurement suggestion

This measurement is done just after the BER tests (Bit Error Ratio tests) *versus* the carrier receive level

Logarithm Tutorial

If we have a finite set of interfering signals, named $I_1, I_2, I_3, \dots, I_n$, the concept of $kTBF$ as a measurement of degradation from interference will be valid for the total interfering value (I_{tot}).

$$I_{tot} = \sum_{i=1}^n I_i$$

where $\sum [\dots]$ symbolizes the summation of the n pieces of the argument [...].

$$I_{tot} = I_1 + I_2 + I_3 + \dots + I_n \quad (1)$$

The interferences present in the summation (from I_1 to I_n) are power levels and, in this way, this summation is, of course, a power

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Logarithm Tutorial (continued)

summation.

If the individual interferences are expressed in linear units (milliwatts, for example) we need only to add all of them.

However, if individual interferences are expressed in logarithmic units, an additional step is required. This is due to the fact that logarithmic absolute units cannot be added directly.

See the following example, where we add two power levels (zero dBm each one).

$$P1 = 1 \text{ milliwatt (zero dBm)}$$

$$P2 = 1 \text{ milliwatt (zero dBm)}$$

$$P3 = P1 + P2 = 1 \text{ mW} + 1 \text{ mW} = 2 \text{ mW} \quad \text{OR}$$

$$P3 = 3.01 \text{ dBm (zero dBm + zero dBm = 3.01 dBm)}$$

First, we must change the individual values from logarithmic units to linear units. Then, we can add these values to determine the logarithmic value of the sum.

See the calculation sequence shown here:

$$I_1 (\text{log}) \rightarrow I_1 (\text{lin})$$

$$I_2 (\text{log}) \rightarrow I_2 (\text{lin})$$

$$I_n (\text{log}) \rightarrow I_n (\text{lin})$$

$$I_1 (\text{lin}) = 10^{I_1/10}$$

$$I_2 (\text{lin}) = 10^{I_2/10}$$

$$I_n (\text{lin}) = 10^{I_n/10}$$

where the values I_1, I_2, \dots, I_n are all expressed as logarithms.

$$I_{tot} (\text{lin}) = 10^{I_1/10} + 10^{I_2/10} + \dots + 10^{I_n/10}$$

$$I_{tot} (\text{lin}) = I_1 (\text{lin}) + I_2 (\text{lin}) + \dots + I_n (\text{lin})$$

$$I_{tot} (\text{log}) = 10 \log_{10} [I_{tot} (\text{lin})]$$

I_{tot} is now, finally, expressed in logarithmic units (the most common logarithmic unit in telecommunications is the dBm — decibel relating to the milliwatt).

(LRXc). A certain BER is used as a reference, say 10^{-3} , which corresponds to a determined power threshold a (expressed in dBm).

A co-channel interference (CCI) and the desired receive signal are injected together. Then, the power threshold for BER equal to 10^{-3} is measured (this is known as the power threshold b). Note that there will be some threshold degradation (the threshold will rise; the value of the power threshold b will be greater than the value of the power threshold a).

$$\text{threshold } b > \text{threshold } a \quad (7)$$

The threshold degradation will be given by:

$$\text{degradation} = \text{threshold } b - \text{threshold } a \quad (8)$$

The thresholds are normally expressed in dBm, creating a degradation expressed in decibels. If the unit Neper relating to the milliwatt (the Npm) is used for the thresholds, the degradation will be expressed in Nepers (Np).

Obtaining $kTBF$ by calculations

$kTBF$ may be derived from the degradation. We have

$$DEGRAD = 10 \log_{10} [1 + 10^H] \quad (9)$$

where the H parameter is given by:

$$H = \frac{I_{tot} - kTBF}{10} \quad (10)$$

In this way, the threshold degradation $DEGRAD$ is a function, *func*, of the total interference power level I_{tot} and the $kTBF$ value.

We shall now express $kTBF$ as a function of the threshold degradation $DEGRAD$ as well as a function of the total interference power level I_{tot} .

$$kTBF = \text{func} [I_{tot}, DEGRAD] \quad (11)$$

$$kTBF = I_{tot} - 10 \log [10^{DEGRAD/10} - 1]$$

Each logarithm is expressed in decimal form:

[a] $I_{tot} = -97.0 \text{ dBm}$ and $DEGRAD = 2.0 \text{ dB}$

$$kTBF = -97.0 - 10 \log [10^{0.2} - 1]$$

$$kTBF = -97.0 - (-2.3) = -94.7 \text{ dBm}$$

[b] $I_{tot} = -85.0 \text{ dBm}$ and $DEGRAD = 10.0 \text{ dB}$

$$kTBF = -85.0 \text{ dBm} - 10 \log [10^{1.0} - 1]$$

$$kTBF = -85.0 - (+9.5) = -94.5 \text{ dBm}$$

Second measurement suggestion

Now we will obtain the $kTBF$ value using a process of successive iterations on the interference itself. The co-channel interference power level is increased until the threshold degradation equals 3 decibels (half-power level). At this point the interference value equals the $kTBF$.

$$I_{tot} = kTBF \text{ for } DEGRAD = 3.0 \text{ dB}$$

To minimize the number of iterations, it is noted that the initial value of the interfering power level is close to the actual $kTBF$ value.

The approximate $kTBF$ value is estimated from the typical values of the carrier-to-thermal-noise relation (CNR or C/N) for different modulation schemes, for a BER equal to 10^{-3} (or 10^{-6}). Typical values of CNR are given for three types of different modulation schemes: 4-PSK, 16-QAM and 64-QAM. Values for CNR with BER = 10^{-3} are given without (), and those for CNR with BER = 10^{-6} are given with ().

	CNR (10^{-3})	CNR (10^{-6})	
4-PSK:	12	(16)	dB
16-QAM:	18	(22)	dB
64-QAM:	24	(28)	dB

For example, consider a radio-receiver using a digital 16-QAM modulating scheme, a 10^{-3} BER, and a carrier receive level of -79 dBm (this value was obtained, for instance, from the evaluation of the BER *vs.* L_{RXc} curve).

Using the theoretical value of 18 dB, from the previous table, we inject an interfering power level of:

$$I_{tot} = -79 \text{ dBm} - 18 \text{ dB} = -97 \text{ dBm}$$

This value is very close to the *kTBF* value (-95 dBm) and generates a 2-decibel degradation. It is only necessary to perform a second iteration, now with an interfering power level of

$$I = -97 \text{ dBm} + 2 \times (3 \text{ dB} - 2 \text{ dB}) = -95 \text{ dBm}$$

to obtain a degradation near 3 dB, and to conclude that the *kTBF* is -95 dBm. Consider the next topic to correct the case of a modulated (non-gaussian) signal.

Modulated signal vs. gaussian-nature signal

An interference that comes from a modulated signal generates a threshold degradation less than the threshold degradation generated by a stochastic gaussian

interference signal.

For a specific threshold degradation, there is a small difference (between one and two decibels) between the power levels of the modulated interference (I_{mod}) and the power levels of the gaussian-nature interference (I_{gauss}) that cause the same threshold degradation.

In my opinion, a margin of 2 decibels is too liberal and subtracting one decibel from the calculated *kTBF* is justifiable. If the calculated *kTBF* ($kTBF_{gauss}$) is -93.5 dBm, for example, we obtain -94.5 dBm for the corrected *kTBF* ($kTBF_{mod}$)

$$kTBF_{mod} = kTBF_{gauss} - 1 \text{ dB} \quad (12)$$

Author information

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